ARCH D4.4

Knowledge Information Management System for Decision Support

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Executive Summary

This deliverable has been prepared for the European Commission-funded research project ARCH: Advancing Resilience of historic areas against Climate-related and other Hazards. It is the key output of task 4.4 "*Knowledge Information Management System for Decision Support*" within Work Package (WP) 4 *"Hazard & Object Information Management System"*.

This deliverable reports on the development of the ARCH Knowledge Information Management System, with the aim of passing integrated data and information (from tasks 4.1, 4.2, and 4.3) to WP5 (tasks 5.1 and 5.2) and WP6 (tasks 6.1 and 6.2) and for integration into the ARCH disaster risk management system in WP7 (tasks 7.6 and 7.7).

The large amount of data needed for assessing and managing disaster resilience in historic areas, and the multiple interconnections between tangible and intangibles entities and services provided by historic areas, brought the ARCH project to face and overcome the complexity of defining a conceptual data model aggregating data retrieved by distinct databases to generate meaningful information and of processing information to generate knowledge.

This deliverable summarizes methods, data and results obtained by the ARCH project to generate relevant information and knowledge to support decision making process related to the resilience of historic areas to climate change and other hazards.

In particular the deliverable reports on:

- The established interoperability between the ARCH Information System and the ARCH Decision Support System (DSS) for the exchange of information
- The great potentialities in terms of knowledge management and knowledge generation that might arise from:
    - the implementation of ontology-based and semantic-based spatiotemporal assessment towards enhancing the awareness and the capacity building on disaster resilience at historic area-level;
    - automated approaches for 3D modelling and the automatic crack/damage detection based on deep learning towards the preventive conservation of cultural heritage buildings.

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List of Abbreviations

Abbreviation	Meaning
ACM	Association for Computing Machinery
AI	Artificial Intelligence
CH	Cultural Heritage
CREAM	CREAtivity Machine
DFO	Dynamic Flood Ontology
DIKW	Data-Information-Knowledge-Wisdom
DSS	Decision Support System
GIS	Geographic Information System
HA	Historic Area
HArIS	Historic Area Information Management System
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
KM	Knowledge Management
POI	Point of Interest
RAD	Resilience Assessment Dashboard
RMI	Resilience Measures Inventory
RPVT	Resilience Pathway Visualization Tool
SOSA	Ontology Sensor, Observation, Sampler, and Actuator
SSN	Semantic Sensor Network
TERMINUS	TERritorial Management and INfrastructures ontology for institutional and industrial USage
THIS	Threats and Hazard Information Management System
VUM	Vulnerability Upper Model
WP	Work Package
WS	Web Service
XML	Extensible Markup Language

1. Introduction

This deliverable has been prepared for the European Commission-funded research project ARCH: Advancing Resilience of historic areas against Climate-related and other Hazards. ARCH will deliver decision support tools and methodologies to improve the resilience of historic areas to climate change-related and other hazards. These tools and methodologies are developed based on collaborative work with the pilot cities of Bratislava (Slovakia), Camerino (Italy), Hamburg (Germany), and Valencia (Spain), following a co-creative approach, including local policy makers, practitioners, and community members. The result is a disaster risk management framework for guided resilience building, which includes:

- an information management system for relevant geo-referenced properties of historic areas, i.e. HArIS – *Historic Area Information Management System*;
- an information management system for geo-referenced data regarding hazards and risks relevant for historic areas, i.e. THIS – *Threats and Hazards Information Management System*;
- a platform for risk and impact analysis of historic areas, i.e. ARCH DSS *Decision Support System*;
- an inventory of resilience building measures and appropriate financing sources, i.e. RMI – *Resilience Measures Information*;
- a visual planning tool for resilience pathways, i.e. RPVT – *Resilience Pathway Visualisation Tool*;
- a resilience assessment method to identify resilience weak points and formulate resilience action plans, i.e. RAD – *Resilience Assessment Dashboard*.

To fully understand the purpose of this deliverable and its relation to other ARCH deliverables it is worth clarifying what we intend for *Knowledge Information Management System for Decision Suppo*rt within the ARCH project and which are the key steps and needs towards that.

Knowledge management (KM) can be defined [1] as: "*the process of capturing, distributing, and effectively using knowledge*". *Wisdom*, *Knowledge*, *Information*, and *Data* are key words and also fundamental concepts in knowledge management. It is essential to understand the differences between these concepts to proceed with practical KM implementation. Towards that we propose the following definitions, modified after [2]:

- ***Data*** is a record of some fact by means of numerical quantities, images, text or other basic representation structures. Data can result from observation, experiment or calculation;
- ***Information*** is processed data in context. Information is a collection of data and associated textual material describing a particular object, event, or process;
- ***Knowledge*** is information that is organized, conceptualized, synthesized to enhance comprehension, awareness, or understanding to enable decision making also in similar contexts.
- ***Wisdom*** is knowledge, gained from the information, put into action. Wisdom gives an ability to support proactive decisions on possible future scenarios, based on past experience.

It is also important to clarify how *Data*, *Information*, *Knowledge* and *Wisdom* relate to each other. The *Data-Information-Knowledge-Wisdom* (*DIKW) pyramid* [3][4] (Figure 1), also known as the "*Knowledge Hierarchy*", is used in information science and management as an effective way for representing purported structural and/or functional relationships between *Data*, *Information*, *Knowledge*, and *Wisdom*. According to the *DIKW* pyramid, *Information* result from *Data*, *Knowledge* is built from *Information*, and *Wisdom* is based on shared *Knowledge*.

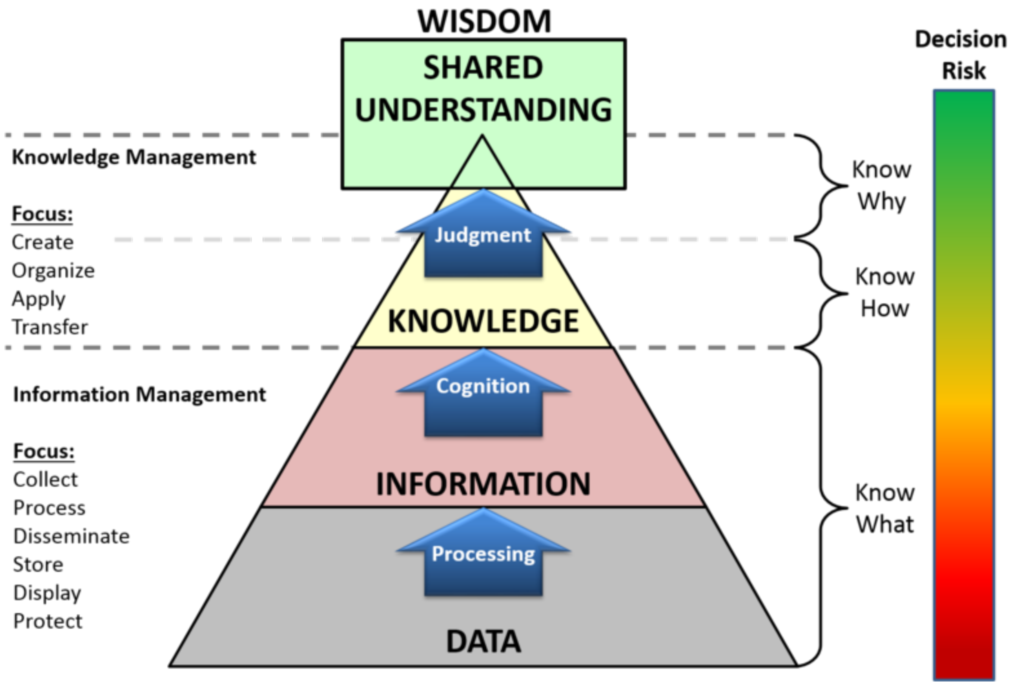

Figure 1. Data-Information-Knowledge-Wisdom, DIKW pyramid [3][4] also known as the "Knowledge Hierarchy"[1],

Finally, it is necessary to clarify the role that *Data*, *Information*, *Knowledge* and *Wisdom* have in the knowledge/awareness creation and decision-making processes that are relevant to the ARCH project.

Data are the individual facts that are out of context (often referred to as raw data), have no explicit meaning, and are difficult to directly understand and use.

To answer relevant questions such as "*What*", "*When*", "*Where*", "*Who*", and to use the *Data* for a specific purpose it is necessary to generate valuable *Information*. Towards information generation data have been processed according to different operations, that are related to the specific purpose for which we aim to use the data, and might include, among others, data aggregation (i.e. the combination of different sets of data), and validation (i.e. ensuring that the collected data is relevant and accurate).

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[1] Dourced from and Modified https://www.pngfind.com/mpng/TRwJix_km-pyramid-adaptation-knowledge-management-cognitive-pyramid-hd/

Once relevant information has been generated, to answer “*How*” questions, as for example the ones listed below, it is necessary to leap from *Information* to *Knowledge*:

- “*How*” is this information relevant to our goals?
- “*How*” are the pieces of this information connected to other pieces to add more meaning and value?
- “*How*” can we apply the information to achieve our goal?.

Once *Knowledge* is generated, to support proactive decisions on future scenarios and being able to answer “*Why*” and “*Know-What*” questions such as the ones listed below, it is necessary to move from *Knowledge* to *Wisdom*:

- know-why: “*why do something*?*”*
- know-what: “*what to do, act or carry out*?"; “*what is best solution/strategy*?”; “*what we do now and what we want to achieve in the future*?”, i.e..

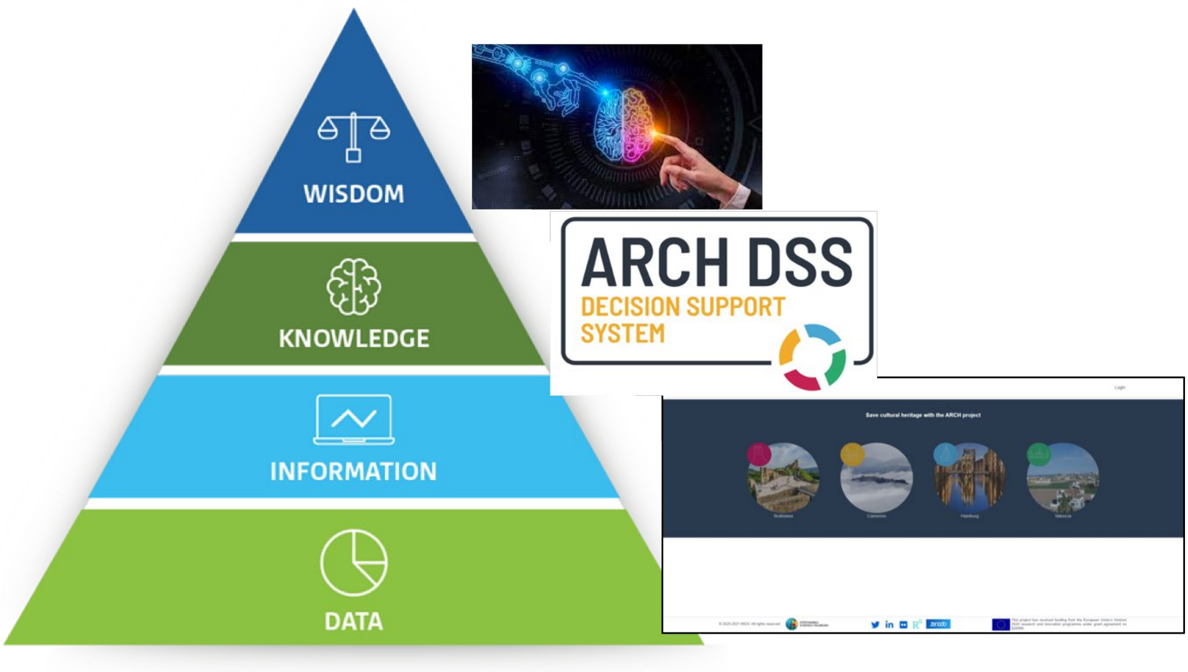

Figure 2. ARCH Information System and ARCH DSS in the *Data-Information-Knowledge-Wisdom, DIKW* pyramid[2]. The possibility to leap from knowledge to wisdom generation can be achieved through a cognitive process performed by a human expert or in automatic/semiautomatic way thanks to the support of a cyber-expert e.g. the *CREAtivity Machine Web Service* (*WS-CREAM*) as explained in Section 3.

The ARCH Information System (platform including both the information management systems *HArIS* and *THIS*) and the ARCH DSS allow to climb the DIKM pyramid going from *Data* to *Information* and to *Information* to *Knowledge*, respectively (Figure 2).

[2] This graphical representation of the DIRK pyramid has been sourced and modified from https://blog.stratasan.com/data-driven-decisions-dikw-pyramid

The ARCH Information System described in Section 2 of this report (and in the previously submitted deliverables D4.2 and D4.3) has generated the relevant information in relation to the key dimensions of risk and resilience assessment (i.e. hazard, exposure, vulnerability) and the key dimensions of Historic Areas (i.e. physical, natural, social, economic, and intangible dimension). ARCH DSS (that will be widely presented in D5.3) has created knowledge by processing the information included in the ARCH Information system and by organizing the knowledge according to the conceptual model of risk (i.e. convolution of hazard, exposure, vulnerability) as presented in the section 1 of deliverable D5.1 and in section 3.2.3.

The work of task 4.4 towards generating *Information* from *Data,* and *Knowledge* from *Information* has targeted the establishment of an interoperability between the ARCH Information System and the ARCH DSS tool, via the definition of metadata, as described in section 2 of this deliverable. The possibility to leap from *Knowledge* to *Wisdom* generation in the current version of the ARCH tools can be achieved through a cognitive process performed by a human expert based on the knowledge available and represented in the ARCH DSS tool.

However, task 4.4 took the first steps towards *Semantic Interoperability* between the *ARCH Information System and* the *ARCH DSS* and towards the possibility to make the cognitive process from *Knowledge* to *Wisdom* automatic/semiautomatic, through a cyber-expert tool. Aiming to provide a feasibility study, Section 3 showcases the advanced capabilities that can be achieved thanks to the combined used of: 1) *Semantic Interoperability* between tools similar to the *ARCH Information System and* the *ARCH DSS tools* achieved via an ad-hoc ontology; 2) an ontology-based automatic tool, namely the CREAtivity Machine Web Service ,WS-CREAM [6]

The idea is to provide with CREAM or similar tools to the managers and stakeholders of the historic area an approach allowing to "*automate*" the climbing of the *Data-Information-Knowledge-Wisdom* pyramid, i.e. by creating knowledge through abstraction as well as by supporting new knowledge generation; as shown in section 3.3, the risk mini-models created by CREAM WS are the result of the cognitive process performed by a cyber-expert who, in its own way, is emulating the creative thinking of the human expert.

Finally, Section 3 of the deliverable showcases the great potentialities of Machine Learning and Artificial Intelligence (AI) approaches allowing automatic knowledge creation related to cultural heritage sites to support preventive conservation and restoration decision making processes. In particular, section 4.1 showcases an autonomous 3D modelling system; and section 4.2 AI-based and Machine Learning driven analysis of the images and/or 3D model to determine type, location and significance of degradations of Cultural Heritage CH objects as well as automatic detection of cracks.

1.1. Gender statement

This document has been developed taking into consideration the guidance on gender in research provided in the Project Handbook (D1.2) as well as State-of-the-Art report number 5 of deliverable D7.1 on “Gender aspects in conservation and regulation of historic areas, disaster risk management, emergency protocols, post-disaster response techniques, and techniques for building back better”.

1.2. Purpose of this report and relation to other deliverables

Deliverable D4.4 reports on the development of the ARCH Knowledge Information Management System that is needed for passing integrated data and information (produced as part of tasks 4.1, 4.2, and 4.3) to the ARCH DSS tool realised as part of WP5 and to WP6 (tasks 6.1 and 6.2) and for integration into the ARCH disaster risk management system developed as part of WP7 (tasks 7.6 and 7.7). As such deliverable D4.4 is directly related to the following deliverables:

- D3.4 Report on co-creating the information system
- D4.1 Sensing and Repositories
- D4.2 Historic Area Information Management System (HArIS)
- D4.3 Threats and Hazard Information System (THIS)
- D5.1 Hazard models for impact assessment
- D5.2 Handbook on heritage asset vulnerability
- D5.3 Decision Support System for risk forecast and emergency management:
- D5.4 IoT Platform for Digital Twin
- D5.5 Digital Twin models for impact assessment
- D6.1 Inventory of preparation, safeguarding, conservation & management, and response & recovery options
- D7.3 ARCH disaster risk management framework
- D7.4 Requirements description
- D7.5 Interface specification and system architecture
- D7.6 System design, realisation, and integration

The chart in Figure 3 is a graphical representation of the interaction between D4.4 and the before mentioned deliverables with their related tasks.

It is worth noting that the *ARCH Information System* is a dynamic system supported by web tools, therefore the different components can be improved even after their delivery. Likewise, any further datasets and information - as well as updates of those already included - collected within the ARCH project will feed this information system, even if they are obtained after the drafting of this document.

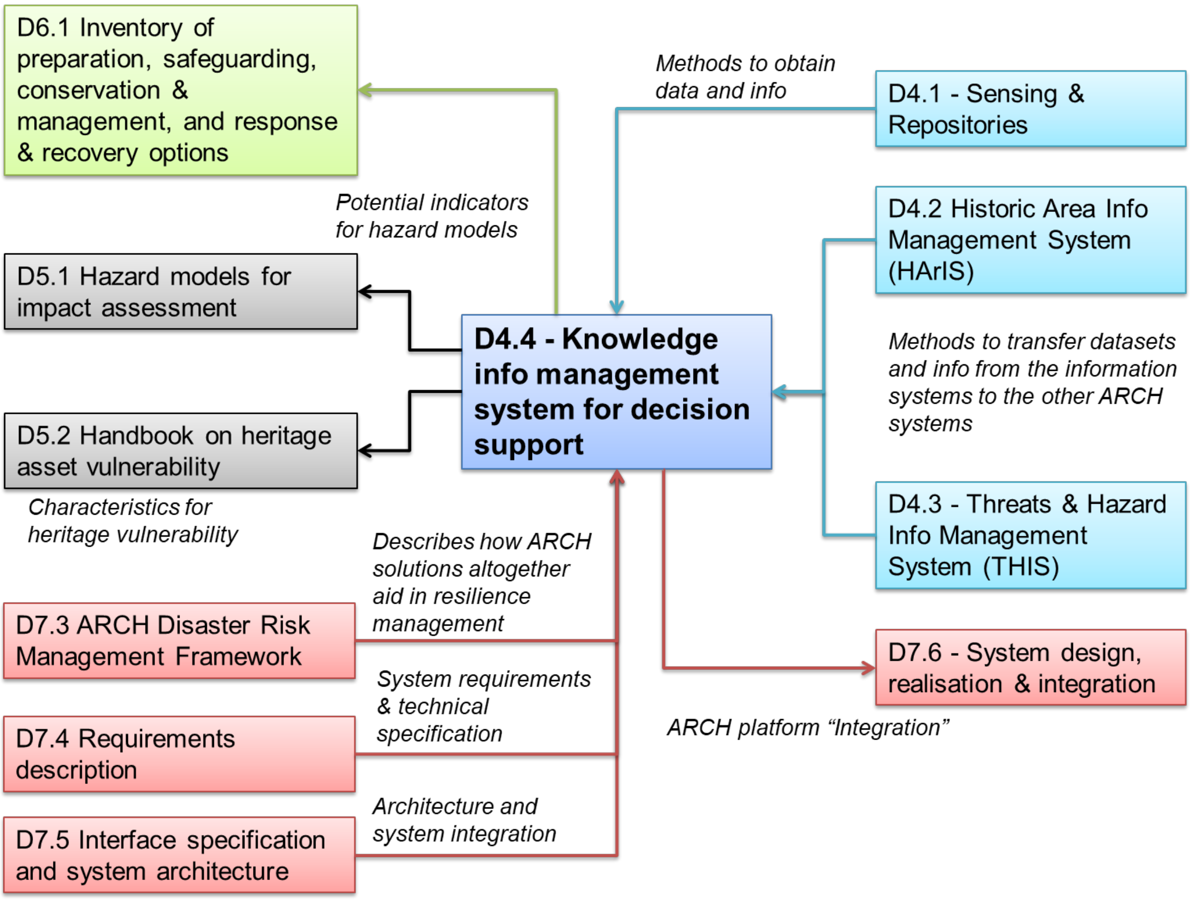

Figure 3. Relation of D.4.4 to other ARCH deliverables

2. ARCH Information tools and interoperability towards knowledge creation

Establishing the interoperability between the *ARCH Information System, developed by WP4 [8][9][10]* and the *Decision Support System ARCH DSS* has been a fundamental step to allow the use of the information collated in geodatabases HArIS and THIS towards knowledge creation in ARCH DSS.

Interoperability[3] can be defined as the ability of a model (either physics or data-based model) to make use of information generated by a simulation performed by another model or collated in a database. The interoperability of tools, platforms and services is ruled by the new *European Interoperability Framework*[4] that is promoting, in the European Union, seamless services and data flows for all the European Public Administrations.

[3] From EMMC-CSA European Materials Modelling Council. Report on Workshop on Interoperability in Materials Modelling Cambridge, 7/8 November 2017 Ref. Ares(2017)6261482 - 20/12/2017
[4] European Interoperability Framework https://ec.europa.eu/isa2/eif_en

While interoperability refers, in general, only to *the exchange of information* without reference to how this exchange is implemented, in practice, there are three main levels of interoperability realisations, namely, **syntactic**, **semantic**, and **cross domain** as shown schematically in Figure 4.

- ***Syntactic interoperability*** allows tools to understand the input and output from each other. This works case-by-case and is not flexible to changes.
- ***Semantic interoperability*** is the ability to communicate shared meaning. It provides much more flexibility than syntactic interoperability, but requires means to describe the data (i.e. via ***metadata***) that link each data element to at least a controlled shared vocabulary, and preferably an associated ***ontology*** defined ad-hoc for a certain domain (definitions of *metadata*, *ontology* and *domain ontology* are provided in Annex A).
- ***Cross-domain interoperability*** refers to an even higher level of semantic, enabling interoperability between domains and ontologies.

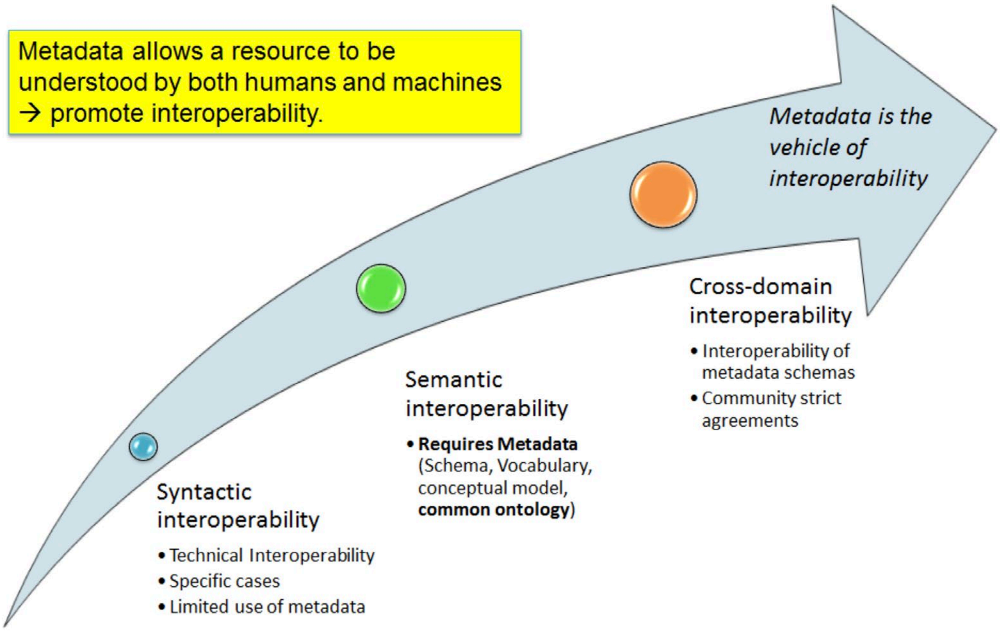

Figure 4. From Syntactic Interoperability, towards Semantic Interoperability thanks to the definition of metada and use of ontologies[5]

The ARCH project worked to establish a *Semantic Interoperability* between the ARCH information systems and the ARCH DSS Decision Support Systems. This has been pursued in accordance with the overall architecture of the ARCH system reported in Section 3 of the ARCH Deliverable D7.5 "*Interface specification and system architecture*" [7], where all the components\subsystems and the connections between all the ARCH tools have been established and described. Towards that a metadata structure for the ARCH Information System and the the interoperability between the ARCH Information Systems and the ARCH DSS have been defined. Annex B showcases an user manual for the ARCH Information

[5] The picture has been sourced and modified from https://www.pngfind.com/mpng/TRwJix_km-pyramid-adaptation-knowledge-management-cognitive-pyramid-hd/

System and the *Geocatalog* allowing to explore the metadata for all the datasets embedded in the ARCH HArIS and THIS geodatabases. Metadata structure of ARCH HArIS and THIS tools

To facilitate the interoperability of the services and data produced within the ARCH project, the "*Technical Guidance for the implementation of INSPIRE dataset and service metadata based on ISO/TS 19139:2007*"[6] was followed to define the requirements to be met by creating metadata, also to make it compliant with the ISO 19115[7]. The open source ESRI geoportal server[8] was used to implement a web Geocatalog enabling the discovery of the geospatial resources (vector layers, raster layers, web services, etc.), which have been developed in the ARCH project and can be explored through the web-platform of the information systems. The Geocatalog tool permits to organise, manage and publish also the metadata.

The metadata is organised in five sections:

- ***Overall information*** with file identifier, language, author, date and version
- ***Reference System Information*** with the geospatial reference identifier
- ***Identification Information*** with abstract, purpose, credits, point of contact and any constrains
- ***Distribution Information*** with format and URL to reach data\service
- ***Data Quality Information*** with indication about quality of the datasets\services

Annex C includes an example of the different sections that make up the metadata of the HArIS and THIS ARCH tools.

2.1. Interoperability between HARIS, THIS and ARCH DSS

The transferring process of data from information systems (HArIS and THIS) towards the decision support system (DSS) is sketched in Figure 5. The georeferenced elements (tables, raster data, vector data, etc.) are included in standard web-services or, directly, made available as files. The metadata and the GIS services related to data included in the ARCH DB and repository, as well as the links to reach them, are reported in the ARCH web-catalogue. Copy of the datasets and the published services are stored on a server managed by INGV and located in its headquarter of Rende (CS) in Italy.

The system provides three approaches for connecting the internal systems:

1. Direct file transfer for "static" data, i.e. those that can be considered as not changing over time (e.g., the location of the immovable assets in the HA or the projections by the climate services);
2. GIS services developed within the ARCH project containing "dynamic" data, i.e. those potentially subjected to variation over the time (e.g., the position of the movable assets) or changing during the time, considering both those updated periodically (e.g., indices

[6] https://inspire.ec.europa.eu/id/document/tg/metadata-iso19139
[7] https://www.iso.org/standard/53798.html
[8] https://www.esri.com/en-us/arcgis/products/geoportal-server/overview

related to the historical climate) and in near real-time (e.g., information about occurred earthquakes);
3. Other web-services providing updated information directly reading them from the DB, that can be also changed from the users (e.g., structural information about the assets).

The methods in the first two points may also be available to allow access to public information by users\external systems, while the third method is subject to authentication because it allows direct access to the DB ARCH. Moreover, the access to DB of third parties is executed by the DSS, if it is possible and no data-structuring operations are necessary, so avoid the useless intermediate passages between internal systems. Furthermore, several datasets will be stored on the cloud (e.g., Zenodo[9]) making them available for download to external users.

[9] https://zenodo.org/communities/h2020-lc-cla-04-arch

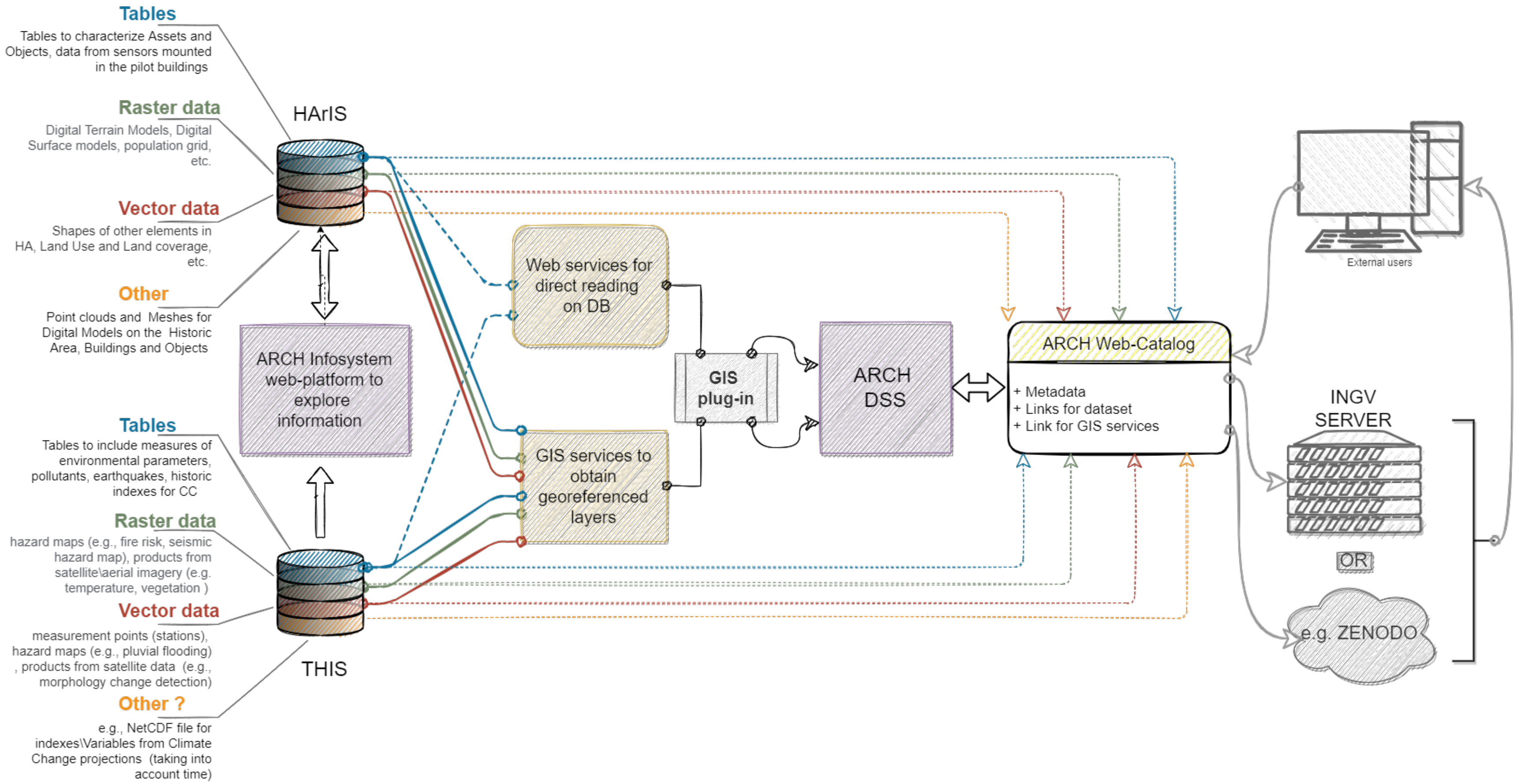

Figure 5. Transferring process of datasets and information from the information systems towards the decision support system, as well as tools to provide them to external users.

3. Semantic Spatiotemporal Assessment in Disaster Resilience towards automatic knowledge creation

This section exploits the possibilities given by a domain ontology to enhance data with semantics and therefore enhancing automatic knowledge creation thanks to the combination of qualitative semantic methods and quantitative analysis methods. This is regarded as a further possible development and exploitation of the tools developed as part of the ARCH project. The final aim would be to support the "*Wisdom*" (at the top of the "*Knowledge Hierarchy*" (Figure 1) described in Section 1 of this report) of decision makers to take thoughtful decisions to increase the resilience of historical areas to climate changes and other hazards.

3.1. Literature Review on Ontologies related to Disaster Resilience

This Section presents a literature review[10] [11] of the ontologies of three sectors deemed relevant for the ARCH project and included in the ARCH Disaster Risk Management Framework presented in D7.3 [12], namely:

1. urban planning,
2. risk assessment
3. crisis management.

The aim is to understand:

- to what extent ontologies have been used in the international literature to support smartness and resilience related to urban services;
- which kind of problems related to disaster resilience have been addressed with ontology-based applications; and
- what has been achieved so far with ontology-based disaster resilience applications.

Towards that the findings of the literature analysis on application of ontologies and semantic methods and technologies are provided by targeting an overview on:

- the distribution of the papers in the ACM research areas,
- the issues addressed
- the services and technologies built by means of ontology-based approaches related to one or more of the specific issues identified.

[10] It is worth mentioning that the work here presented has been already evaluated by the scientific community and recently published in the journal Sustainability [11]. The papers were primarily searched in the SCOPUS database and the selected ones were classified according to macro-areas of the ACM Computing Classification System (CCS), which is a widely known taxonomy in the field of computer science.

3.1.1. Urban Planning

Urban planning, also known as regional planning, town planning, city planning, or rural planning, is a technical and political process that is focused on the development and design of land use and the built environment, including air, water, and the infrastructure passing into and out of urban areas, such as transportation, communications, and distribution networks and their accessibility Urban planning, targets the design and regulation of the uses of space focussing on the physical form, economic functions, and social impacts of the urban environment and on the location of different activities within it. Sustainable urban planning targets the developmental of strategies and practices that ensure liveable, self-sustaining communities over the long term, meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Issues for Urban Planning

Urban planning for smart city encompasses approaches devoted to planning the “smart” part of the city to best integrate technological innovation with the specific urban peculiarities and historical and cultural value [13] [14].

One issue is planning to improve resilience of the city, for example the adaptive capacity to climate change-related hazards or protect and react to other natural and anthropic adverse events [14][15] and enact specific mitigation strategies, such as urban heat island mitigation strategies [16].

This encompasses decision-making and planning for various aspects of the city, including housing, mobility, economy, education, welfare and health aspects [15]. Thus, the specific issues in urban planning are mostly addressed by the works analyzed in these mentioned sectors. Indeed, effective decision making for urban planning requires a holistic analysis which is hindered by problems related to the quantity, quality, variety and/or actual availability of data and knowledge to base such decisions. Within this sector, data integration [17][18][19], and visualization from spatio-temporal perspectives [20][21], and crowd-sourcing information for urban planning [11][6] are other issues to be addressed.

Concerning planning for smart mobility, the issues concern intelligent transportation systems to improve safety and efficiency of the urban services [22][23][24], creating new services for citizen such as parking guidance and information [25][26], and use mobility data to support decision making [26].

Ontologies for Urban Planning

In [27] an ontology for urban infrastructure inter-asset management is presented to model assets (e.g., road, ground, cable), triggers (e.g., pipe leaking) and potential consequences (e.g., traffic disruption). The ontology aims to represent cascading social, economic and environmental effects to the aim of decision making.

An ontology devoted to *Urban Heat Island Mitigation Strategies* (UHIMS) is presented in [16]. Indeed, the increase of urban temperature generally impacts on energy consumption, outdoor thermal comfort, air quality, and human health. Thus, strategies are defined to face such a problem. In the ontology, UHIMS strategies are composed of: the techniques to achieve the goals of UHIMS; the urban contexts, i.e., geographic, climatic and social-economic condition for UHIMS; and the performance metrics for UHIMS performance assessment.

The *HEritage Resilience Against CLimate Events on Site* (HERACLES) Ontology [14] represents knowledge in the field of cultural heritage preservation from effects of climate change. The cultural heritage concept is related to the Vulnerability and cultural heritage value concepts to describe a risk, which quantifies possible threats to the cultural heritage from the economic perspective.

In [24] an ontology for smart transportation is illustrated. This ontology has a modular structure and contains concepts to represent the various aspects of a road traffic scenarios, such as vehicles, infrastructure elements, sensors, and driver behaviors. The sensors sub-domain is based on the *Semantic Sensor Network ontology* (SSN) and specifies the different types of sensors used for intelligent transportation systems.

The *Connected Traffic Data Ontology* (CTDO) [28] represents vehicles within the traffic ecosystem. The ontology combines sensory modelling of *Semantic Sensor Network* (SSN) and *Ontology Sensor, Observation, Sampler, and Actuator* (SOSA) ontology and geospatial data and is proven to efficiently store the *Vehicle-to-everything* (V2X) broadcast messages coming from connected vehicles.

CityGML [29] is a standard model by the Open Geospatial Consortium (OGC) for the representation and interoperability of 3D city models. In particular, *CityGML* focuses on the geometrical, topological, and semantic aspects of 3D city models, including buildings, vegetation objects, water bodies, and transportation facilities like streets and railways. This model provides useful semantic structures for a variety of application domains such as urban planning, indoor/outdoor pedestrian navigation, environmental simulations, cultural heritage, and facility management.

Km4City [20] is a knowledge model for the city and its services, initially based on the models of the data sets regarding Florence and Tuscany in Italy, and then enriched by using similar datasets available on other open data portals. The ontology covers seven macro-aspects, five of which are city-specific, such as: administration, encompassing PA and its specifications; the street model; the point of interests, including services and activities; the local public transportation; and sensors, such as those installed in the streets and on moving vehicles. The other two aspects deal with modelling of time and of metadata.

In [30] some *Ontology Design Patterns* (ODP) are proposed to support semantic modelling of various aspects of a city. In particular, these patterns are devoted to modelling: the administrative area, such as the jurisdiction purpose of a place; the city (physical) objects, including buildings, transports and devices; the events; the Key Performance Indicators (KPI)s to monitor the performance of a city (e.g., noise or pollution data, recycling rate, etc.); the measurements, including those to evaluate KPIs; the public services, such as waste management, public parking, and water quality control; and the topology of the city. These ODPs are the outcome of a systematic analysis of the literature that takes into account ontologies and data models addressing specific aspects of a smart city, including *GeoSPARQL*, *CityGML* [29], *Km4City* [20]. Thus, the ODPs result from an abstraction work of the various modelling solutions.

Services and Technologies for Urban Planning

The proposed semantics-based approaches for decision making to the purpose of urban planning include models and technologies to enable data/information collection by means of participatory processes, supported by gamification [15], or platforms for the ingestion of public and private data for smart city, including open data from public administration and private data coming from transport systems [20]. Along this line, a framework for citizen-related big data analysis to support governance decision-making is proposed in [31]. The framework uses ontology models to standardize urban governance-related attributes, personas, and associations using data mining and Bayesian networks techniques.

The paper of [32] presents *3cixty*, a framework to building a knowledge base that contains descriptions of events and activities, places and monuments, transportation facilities as well as social activities of a city. The development of an information service for tourists visiting the city for a big event, such as Expo, is discussed as an application, which leverages on the *KM4City* ontology and collects data from static, near- and real-time local and global data providers.

Intelligent transportation and automation are addressed in various works. To provide some examples, in [33], a specific instance of *Internet of Everything* (IoE) for driver-less vehicle(s) is proposed. The framework uses reasoning upon ontologies, and learning technologies to enrich the formal model of the *IoE* and to assist the vehicle in driving decisions. Semantic interoperability of smart city *Internet of Things* (IoT) applications for development of smart urban mobility services is addressed in [24] to improve safety on road by supplying traffic information, and in [26] with the aim to provide parking guidance and mobility suggestions. Finally, in [23] context representation, ontology and Bayesian networks are used to analyse data from various sensors in an urban area in order to predict the bicycle-sharing public service usage in the city of London.

The paper [34] describes the Smart City Service System, a knowledge based system to support the decision-making processes of a city. The knowledge base extends *Km4City* with *EventOntology*[11] to represent events with more details and with technology oriented ontologies such as OWL-S, to support the description of services, and SSN to extend the representation of sensors and sensor data. The integrated information is analyzed to provide situation-awareness of the city by means of inference and classification processes. This allows the governors, policymakers, and decision-makers to identify trends that can help predict future situations and to make coherent and informed decisions for improving the smart city, thus offering new services and realizing innovative projects.

3.1.2. Risk Assessment

Different classifications of smart city risks have been proposed. For instance, [35] classified them as organisational, social, and technological based on the city aspects they address whereas Ullah et al. as technology-related, organisational, and external environment-related.

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[11] The Event Ontology. Available online: http://motools.sourceforge.net/event/event.html (accessed on 15 May 2021).

Most of the papers addressing ontologies and semantic technologies devoted to risk management and smart cities deal with theory of computation and, hence, to knowledge and data management.

Issues for Risk Management

The risk management sector offers two main types of issues for the community of researchers in the field of ontologies and semantic solutions. The former concerns qualitative risk assessment and it deals with the problem of predicting likely and unlikely (i.e., black swans) risks for a city. A further level of complexity is given by the need to predict chains of risks. The latter is related to quantitatively evaluate the level of risk for an urban area depending on available contextual information.

Ontologies for Risk Assessment

Among the first researchers to treat these topics, we cite [36] which presented an ontology to model systems, events, and damages, and [37] that presented the Vulnerability Upper Model (VUM). i.e., an upper ontology model to represent risk, threat, system stakeholder, system, severity, and vulnerability. They presented also a case study concerning vulnerabilities of water systems and tested the VUM during workshops with stakeholders.

[38] presented an ontology for road risks, which includes concepts representing the main elements of the road scene as vehicles, pedestrians, and environment objects. This organizes risks as risks from objects, depending, e.g., on the speed of the car, environmental risks, e.g., depending on weather conditions and road environmental risks, e.g., depending on road conditions.

The Human and Ecological health Risks Ontology (HERO) [39] is an ontology, which includes knowledge on sensors, geospatial and temporal aspects, and health risks depending, for instance, on air or water quality. The ontology is at the basis of a system for automatic prediction of air quality and related health risk.

Among the other ontologies for representing general risks, we cite the common ontology of value and risk [40].

Services and Technologies for Risk Management

[38] developed a software application to assess risk based on the pedestrian behaviour in a video scene, a road risk ontology, and some inference rules specified in Semantic Web Rule Language (SWRL).

Similarly, [41] developed a system based on rule reasoning to determine responses to risks due to solid waste crisis. This uses Pellet [42], the inference engine available in Protégé [43], SWRL rules, a domain ontology on waste management, and information on waste crisis.

A different approach based on a domain ontology representing factors influencing flood disaster and Bayesian networks is presented in [44]. Among the above-mentioned factors, the authors cited the disasters drivers (e.g., accumulated rainfall and rainfall duration), disaster formative environment (e.g., topography and river network), and disaster bearers (e.g., pipe and road density, and population density). This approach was developed starting from historical case data during the period 2010–2018 and was used to predict and evaluate the flood disaster risk in Zhengzhou City from 16 to 20 August 2019.

[45] proposed an approach to generate cascading risks in interoperable socio-technical systems based on the TERMINUS ontology and SPARQL queries. Afterwards, [46] proposed a similar approach by means of case-based reasoning.

Finally, [47] presented a decision support system to predict the potential impact of a trigger with location specific data. The system is equipped with domain ontologies and a set of rules that model critical infrastructures interdependence.

3.1.3. Crisis Management

Crisis management is a complex process that encompasses activities related to a crisis event. To cope with this event, these activities are usually subdivided into phases. The most common ones are *preparedness, response, recovery, and mitigation*. According to our scientometric analysis, most of the works related to applications of semantic technologies in this sector mainly cover the *preparedness* and *response phases*. The following three Association for Computing Machinery, ACM, macro areas: theory of computation, information systems and computing methodologies. This means that, in this sector, semantic technologies are mainly used to support data and knowledge management and information systems to be used in operational context.

Issues related to semantics-based applications for crisis management include:

- *emergency scenario design* [48]. This is defined as the process of imagining crisis situations and describing them through models and stories. Emergency scenario design is usually performed in the preparedness phase.
- *situational awareness* that is defined as the achievement of an overall picture on a crisis, which includes the perception of elements and comprehension in the current situation and projection of future status [49].
- *communication* [50][51] and *information sharing* [52] during emergencies.

Ontologies for Crisis Management

The Smart Cities & Emergency Management Ontology [48] represents natural and anthropic events that could cause a crisis, impacted services and users, and human services devoted to respond to emergencies. The ontology includes 284 concepts and 117 relationships and is public[12].

The Dynamic Flood Ontology (DFO) [52] is an ontological upper model to represent the spatiotemporal changes occurring in a flood disaster situation. This can be used to make queries relevant during an urban flood scenario to the purpose of situational awareness.

[12] Smart Cities & Emergency Management Ontology. Available online: http://tinyurl.com/crisismng4-0 (accessed on 15 November 2021).

POLARISCO [53] is a modular ontology addressing knowledge of French emergency responders involved in the disaster response process. The ontology consists of 8 modules related to knowledge common to the different crisis actors and knowledge, concerning respectively, firefighters, healthcare units, police ontology, gendarmerie ontology, public authorities, exchanged messages, and healthcare. POLARISCO extends the Basic Formal Ontology (BFO) [54] which is a widely adopted upper ontology. This ontology is public[13].

ResOnt is an ontology [51] that reuses existing emergency management and upper-level ontologies to represent the abstract (e.g., tasks and phases) and material entities (e.g., hazardous materials) involved in an emergencies to the purpose of supporting information exchange between rescue operators.

Empathi[14] is a middle-sized ontology for emergency management and planning about hazard crises [55] It contains 423 classes and 338 relations and includes concepts as impact, affected population, service, and volunteer support. It aims at capturing and integrating information from different sources such as satellite pictures, sensors and social media content posted by people. It imports several external vocabularies such as GeoNames[15], FOAF, LODE[16], and SIOC.

Finally, [56] propose COSIMMA, a comprehensive meta-model for representing collaboration during crises. This includes a core metamodel including high level concepts related to collaboration and four packages representing, respectively, the context, the involved partners, the objective, and the behaviour.

Services and Technologies for Crisis Management

M-CREAM[17] [57] [48] is a web application that aims at supporting creativity in designing crisis scenarios. These are the outcome of a composition of automatically generated atomic fragments, named as mini-stories. This software leverages SPARQL [58] query processing and semantic similarity reasoning.

PROMES [53] is an ontology-based messaging service aimed at supporting information exchange in the response phase, which ensures mutual understanding among stakeholders. In PROMES, a mediator resolves terminology inconsistencies by semantically transforming messages through the POLARISCO ontology.

[59] propose to build multiple instances of semantic virtual spaces on top of the cloud-enabled Internet of Things, IoT, infrastructure of a smart city to increase, for instance, situational awareness during emergencies. Such semantic virtual spaces are abstractions of the IoT infrastructure that can enable different smart city applications.

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[13] POLARISCO Ontology. Available online: https://github.com/LindaElmhadhbi/POLARISCO (accessed on 15 May 2021).
[14] Empathi Ontology. Available online: https://shekarpour.github.io/empathi.io (accessed on 15 May 2021).
[15] GeoNames Ontology. Available online: http://www.geonames.org/ontology (accessed on 15 May 2021).
[16] LODE Ontology. Available online: http://linkedevents.org/ontology (accessed on 15 May 2021).
[17] M-CREAM Website. Available online: https://sites.google.com/view/m-cream (accessed on 15 May 2021).

Rescue MODES (Medical and Operational Data Exchange System for Rescue operations) is a communication and information exchange system aimed at supporting situation awareness [51] by allowing French emergency actors involved in rescue operations to design system interfaces in a customised way. To this purpose, MODES uses SPARQL queries and the ResOnt ontology.

3.2. Towards Semantic Spatiotemporal Assessment of disaster resilience

Disaster Resilience aims at limiting the impact of harmful events on Urban areas including Historic Areas by promoting capacity building and by increasing awareness on possible consequences. Qualitative risk assessment allows to figure out possible risk situations and to prioritize them, whereas quantitative risk assessment is devoted to measure risks from data, to improve preparedness in case of crisis situations. An automatic approach towards a comprehensive risk assessment is proposed in this section encompassing qualitative and quantitative risk assessment and allowing to generate geo-localized *risk mini-models* dynamically associated with sensitive points of interest (POIs). Examples of points of interests are hospitals, transportation services, as well as museums, places devoted to cultural activities or other peculiar places identifiable in Historic Areas. In general, *risk mini-models* are fragments of conceptual models representing possible risks of socio-technical systems [60]. Risk mini-models related to a specific POI could change in time. For instance, the level of risk for a metro station could vary according to the time of the day (e.g., from very high level during the rush hour to low during closing times). By ingesting temporal data on the level of operability of urban services, we compute dynamically the level of risk of all the automatically generated risk mini-models.

The proposed approach overcomes limitations of existing qualitative risk assessment approaches, as they only rely on past data and on the experience and the different perception of experts, by exploiting computational creativity techniques. Computational Creativity is a new field of Artificial Intelligence devoted to defining computational systems that create artifacts and ideas [61]. We refer these methods to the creative process of the experts while they are conceiving risks that could lead to possible disruptive crisis situations that never happened in the past. In a recent paper [48] we explicitly validated the effectiveness of the proposed approach in supporting emergency management officers and risk analysts in conceiving novel emergency scenarios for smart cities.

The proposed approach leverages on a semantic and spatiotemporal representation of knowledge of the urban area and relies on a software system that allows the dynamic generation of geo-localized risk mini-models. The system consists of the following components:

- a knowledge base is provided by the TERMINUS *(TERritorial Management and INfrastructures ontology for institutional and industrial USage)* domain ontology [63], a domain ontology formalizing knowledge concerning environment, city services and infrastructures and related risks,
- a geo-database including data on urban areas and how they vary in time; WS-CREAM, a web service built on top of CREAM (*CREAtivity Machine*) [48] implementing the

computational support for automatic risk identification and ranking, by querying the ontology and using context data;

- CIPCast [64] a GIS (Geographic Information System)-based tool for risk analysis of critical infrastructures, enhanced with forecasting and decision support functionalities.

We presented how these systems can operate in synergy to perform semantic spatiotemporal risk assessment for urban areas, and provide validation results of the approach on two case studies within the city of Rome. Validation has been performed by involving experts with experience in real past situations. The results demonstrate that the generated risk mini-models are generally plausible and the automatic evaluation is useful to provide an objective input for risk assessment.

This Section has been organized as follows. The first subsection presents relevant work. The literature review was mainly conducted in the research areas concerning both quantitative and qualitative risk assessment. The second subsection describes the ideas behind qualitative and quantitative risk assessment. The proposed software system is described in the third subsection while the forth one presents the validation test.

3.2.1. Related Work

The most common dynamic risk assessment approaches for metropolitan areas subjected to natural events are either quantitative or qualitative risk assessment.

Examples of quantitative risk assessment are the one proposed by the World Health Organization,[65] that, among the different causes of death, includes also costal flood mortality and earthquake risk assessment e.g [66][67].

Examples of qualitative risk assessment, include, among others, [68] that discusses types of risks due to interdependencies of critical infrastructures, [69] presenting a semantic model for system-of-systems risks and discussing water systems risks with roots on climate change hazards, [70] that, similarly, presents a modelling approach to cause-effect relationships underlying risks and vulnerabilities, developed within the EU project "*Climate Resilient Cities and Infrastructures – RESIN*". Both works propose conceptual modelling approaches for vulnerability assessment of urban areas. These identify some upper-level concepts as hazard, exposure, and impact that should drive adaptation strategies due to climate change. [71] proposes an approach mixing qualitative and quantitative risk assessment. With respect to these works where qualitative assessment is performed by interviewing experts, our proposed activity instead is automatized by means of semantics-based and computational creativity techniques.

Support tools for qualitative risk assessment, finalized to decision making for resilient cities, include the Quick Risk Estimation (QRE)[18] tool of the United Nations Office for Disaster Risk Reduction (UNDRR), developed with the support of the European Commission under the Sendai Framework, and freely available since October 2019. This tool, which is based on MS Excel, is aimed to help city authorities and other stakeholders in the common understanding

[18] https://www.unisdr.org/campaign/resilientcities/toolkit/article/quick-risk-estimation-qre.html

of current and future risks to assets of cities. These users are guided in manually scoring likelihood of threats and rating exposure, vulnerability and response measures on assets in a 5-Likert scale [72]. Based on these data, the QRE tool computes a compound risk level by means of a risk matrix. In our approach for risk assessment, not only risks are automatically assessed by means of a similar risk matrix and same computation methods, but we also automatize the scoring of the individual risk parameters based on real data, as explained in the subsection 3.2.3, so avoiding error-proneness of human-based data entry and subjectivity of the scoring.

Various initiatives in the literature are devoted to building ontologies for risk assessment. One of the first was the vulnerability upper model (VUM) and a VUM ontology, presented by [69], including concepts as risk, threat, system, stakeholder, severity, and vulnerability Then this ontology was extended to build the first version of the TERMINUS ontology presented in [63]. After these, other initiatives include the common ontology of value and risk presented by [73] and the ontology of emergency managing and planning about hazard crisis presented by [74]. Other ontologies refer to close domains as the ontology proposed by [75] that covers disaster management and the related operational emergency response system. TERMINUS was used as it focuses on the knowledge required in this ARCH project, which concerns territory, risk and crisis management. Furthermore, it is structured as a multi-level specialization hierarchy that is a feature required in order to use the computational creativity functionalities of WS-CREAM effectively [62].

Currently, the TERMINUS ontology used in this work covers physical and functional vulnerabilities of infrastructures and urban services to describe risks in an urban area. In future works, we plan to extend it with psychological vulnerabilities of people for a more detailed account for human aspects in the description and assessment of risks. Among such type of studies, the paper by [76] investigates impacts of climate change hazards on human health, including emotional resilience and psychosocial wellbeing, whereas the paper by [77] analyzes predictability of the stress influence in the management of a crisis.

Recent works address the problem of spatiotemporal assessment of risks either from a quantitative perspective [78] or by simulating cascades of faults [79][80] due to critical infrastructure interdependencies. In [78] the spatiotemporal distribution of flooding is simulated by using the LISFLOOD-FP model and the spatial movements of residents are simulated during the urban flooding time period. Instead, in [79] and [80] the possible status of localized critical infrastructures is computed over an entire time period by means of a software based on a time-dependent Markov chain model. Again, with respect to them, none of these approaches uses semantic technologies to automatize the risk assessment process. However, in the case of operational scenarios management, tools based on semantic technologies exist and are presently under advanced testing (e.g., see [81]).

Adopting creativity approaches for serious purposes is currently one of the aims of the open innovation [82] community. For instance, [83] present a creative approach to open innovation for health and safety in manufacturing plants. With respect to them, we adopt semantic query processing to support this creative process. Finally, [84] propose a creative approach for knowledge acquisition to support innovation. We share with them the use of an ontology but we propose different reasoning techniques and a different application scenario.

3.2.2. Foundational Aspects of Semantic Spatiotemporal Assessment of Urban Risks

In this subsection we present the foundational aspects of the proposed approach for risk assessment.

A risk mini-model is defined by a set of concepts representing a risk situation from a semantic perspective. This set includes a service (*s*), a vulnerability (*v*), a critical event (*c*) and the hazard (*h*) causing it. The formal definition of the *risk mini-model r* is the following:

$$r = \{s, v, c, h\} \text{ with } s \in S,\ v \in V,\ c \in C, \text{ and } h \in H. \quad (1)$$

A geographical area could include one or more POIs. For the sake of simplicity, we consider a POI as a system providing a service. For instance, we consider a metro station from the perspective of service that can be provided to commuters. Other perspectives for a system are, for instance, the economic value and the physical infrastructure. A detailed discussion on system aspects can be found in [63]. Given a POI, a *geo-localized temporal risk mini-model* can be considered as an instance of a risk mini-model that represents a POI, its semantic functional representation, a vulnerability, a critical event and the hazard causing it, the geographical coordinates of the POI, and the time of the critical event. Hence, the geo-localized temporal risk mini-model r_p is defined as follows:

$$r_p = \{r, p, x_i, t\} \quad (2)$$

where *p* represents the POI, x_i are the spatial coordinates (*i* = *1*,*2*,*3*) of the POI, and *t* is the time.

Then we define the *RiskLevel* mapping function that maps the domain of the geo-localized temporal risk mini-models to the level of risk:

$$RiskLevel: \{r_p\} \longrightarrow \mathcal{L}\ . \quad (4)$$

where $\mathcal{L} = \{Very\ High, High, Medium, Low, Very\ Low\}$.

A detailed treatment on how the *RiskLevel* mapping function is computed is presented in subsection 3.2.4.

Finally, we define the semantic spatiotemporal risk space as the set of all the pairs consisting of a geo-localized temporal risk mini-model and its corresponding risk level:

$$\mathcal{R}_p = \{(r_p, l)\}\ . \quad (5)$$

Figure 11 depicts as colored circles some geo-localized temporal risk mini-models for an urban area. Colors represent the level of risk in a given instant of time (red: high, yellow: medium, green: low). As it can be deduced from the figure, the level of risk of a geo-localized temporal risk mini-models can change over time.

According to our approach, a risk analyst selects a POI included in an urban area. Then for that POI he/she automatically retrieves a ranked list of possible geo-localized temporal risk mini-models. Finally, he/she selects one of them to observe its level of risk and its temporal evolution over time.

3.2.3. Software System for Qualitative Semantic Spatiotemporal Assessment of Risks

The automatic approach for semantic spatiotemporal risk assessment enhances the decision support system capabilities of a pre-existing GIS-based system devoted to Critical Infrastructures (CI) protection [64]. A view of the overall system architecture is in Figure 6, showing the functional blocks to enable risk assessment following both quantitative and qualitative methods, and the data and domain knowledge they use. More specifically, the overall system consists of independent services exposing the required functions for risk assessment to a middle layer, which is responsible for their coordination and of their interaction with the components of the knowledge base. A WebGIS interface is used to both activate some of the system functions and to query GIS data from a map.

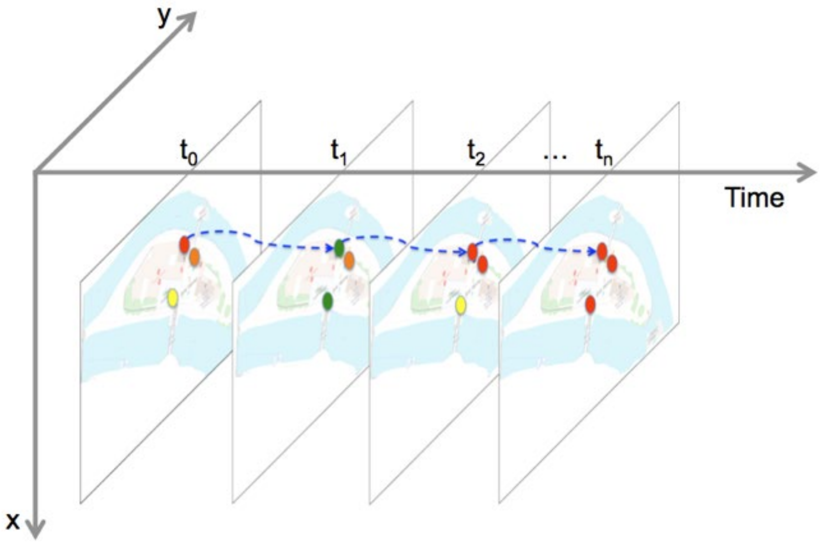


Figure 6. Evolution of level of risk of a geolocalized temporal risk mini-model

The quantitative risk assessment services in Figure 7 realize a decision support system named CIPCast, conceived and designed in the framework of a EU-funded project CIPRNet *Critical Infrastructures Preparedness and Resilience Research Network*, (www.ciprnet.eu), and further developed in subsequent research projects and activities (project RoMA and RAFAEL, funded by the Italian Ministry of Education, University and Research). Instead, the semantic qualitative risk assessment services rely on a domain specific configuration of the CREAtivity Machine Web Service (WS-CREAM) [62] by means of the TERMINUS ontology, representing knowledge related to hazards, systems and emergency management.

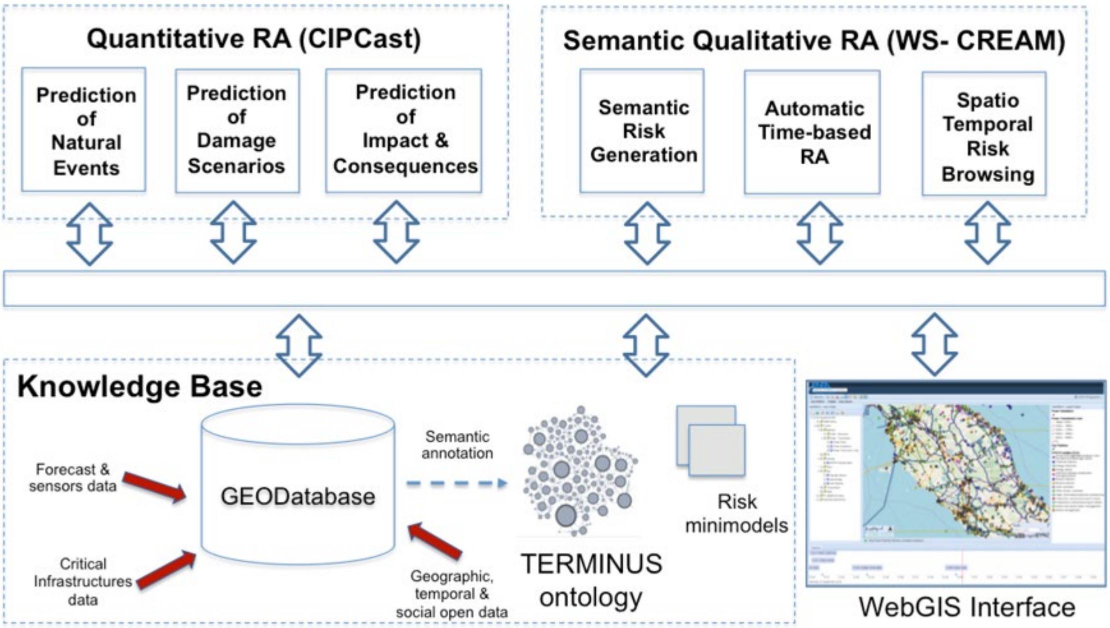


Figure 7. Semantic Spatiotemporal system architecture

CIPCast Decision Support System (DSS) functionality for quantitative risk assessment

CIPCast is conceived as a combination of free/open-source software environments that includes GIS features to perform operational risk prediction and analysis of critical infrastructure for natural hazards such as earthquakes. Indeed, multisource data and GIS-integrated analysis contribute to a better emergency planning, providing fundamental information for immediate response. All data and information available to such a purpose, such as base cartography, risk maps, critical infrastructure features data, data from sensors, scenario produced is stored and managed in a PostGIS-based geo-database. A specific component is devoted to dynamically acquiring external data from many different sources (e.g., weather and seismic data stations), to establish the current external conditions. These data are used to implement the following functional blocks for quantitative risk assessment.

- *Prediction of Natural Events*, by estimating the expected manifestation strength for predictable events in the areas under observation;
- *Prediction of Damage Scenarios*, by correlating the strength of the expected hazard manifestations to the *specific* vulnerability (i.e. that related to the perturbing event) of the different critical infrastructure (CI) components located in the affected area. The damage scenarios are performed for all the CI components having a high probability of being damaged due to the hazardous event(s).
- *Prediction of Impacts and Consequences*, by combining: (i) damages expected for the CI components (e.g., the breakage of a transformer in an electric substation); (ii) topological and behavior features of the network and (iii) network (inter-)dependencies, in order to estimate over time the degradation of the service(s) level provided by the network(s) (e.g., an electric outage caused by a failed substation).

CIPCast can exploit different types of data, both from its own GIS database (geodatabase) and from external repositories. In particular, the geo-database contains several data features: i) territorial and environmental data (basic cartography, hydrogeological data, morphology, geology, etc.); ii) socio-economic data (census data); iii) data about structures (features and characteristics of buildings) and infrastructures (power lines, gas pipelines, water supply network, telco network components, roads and railways, etc.); iv) natural hazard and risk maps (earthquake catalog, seismic risk, inventory of landslides, flood risk, etc.); v) point of interest (POI) data. To predict the damage scenario, CIPCast gathers real time data from field sensors and from external repositories/services. In particular, it acquires: i) earthquake events from the seismic network of the Italian institute for geophysical studies (INGV); ii) weather data and forecast from meteorological models (CETEMPS) and services, reporting data on rainfall, temperature, humidity, wind, pressure etc. in a given area; iii) satellite remote sensing data (e.g. measurements of displacement through SAR data).

Risk assessment functions of CIPCast concern physical damages estimations on buildings and components of critical infrastructures. Given the geographic location of specific elements (e.g. critical infrastructures and POI), CIPCast can assess - for each element - the possible degree of damage depending on the type of event expected (and its intensity), taking into account the vulnerability of the element itself to a specific hazard (such as earthquake and flood) [85]. Then, in the case of critical infrastructures, CIPCast evaluates the impact that the expected service damages could cause on the affected infrastructure element (e.g. substation, powerline, and pipeline) and, consequently, on the entire infrastructure [86].

Furthermore, a specific seismic risk module has been realized, which operates as a stress tester enabling to simulate earthquakes and assessing the resulting chain of events [87]. Such CIPCast module firstly simulates the ground shake map (related to earthquake intensity), by also considering the amplification effects; then estimates the expected damages to buildings and other infrastructure elements. It allows to:

- simulate earthquake events (synthetic or by reproducing past events actually occurred) and estimate the (deterministic) scenarios in terms of macroseismic intensity;
- estimate damages on buildings and infrastructures, whose vulnerability was previously estimated;
- estimate consequences on population (casualties, people to be evacuated) and on the delivery of services (e.g. buildings collapse and consequence on roads).

Additionally, some decision-making support is provided to operational processes such as multiple strategies to manage crisis scenarios. Figure 8 presents a screenshot of the CIPCast interface showing the level of damage for buildings in a large area affected by a simulated earthquake.

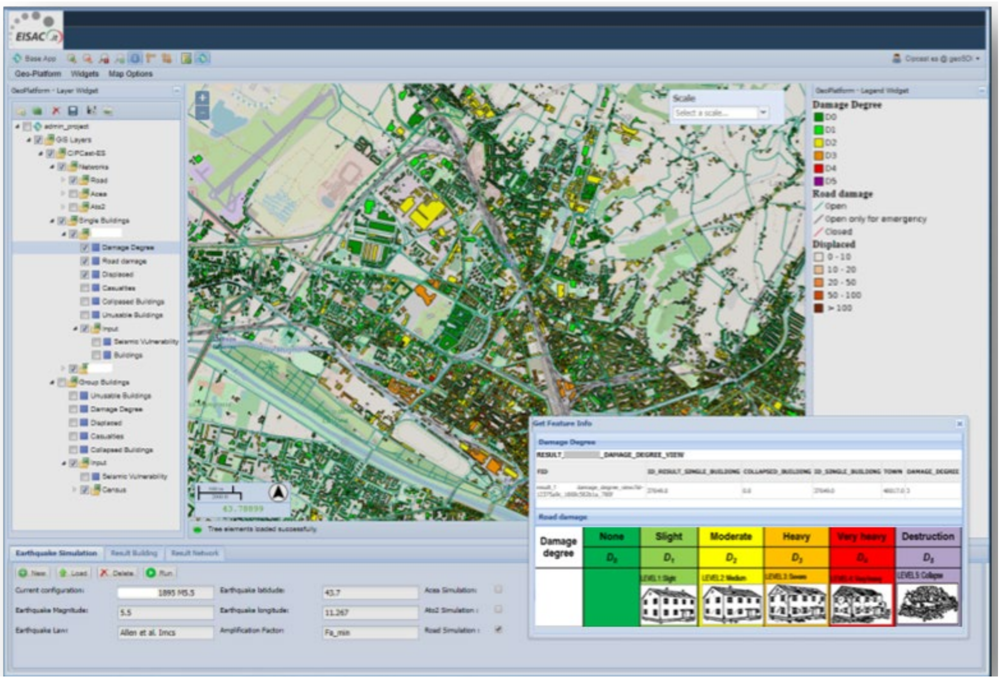


Figure 2 Level of damage for buildings in a large area affected by a simulated earthquake

WS-CREAM functionality for semantic qualitative risk assessment

The automatic functions for semantic spatiotemporal risk generation and assessment aims at supporting a user, such as a risk analyst or a city planner, to imagine possible scenarios and identify relevant ones for objectives such as city emergency management and/or risks mitigation. Indeed, this component provides an automatic ranking of the generated situations, based on context information on spatiotemporal dimensions, a useful function to speed up the subsequent qualitative assessment activity by the user.

These functions rely on: spatiotemporal context data; a domain ontology for territorial management and infrastructures; and a risk assessment function. The context data is supplied by the GIS database, the domain ontology used by this system is TERMINUS [88] and the risk assessment function, which can be specified in a configuration file, consists of a risk matrix accounting for hazard – damage levels evaluated on a psychometric Likert scale for questionnaires [72]. A detailed description of TERMINUS and the semantic spatiotemporal qualitative risk assessment functions follows.

TERMINUS: An Ontology for Territorial Management and Infrastructures

TERMINUS is a domain ontology that includes semantic representations of environment, critical infrastructures and related hazards, risks and threats. An ontology is a formal specification of a shared conceptualization [89][90]. It defines concepts, relationships, and axioms relevant for representing a domain of interest. TERMINUS has been engineered by considering real (historical) situations and by extending some ontology design patterns. At the current stage, TERMINUS has been built by deriving concepts from the vulnerability upper model (VUM) design pattern [69] from the system aspect design pattern presented by [45] and from the risk of system service design pattern [88] that is presented in the following. It also includes knowledge related to interdependencies between critical infrastructures [68]. In particular, the risk of system service design pattern allows representing risks for city services due to catastrophic events as earthquakes, floods, and landslides. This ontology design pattern is depicted in Figure 9. It consists of five upper-level concepts: Hazard, Critical_event_of_system, Functional_vulnerability, System_service, and Stakeholder. The description of these five upper level concepts is presented in Table 1, whereas the description of the relationships between them is presented in Table 2.

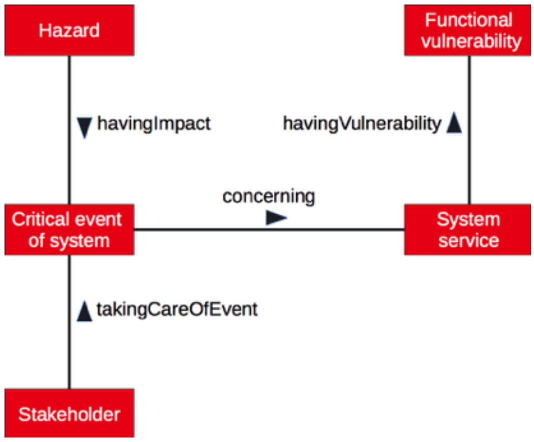


Figure 9. Vulnerability Upper Model representation of the design pattern to model risks for system service

Table 1. Description of the five upper-level concepts belonging to the risk of system service ontology design pattern.

Concept name	Description
Hazard	Event or trend or their impacts (e.g., floods, droughts and sea level rise) with likely detrimental consequences to human systems (Adapted from Hazard concept as described by [91]).
Critical_event_of_system	Event representing one or more effects on systems from exposure to a hazard; effects are mediated by the strength of the hazard and the vulnerability of the exposed system (Adapted from the Impact concept as described by [91]).
Functional_vulnerability	The propensity of a system function to be adversely affected. This results from the balance between sensitivity and adaptive capacity (Adapted from the Vulnerability as described by [91]).
System_service	Service provided by system.
Stakeholder	A person or organization that is interested in a system or its subsystems.

Table 2 Description of the relationships between concepts belonging to the *risk of system service* ontology design pattern.

Object property name	Description
havingImpact	Conceptual relationship between a Hazard and a Critical_event_of_system.
concerning	Conceptual relationship between a Critical_event_of_system and one of its provided services (i.e. System_service).
havingVulnerability	Conceptual relationship between System_service and one of its function vulnerabilities (i.e. Functional_vulnerability)
takingCareOfEvent	Conceptual relationship between Stakeholder of a system and Critical_event_of_system.

Finally, Figure 10 shows an excerpt from TERMINUS ontology showing a fragment of the taxonomy related to the *Critical_event_of_system* concept.

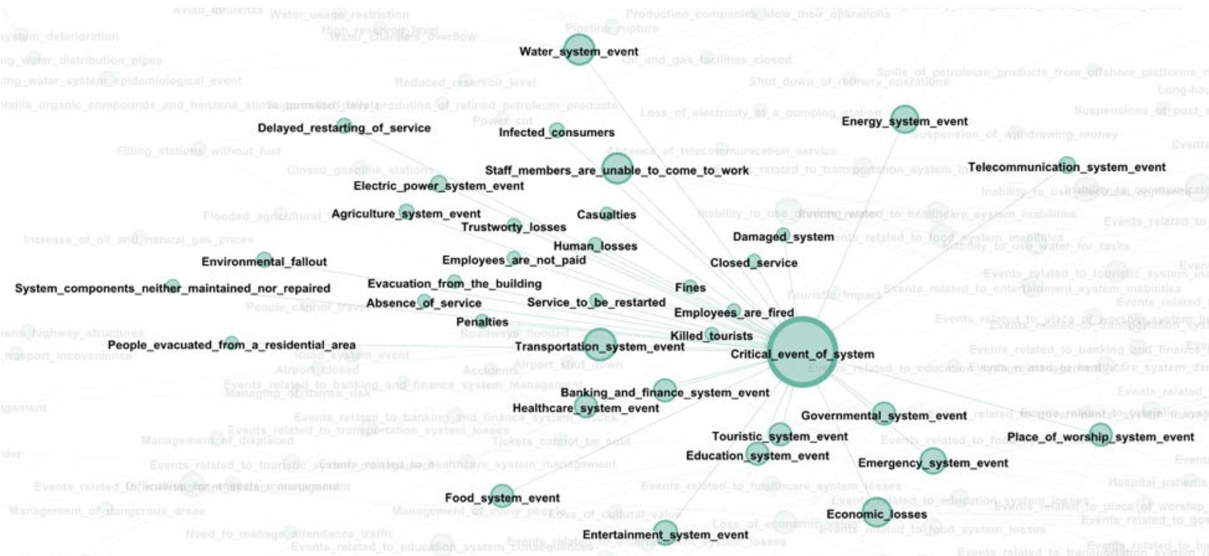


Figure 10. Excerpt from TERMINUS ontology with a fragment of the taxonomy related to the Critical_event_of_system concept

Semantic risk generation

This function takes as input a list of service types, semantically annotated with TERMINUS concepts, which are present in a user selected urban area, and the type of hazard with its associated properties. Semantic annotation was done manually by some experts knowing the addressed geographical area. A SPARQL query [60] is automatically built from the pre-defined ontology pattern, as that derived by the conceptual model in Figure 10, addressed in the configuration file, which is run on the TERMINUS ontology to retrieve a list of semantic descriptions of possible service risks. These are represented as records of the following table.

[*System service*, *Hazard*, *Functional vulnerability*, *Critical event of system*, *Stakeholder*] (1)

These records are built with concepts of TERMINUS, where the System_service component specifies the type of service among those provided as input, and, possibly, the Hazard component specifies the type of the hazard chosen by the user.

Automatic time-based risk assessment

This function implements risk ranking mechanisms accounting for both semantic criteria and for contextual information related to the characteristics of the POI and of the geographical area where it operates. Specifically, all entities of the risk mini-model, except the Stakeholder whose role is limited to risk description and understanding, are associated with one or more metrics, which are either evaluated at conceptual level, or at instance level. Then the overall risk is assessed, by aggregating these values according to a time-dependent formula that can be configured for the system. The entity-level metrics are defined as described in Table 3 and they are individually assessed by some experts in the system preparation phase. Indeed, these values depend on geographical and environmental information, on the specific city, on the service types and on risk expert's knowledge, and they can be updated during system operation following the changes at the information sources.

Table 3. Risk assessment metrics

Entity	Metric	Input	Description
System service	*ServiceValue* (SV)	POIName	<u>*Aim*</u>: instance level metric applied to a POI, indicating the relative value and/or criticality of the specific service within the city i.e., compared to other services. <u>*Value:*</u> expressed in a Likert scale. <u>*Data source*</u>: Rome municipality.
	TimeRelevance (TR)	POIName	<u>*Aim*</u>: instance level metric applied to a POI, indicating the level of operation of the service at the time of occurrence of an adverse event. Hence, this metric provides a time-related weight for the possible consequent loss, functional, economic or quantity of victims, for the given POI. <u>*Value*</u>: expressed in a Likert scale. <u>*Data source*</u>: operation time profile of the service (e.g, opening-closing time and number of visits throughout operation), available from Google
Vulnerability	*VulnerabilityLevel* (VL)	Functional Vulnerability	<u>*Aim*</u>: conceptual level metric associated with a specific functional vulnerability type of a service, indicating the relative importance of that vulnerability. <u>*Value*</u>: expressed in a Likert scale, specified in the ontology as attribute of the given Functional_Vulnerability entity. <u>*Data source*</u>: domain expert's knowledge.
Critical event	*ConsequenceLevel*	CriticalEvent	<u>*Aim*</u>: conceptual level metric associated with a specific type of critical event (e.g., loss) that may

of system	(CL)		occur at a service after an adverse event, indicating its relative importance for the service. *Value:* expressed in a Likert scale, specified in the ontology as attribute of the given type of Critical_Event_Of_System entity. *Data source*: domain experts' knowledge.
Hazard	*HazardRiskLevel* (HR)	Hazard, POIPosition	*Aim*: instance level metric associated with a type of hazard and the geographical position of the specific POI, indicating the probability of occurrence of that hazard in the locality of the POI. *Value*: expressed in a Likert scale, which is defined for each type of hazard. *Data source*: ISPRA[19]

During a risk assessment activity, a pre-defined risk formula:

RiskLevel(POI, RM, x_i*, t)*: = *RiskLevel*(POI, RM, [SV, TR, VL, CL, HR]) (2)

is applied to every POI, risk mini-model RM, geographical position of the POI x_i and the time *t*. This formula aims at assigning a time-dependent risk level to each risk mini-model of a POI of the city. Essentially, a risk level indicates the importance of the identified risk, so it serves the purposes for comparing risks with other risks of the same POI. One approach, commonly used in qualitative risk assessment, is to combine risk levels with a risk matrix, a two-dimensional table for combining likelihood of hazard and severity of impact on a system. For the application presented in this Section, the risk matrix is shown in Figure 11, and it is very similar to the matrix proposed by the United Nations Office for Disaster Risk Reduction. The severity level of a risk mini-model for a POI is computed as the *geometric mean* of the values: SV, TR, VL, and CL in (2), and the likelihood ranking is provided by official studies from environmental institutions.

		Severity Level				
		Very Low	**Low**	**Medium**	**High**	**Very High**
Likelihood	**Very Low**	Very Low	Very Low	Low	Medium	Medium
	Low	Very Low	Low	Medium	Medium	Medium
	Medium	Low	Medium	Medium	Medium	High
	High	Medium	Medium	Medium	High	Very High
	Very High	Medium	Medium	High	Very High	Very High

Figure11. Risk Matrix.

[19] http://www.isprambiente.gov.it

Spatiotemporal Risk Browsing

Once the risks mini-models are ranked by the automatic time-based risk assessment component, various types of browsing functionality can be implemented, according to the spatiotemporal dimension or risk relevance values. An example of result visualization of risk mini-models based on time and risk relevance is shown in Figure 12.

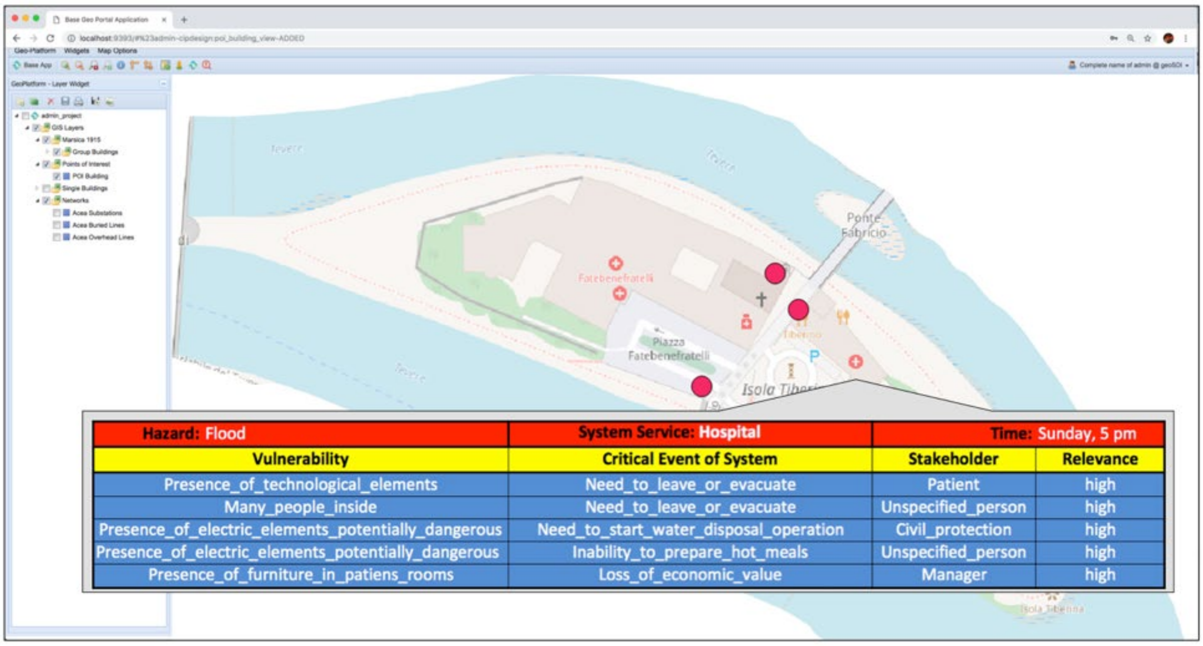


Figure 12. Example of result visualization of risk mini-models based on time and risk relevance.

Usage scenario of the overall system

One of the envisaged usages of the overall system is in the *prevention phase* from potential crisis events that pose risks to a specific urban area. The following scenario illustrates such a use case. A risk analyst wants to assess the consequences of an earthquake for a zone of an urban area. The analyst specifies the hazard and selects the city area by interacting with a map by means of the WebGIS interface of the system. Relevant geographic information for that area includes: points of interests such as schools, hospitals, public places; and CI components such as water pipes, road characteristics, and position of electric substations.

Two types of studies are currently supported by the system, namely: (i) damage estimation on buildings and infrastructure components of the area by means of simulation models; (ii) initial qualitative multi-perspective assessment of risks for the POIs of the area and consequences for citizens. Whereas the first type of analysis may be completely automatic as it relies on full availability of the required data, the second type is a machine assisted human activity, as complete information is hardly available and requires elicitation of tacit knowledge from several experts. For the second type of study, the entities within the selected area by the analyst are automatically identified and this information exploited to generate semantic descriptions of possible risk scenarios. The results are supplied to the risk analyst on the WebGIS interface. The analyst is also supported by the system in the identification and browsing of all relevant risk situations, with the final aim to improve completeness, and hence reliability, of the assessment.

3.2.4. Exemplification of a semantic spatiotemporal risk assessment in an urban area

To evaluate and appreciate the effectiveness and usefulness of the proposed semantic spatiotemporal risk assessment approach, an example of implementation is herein showcased with reference to two urban areas in Rome (Italy)[20]. In particular, we intended to investigate the support, that such a system might give to a risk analyst and/or a city emergency operator to identify risk situations and evaluate their priority in order to handle them. To this purpose, we set the following research questions.

- RQ1-"*To what extent the semantic risk descriptions generated by the system are plausible?"*;
- RQ2 -"*To what extent the system is useful for risk assessment*?".

A detailed description of the performed experimentation follows.

System set-up The selected areas for the study are: General Hospital "*Policlinico Umberto I*" and Isola *Tiberina*. We selected the first area (*Policlinico*) for the case study because this area is highly crowded due to the presence of the largest Rome University (Sapienza University), one of the largest universities in Europe with over 110 000 students, a large hospital (with availability of 1200 beds), several public and private services, restaurants, a metro service and an historical cemetery. A map of this area including some relevant POIs is depicted in Figure 13. For this case study we would like to investigate the possible risks due to the impact of an earthquake on such a crowded area. The second selected area, the Isola *Tiberina* area, has been considered as it includes another important hospital in Rome, museums, restaurants and governmental offices. This area is also close to the *Tevere* river and, as such, it is exposed to flood risk, whose possible impacts we aim at investigating. A map of this area with some relevant POIs is reported in Figure 14. An example of assessment of a semantic spatiotemporal risk mini-model related to the Isola Tiberina area is presented in Table 4.The following activities were required to configure the system and prepare the queries for the experiment.

- *Specification of the hazard event*. As above-mentioned, risks from an earthquake event were required for the Isola Tiberina area and from a flood event for the Policlinico area.
- *POIs identification and selection*. Two subsets of POIs located in the two selected areas were chosen according to the following criteria: (1) each subset must include relevant POIs for the city; (2) the two subsets include POIs of the same service type; (3) each subset contains POIs of various types. So, for Policlinico area, the POIs included in Table 5 were chosen. Instead, for Isola Tiberina area, the selected POIs are reported in Table 6.
- *Selection of temporal data*. Two different week days/time were decided for the assessment of the risks from the hazard events. Namely, Sunday at 11:00 and Tuesday at 21:00, were chosen for Isola Tiberina, instead Sunday at 21:00 and Tuesday at 18:00 were decided for Policlinico. Furthermore, the service levels of the individual POIs of the areas were set

[20] It was not possible to implement the test in one of the ARCH pilot cities as this test requires a fully operational GIS-based Decision Support System DSS, that is still under finalisation for the ARCH Cities in line with ARCH project timeline. This test also requires the development of an ad-hoc ontology-based automatic tool, e.g. WS-CREAM, which is not foreseen as part of the ARCH project

correspondingly. Concerning Isola Tiberina, Sunday at 11:00 am was chosen because we assumed that there are several people in the POIs of the area on that day and at that time. Instead we assumed that there are relatively few people on Tuesday at 21:00. Concerning Policlinico, Sunday at 21:00 am was chosen because we assumed that there are few people in most of the POIs of the area (except the selected restaurant) on that day and at that time. Instead we assumed that there are relatively more people on Tuesday at 18:00 as hospital and metro station are expected to be crowded.

Table 4. Isola Tiberina risk mini-model.

Functional_vulnerability: People_inside **System_service**: Pharmacy **Critical_event_of_system**: Health_and_physical_consequences **Stakeholder**: Patient **Hazard**: Flood
POI name: Farmacia Ospedale Fatebenefratelli
Risk level on Sunday at 11:00: very high
Risk level on Tuesday at 21:00: high

Experiment. The semantic risk mini-models generation and qualitative spatiotemporal risk-assessment functions run on the areas and temporal based input sets described above. Then, four risk-assessment experts, with good knowledge of Roma geographical and urban characteristics, were asked to estimate the quality of the obtained results. In particular, two of them, *expert A* and *expert M*, analysed the risk assessment lists for the POIs in the Policlinico under an earthquake hazard, and the other two, *expert G* and *expert V*, analysed the risks for the POIs in the Isola Tiberina area under a flood event. Each expert was asked: (1) to judge the plausibility of the generated risk mini-models with a yes/no answer; (2) to evaluate on the basis of a three-levels Likert scale their relevance for each corresponding POIs on the map. After the assessment, each expert was asked to provide the criteria followed for attribution of the risk level, by weighting from 0 to 5 the following aspects: *Hazard localization*, i.e., hazard risk level for the POI localization; *Economic value*, i.e., the relevance of the POI in the city; *Vulnerability*, i.e., the type of vulnerability supplied in the risk mini-model; *Critical event*, i.e., the type of impact supplied in the risk-mini-model; and *Time*, i.e., the time indicated for the hazard event. The obtained risk evaluations and comparison with the system results are reported in Table 7 and Table 8. Furthermore, Table 9 summarizes the accordance of the risk results by each expert with those by the system, and Figure 20 the accordance of the experts on the risk evaluation criteria, compared with that used by the system.

Table 5. POIs selected for the Policlinico area scenario.

POIName	Type
Cimitero Monumentale del Verano	Cemetery
Ambasciata presso la Santa Sede Ungheria	Embassy

Istituto Superiore di Sanità	Office
Policlinico	Hospital
Police Station	Police
Ufficio Postale Roma 62	Office
Ristorante La Casetta Snc	Restaurant
Policlinico metro station	Station
Sapienza University	University

Figure 13. Policlinico area and related POIs.

Table 6. POIs selected for the case study related to Isola Tiberina area.

POIName	Type
Farmacia Ospedale Fatebenefratelli	Pharmacy
Ospedale Fatebenefratelli	Hospital
Musei Capitolini	Museum
Santa Maria in Cosmedin	Worship place

Figure 14. Isola Tiberina area and related POIs.

Answers to the research questions

RQ1 concerns validation of the automatically generated risk mini-models by the experts. As shown in Table 7, all the risk descriptions for the POIs of Isola Tiberina were judged plausible by the assigned experts and about 90% of the risk descriptions for the POIs in the Policlinico area were judged plausible by both *expert A* and *expert M*, who evaluated them. This is a very good result, which is also related with the quality of the source ontology and appropriateness of the risk semantic model.

Table 7 Plausibility of the risk mini-models for the POIs of the two areas according to the experts

Area	Time	E*	Plausible RMM	Not plausible RMM	Plausible %	Not plausible %	Not plausible (shared)	Not plausible (shared)
Policlinico	18:00 Tuesday	A	392	71	84.67 %	15.33 %	49	10.58 %
	21:00 Sunday	M	253	210	54.64 %	45.36 %		
Isola Tiberina	21:00 Tuesday	G	290	12	96.02 %	3.98 %	0	0 %
	11:00 Sunday	V	302	0	100%	0 %		

*Expert

RQ2 is concerned with evaluation of the automatic support to the qualitative risk assessment process. Especially in the case of less familiar risk descriptions, as in the case of our risk mini-models, this process is human-based. Therefore, we used this trial to measure differences (if any) in the human perceptions of risk situations, even when performed by domain experts, and an automatic assessment leveraging on: an urban risk knowledge base, environmental risk data, and a type of risk formula as in the common practice for qualitative risk assessment. In this respect, for each area, in Table 8 we reported the number of risk mini-models judged of low, medium or high relevance by each of the two evaluators for each POI, and compared with the results by the system. From the data in Errore. L'origine riferimento non è stata trovata., we noticed that the expert results generally differ from the system results, and that, for both areas, results by the two experts also differ. Table 9 presents the detailed analysis of agreement in relevance level assessment between experts and the system (WS-CREAM). This shows the number of risk mini-models that were judged at the same level of relevance. Also, this analysis confirms the need of an objective means to assess the relevance.

Table 8. Comparison of the qualitative risk assessment by the system with that by the experts.

Area	Time	High relevant RMM	High relevant RMM (system)	Medium relevant RMM	Medium relevant RMM (system)	Low relevant RMM	Low relevant RMM (system)
Expert A	**#**	79	0	139	345	245	118
	%	17.06 %	0 %	30.02 %	74.51 %	52.92%	25.49 %
Expert M	**#**	51	0	100	305	312	158
	%	11.02 %	0 %	21.60 %	65.87 %	67.39 %	34.13 %
Expert G	**#**	7	180	45	29	295	138
	%	2.02 %	51.87 %	12.97 %	8.36 %	85.01 %	39.77 %
Expert V	**#**	81	206	173	6	93	135
	%	23.34 %	59.37 %	49.86 %	1.73 %	26.80 %	38.90 %

Table 9. Analysis of agreement in relevance level assessment between experts and WS-CREAM.

POIName	Number of mini-models evaluated as WS-CREAM	Percentage of mini-models evaluated as WS-CREAM	Number of mini-models evaluated differently by WS-CREAM	Number of mini-models evaluated differently by WS-CREAM
Expert A	186	40.17 %	277	59.83 %
Expert M	199	42.98 %	264	57.02 %
Expert G	134	38.62 %	213	61.38 %
Expert V	89	25.65 %	258	74.35 %

4. Knowledge Management System for the preventive conservation of Cultural Heritage buildings: ARCH case studies

4.1. Autonomous 3D Modelling System

The 3D scanning and analysis system has been developed by RFSAT as a Software Development Kit (SDK) in C++ using Microsoft Visual Studio 2019. As such it can be effortlessly incorporated into any custom application in order to enhance its functionalities. Although it is advisable that the 3rd party applications incorporate the full processing chain, each of the functionalities can be also used individually.

4.1.1. Pre-requisites

When deploying the SDK in the 3rd-party development and production environment, one must consider the following pre-requisites:

- Operating System: computers running Microsoft operating system is required to be able to use the SDK. Recommended operating systems are Windows 10 and Windows 11, although back compatibility with Windows 8 is also supported.
- Integrated Development Environment: the SDK has been developed for and will require Microsoft Visual Studio 2019, at least the standard edition.
- MATLAB: release 2020a or later with MATLAB Production Server
- CURL (https://curl.haxx.se) for interacting with Parrot Sequoia camera via HTTP-API
- Canon SDK (https://www.didp.canon-europa.com) v3.5 for linking with cameras via USB
- Pix4D Mapper Pro version 4.2.27 for automated 3D modelling. The latest version can be downloaded from: https://mapper.pix4d.com/download/mapperlatest.
- UgCS Ground Station: it can be downloaded from: https://www.ugcs.com
- Autodesk ReMake / ReCap Photo and "Reality Capture API" installed
- Microsoft Windows 10 SDK: the latest version can be downloaded from: https://developer.microsoft.com/en-us/windows/downloads/windows-sdk/
- Zaber Wrapper library (64-bit DLL version)
- Autodesk FBX SDK. It can be downloaded from: https://www.autodesk.com/developer-network/platform-technologies/fbx-sdk-2020-0

4.1.2. Automated 3D Scanning Module (SWSCAN)

The purpose of the Automated 3D scanning SWSCAN module is to perform automatic production of the 3D Mesh model using 3D photogrammetry (Figure 15). Images can be captured using the following methods:

- Raster cameras attached to a robotic arm. For details of this functionality, please refer to SCAN4RECO project demo video at: https://www.youtube.com/watch?v=2oHkNzr_d0A. Two types of robotic arms are supported: one developed by AVASHA in SCAN4RECO project for large scale (up to

2 x 2m) and demo platform built by RFSAT using Lego Mindstorm for small objects up to 1kg. Additional custom robotic arms can be also added.

- Autonomous aerial surveillance using DJI drones, developed for ARCH project. Currently the SDK supports DJI drones such as Inspire 1 (v1 and v2) and Mavic Pro (V1 and v2). Additional drones supported by UgCS Ground Station (https://www.ugcs.com) are also supported.
- <u>OPTIONAL</u>: simulation of drone acquisition via synthetic Virtual Reality environment developed using Unreal Engine 4. This has been developed for demonstration purposes, in case that real-life operation may not be possible. This approach uses pre-build 3D mesh models of pilot areas to be re-scanned in synthetic environment. Note that this replaces ONLY image acquisition part of the SDK, after which the standard processing chains follows.

Figure 15. RFSAT automated 3D scanning.

The architecture of the automated drone scanning system is presented in Figure 15. It contains a Ground Station with a range of supported UAS/UGV/UUV drones that can be operate either manually (legal requirement) and automatically for capturing visual material (image and/or video) which can be then used to build 3D models of the objects and perform automated, neural-network assisted analysis for detection of various types of defects, from cracks to discolorations and physical damages. The physical version of the architecture from Figure 15 in presented in Figure 16.

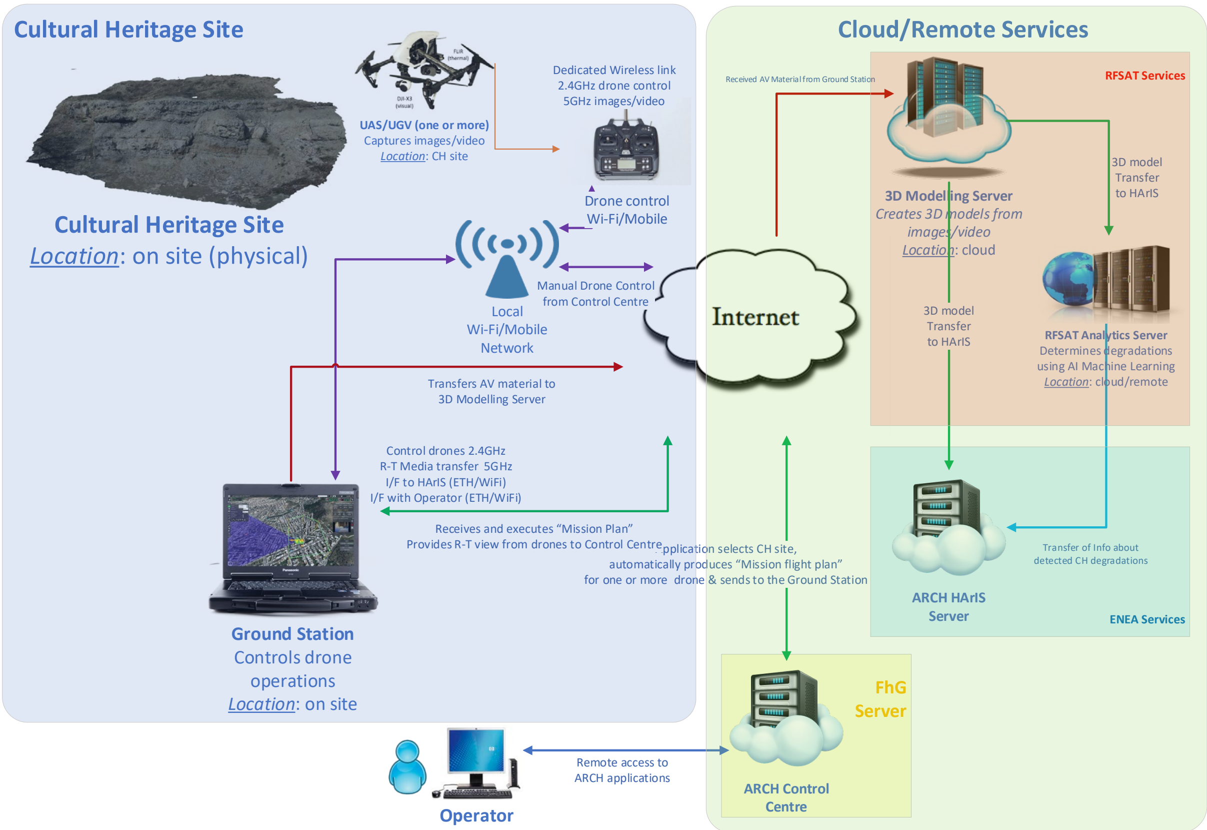


Figure 16. Physical architecture of RFSAT automated 3D scanning & analysis of degradations.

The remote and/or cloud-based services mentioned in the architecture include:

- **RFSAT 3D Modelling Server**: operates in two (selectable) modes, as cloud services or on a multi-GPU parallel processing server installed at RFSAT offices. Two engines are available: PIX4D and Autodesk. An API written in MS-VCPP2019 has been developed to enable integration of 3D modelling into custom applications.
- **ARCH Control Centre** (with embedded RFSAT application): expected to be provide by FhG and allow access to and integrate all ARCH services. The RFSAT application will allow selection of the CH site and based on its structure to derive a flight plan for drones such that to acquire required audio-visual material, as required for performing 3D modelling and/or image-based analysis of degradations to CH structures. Semi-automatic approach will assist users in building a mission plan.
- **RFSAT Analytics Server**: based on images acquired from drones of the CH site (optionally also the 3D models of the site from RFSAT 3D Modelling Server) will perform AI-based and Machine Learning driven analysis of the images and/or 3D model to determine type, location and significance of degradations of CH object. This server operates on an embedded UP2 PC running Linux with Intel Movidius VPU employing neural network co-processor for faster data analysis.

By communicating the developed 3D mesh models to THIS, it provides a base for subsequent analysis of degradations, being either geometrical erosions analysed using Machine Learning algorithms and/or direct analysis of model geometry and bio-growths detectable using Machine

Learning techniques. Those techniques have been described in more detail in deliverables D4.1 and D4.2.

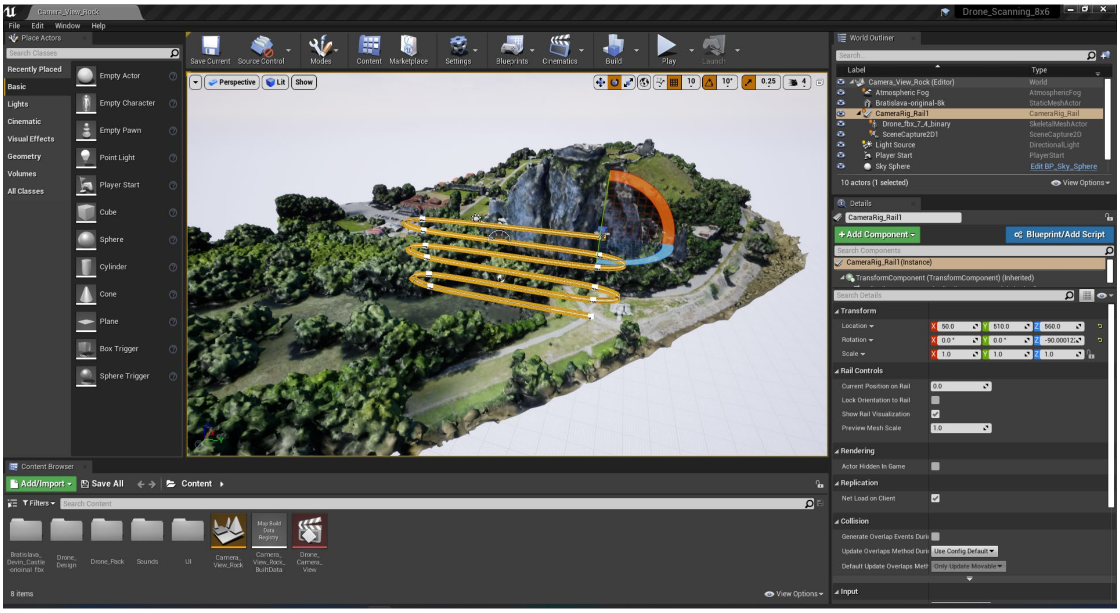
The 3D modelling is mainly based on 3D photogrammetry and employs two different engines, depending on application, one being PIX4D engine that operated on a dedicated RFSAT multi-GPU server, while Autodesk engine offers capability of using cloud processing engine. An API for using both serves has been developed by RFSAT for assisting integration into custom applications built with Microsoft Visual C++ 2019 IDE. Details of this implementation are described in the following sections; a reference guide in provided in Annex D.

4.1.3. Synthetic Gaming Environment for Simulated Drone Operations

Considering that COVID-19 imposed travel restrictions and related limitations have caused problems in performing on-site 3D aerial surveillance and 3D model creation using RFSAT developed SDK, a demo version has been developed to illustrate the concepts and operation of the developed algorithms. With aid of partners local to pilots sited, models of various objects and areas have been built by INGV and UNICAM, e.g. for the Bratislava rock formation around the Devin castle. Similarly a point cloud of the Palace in Camerino has been also produced, although the 3D model was not available at the time of writing this deliverable. Hence to demonstrate its developments, RFSAT has built a virtual environment where it can simulate the part of its SDK that launches autonomous systems for acquiring the images. Those images are then fed into the processing chain illustrating automated “building” of 3D models from such images and subsequently for degradation analysis using algorithms described in deliverable D4.1 in section 5.3. A summary of the latter implementation is summarised in section 2.6 below and the following ones.

The original model of the Devin castle are in Bratislava and its “automated drone recreation” using synthetic Unreal Environment integrated with SDK from RFSAT is shown in Figure 17a.

(a)



(b)

Figure 17. Simulated autonomous drone scanning of the Devin Castle area in Bratislava.

Figure 17b shows the drone flight path that has been imported into the synthetic environment. Once the “game” is executed, images are being acquired from a drone “flying” over the area of interest “acquiring” a list of images are pre-defined intervals and at pre-defined locations, as if it was done in a real environment by a physical aerial UAS. Once the simulation finishes, the SDK takes over the next processing steps as if it was for real.

4.1.4. Integration with UgCS Ground Station for Autonomous Drone Surveys

The SWSCAN automated 3D modelling system supports use of autonomous aerial drones via UgCS Ground Station[21] application, which offers drone flight planning and control. It supports a number of commercial drones including DJI ones used by RFSAT such as M600/600, M300, M200/210/210RTK, M100, Inspire 2/1/1Pro/Raw, Phantom 4/4Pro/4ProV2/4RTK, Phantom 3, Mavic Pro/2 series, Spark, N3 and A3.

The main functionalities of the UgCS Ground Station that are used in SWSCAN are automated drone mission planning, built-in Photogrammetry and Geotagging tools, Digital Elevation Model (DEM) and KML file import enables map customisation.

The work flow used in SWSCAN to perform 3D scans automatically via UgCS involves:

- 3D Route Planning: using a mission planner with a Google Earth-like 3D interface the route can be planned for UAVs, offering more control by allowing to view flight plans from all angles, taking into account any obstacles such as terrain or buildings. In addition to standard horizontal surveys, the vertical façade scan flights paths can be also defined, being most valuable for 3D scanning of buildings in the cities. For examples of horizontal and façade scan flight routes refer to Figure 18.

[21] UgCS Ground Station: https://www.ugcs.com/

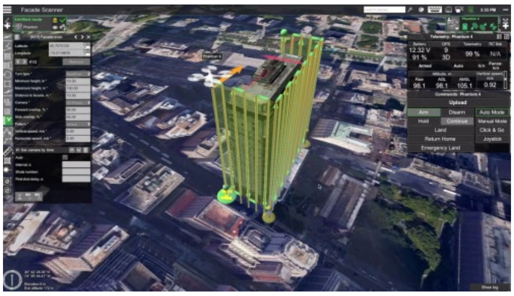

(a)

(b)

Figure 18. Example flight missions planned in UgCS for area scans (a) and façades (b).

- <u>Creation of a route from KML</u>: in addition to manual planning of routes , they can be imported from KML files to provide boundaries of the survey area so to set precise survey location. “*LineString*” segments of the KML file define Waypoint routes. “*LinearRing*” segment can be also imported as “*Area scan*” ,“*Photogrammetry*” or “*Perimeter*” route type.
- <u>Automated flights with pre-flight emulation</u>: once routes are planned, dry flights can be executed using a built-in emulator to assess in advance if there are no faults that would cause a loss of the drone due to collisions with the ground or other obstacle. Subsequently the drone can be launched and surveillance performed automatically, involving both the collection of images and video. Both are subsequently passed to the next stages of the SWSCAN workflow to provide 3D models, DTM images etc.

The **Ground Station**, operates from Panasonic Toughbook with Win10 (Figures 15, 16) to:

- receive flight plans (file) from RFSAT app on the ARCH Control Centre
- launch and operates drones in automated mode to execute flight plan mission
- acquire visual material (images & video) of the CH site from various angles
- send visual material to RFSAT 3D Modelling Server
- send directly (option) visual material to RFSAT Analytics Server

NOTE: all aerial drone surveys are performed under full control of human operators, compliant with EASA rules governing BLOS (Beyond Line of Sight) operations, such as constant supervision of the drone location and relay of the its flight controls and camera feeds, thus permitting taking over manual control of the drone from automated execution.

4.2. Automated Detection of Cracks

The use of HArIS decision support offers added value in cultural heritage for preventive conservation purposes. One of the most common purposes is material aging. Material aging has a significant effect on the realistic rendering of artwork objects. Small deformations of the surface structure, colour or texture variations contribute to the realist look of artwork objects. These aging effects depend on material composition, object usage, weathering conditions, and a large number of other physical, biological, and chemical parameters. The 3D geometry combined with multispectral material analysis provides quantitative measurements of the surface texture and roughness as well as significant deformations and cracks, which is used to obtain information about material changes over the time in terms of its surface deformation. In this work we focus on local deformations due to corrosion/erosion and finally cracks mainly by modelling the behaviour of displacements locally. Using the described simulation algorithms cracks that may appear or expand in the future will be timely detected by decision support diagnosis module and appropriate conservation and protective techniques can be applied.

The analytics algorithm uses Machine Learning and Artificial Intelligence methods and thus requires prior teaching using example images of similar defects. Results from both RFSAT servers can be then transferred to HArIS for further processing and visualisation by end user.

For examples please refer to deliverable D4.2 and section 5.4.2, where simulation of ageing effects on bronze cultural objects due to negative weather conditions has been presented.

Similarly for details about RFSAT approach to detecting degradations through analysis of 3D model geometry, for instance for detecting and quantifying cracks, please refer to deliverable D4.2 and section 5.4.4, with section 5.4.5 outlining implementation approach with example.

4.2.1. Cracks Identification using Deep Learning

Deep learning approaches provide a powerful method to interpret large quantities of data automatically and relatively quickly. Deterioration is often multi-factorial and difficult to model deterministically due to limits in measurability, or unknown variables. Deploying deep learning tools to the field of material degradation is a natural fit to the field of historical object analysis for assessing risks of continuing damage to object of important historical and cultural value. Review of the current research in deep learning for detection, modelling and planning for material deterioration is driven by budget reductions, increasing safety and increasing detection reliability. Researchers make string progress, though several challenges remain, not least of which is the development of large training data sets and the computational intensity of many of these deep learning models.

The general overview of Deep Learning and Artificial Intelligence methods used in ARCH have been already outlined in deliverable D4.2 in section 5.4.3 with the state of art analysis. Therefore this section will avoid repetition and will focus on the implementation aspects of such a system in ARCH by RFSAT for the detection of biological growths due to periodic water immersion as it is common for the canal areas in Hamburg. Some indicative results are also presented at the end of this section from the analysis of images from Hamburg canals.

4.2.1.1. Overview of the technique

The development has been based on the concept demo suggested by Kenta[22] on MATLAB Central WEB portal. His demo demonstrated the idea of fine-tuning a pretrained SqueezeNet[23] deep convolutional network to classify images between those with cracks and those without. The author has suggested also a fine-tuning approach that has been also adopted for ARCH. Due to limited amount of representative images from Hamburg pilot, the classification has been

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22 https://github.com/KentaItakura/Classify-crack-image-and-explain-why-using-MATLAB

23 Iandola, Forrest N., Song Han, Matthew W. Moskewicz, Khalid Ashraf, William J. Dally, and Kurt Keutzer. "SqueezeNet: AlexNet-level accuracy with 50x fewer parameters and <0.5 MB model size." arXiv preprint arXiv:1602.07360 (2016): https://arxiv.org/abs/1602.07360

trained on the original dataset of concrete crack images[24] introduced by L. Zhang[25] with extra images acquired from Hamburg pilot. Alternative methods of using one-class SVM can be also used, as also suggested by Zhang[26], for the limited number of anomaly images, in which case learning only with normal images can be performed. IN our case we've decided for the former, more complex while also more universal approach.

The main dataset from Zhang contained concrete images with cracks, collected from various METU Campus Buildings. It contains both positive (with cracks) and negative (no cracks present) images to be used for classification. Each set contains 20000 images with 227 x 227 pixels with RGB channels. This data set has been built out of 458 high-resolution images (4032x3024 pixel) with the method proposed by Zhang[27] since original high-resolution images had variance in terms of surface finish and illumination conditions. For compatibility with main database, images from Hamburg have been processed in similar manner to supplement the main database and ease applicability to Hamburg pilot site surveillance.

4.2.1.1.1. Experiments on Hamburg Images

Our of the total of 75 images of the exterior and additional nine (9) images of the interior of the Speicherstadt areas in Hamburg, finally the 21 high0-resolution images have been selected as the most suitable for training the Deep Learning model. From those almost 60 final images of cracks have been extracted and added to the Zhang database to train the model. The number of those images were incomparably less than those from the original Zhang database, which made the model less sensitive to detecting cracks in walls of the building that differed significantly to Zhang's cracks from concrete walls. Nevertheless, surprisingly some of the cracks have been correctly detected as it can be seem in Figure 19. It is surprising that although two (2) cracks are visible, only the dominant one has been identified, while the less apparent one was ignored. This may be either due to the insufficient number of images of the specific type of the brick wall material from *Speicherstadt* that was used for training the model or could the also the inherent limitation of the model to identify only a single features. This will require further investigative work and larger image datasets.

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[24] Crack image dataset: https://data.mendeley.com/datasets/5y9wdsg2zt/1

[25] Zhang, Lei, et al. "Road crack detection using deep convolutional neural network." 2016 IEEE international conference on image processing (ICIP). IEEE, 2016: https://ieeexplore.ieee.org/abstract/document/7533052

[26] https://github.com/KentaItakura/Crack-detection-using-one-class-SVM

[27] Lei Zhang , Fan Yang , Yimin Daniel Zhang, and Y. J. Z., Zhang, L., Yang, F., Zhang, Y. D., & Zhu, Y. J. (2016). Road Crack Detection Using Deep Convolutional Neural Network. In 2016 IEEE International Conference on Image Processing (ICIP). http://doi.org/10.1109/ICIP.2016.7533052

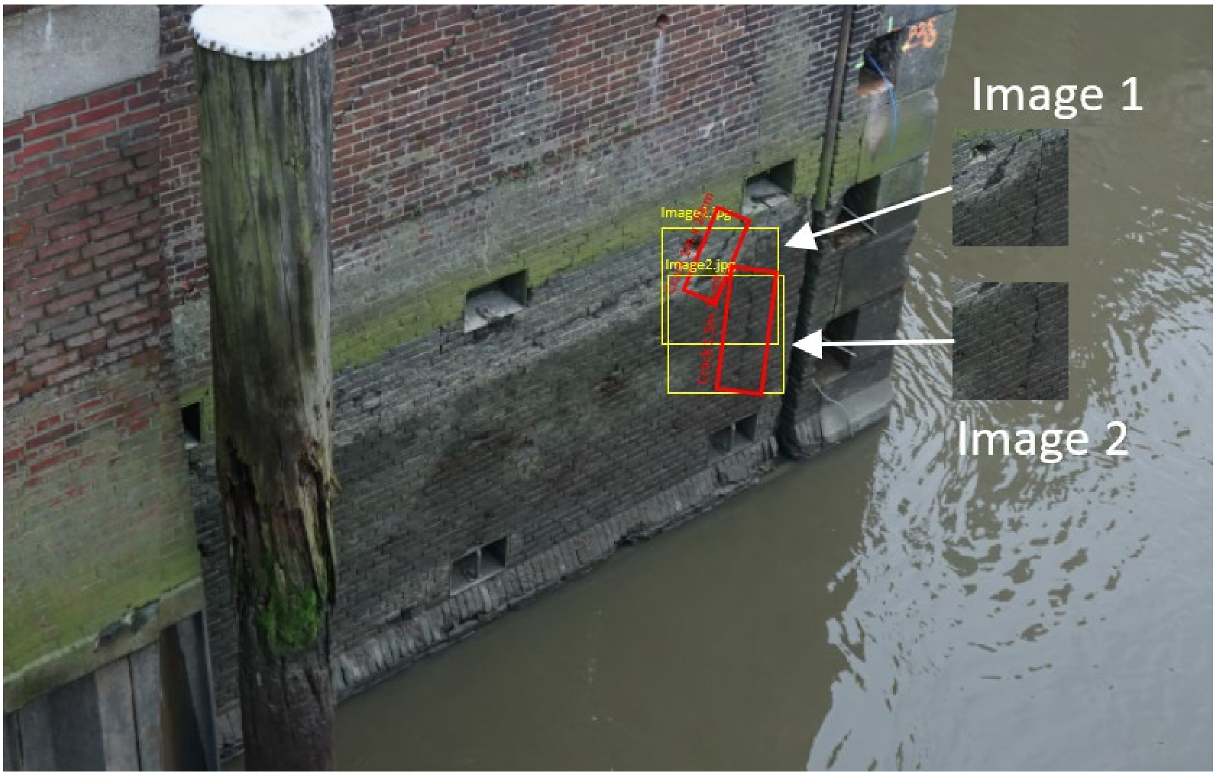

Figure 19. Example of crack detection on the walls of buildings in Speicherstadt canals in Hamburg.

The original software by Zhang has been extended to provide not just identification of images used for training the model, but also to produce the orientation and approximate length and width of the crack. Note that with the lack of precise location of the camera w.r.t. the object and unknown parameters of the camera, very approximate measures have been calculated under the assumption of the size of elements in the image. The presented results show two images with cracks that were used for training the model correctly identified (shown in yellow), which were subsequently superimposed onto the original high-res image. Furthermore, orientation and size approximations have been also provided (shown in red).

Based on the absolute size of the crack, subsequent assessment of the seriousness of the structural deficiency could be performed. However, since this requires support from civil engineers and/or architects, this has not been performed in the current software version, expected to be pursued in the follow up research work.

Similarly work on identification of biological growths has been pursued using similar Deep Learning techniques, although by the deadline for submitting this deliverable D4.4, there were no demonstrable examples available yet. This is primarily due to insufficient number of images available from Hamburg that would make it possible to reliably train the model. Until the time of writing this deliverable, we were also unsuccessful in finding any online datasets of suitable images. Hence this work will proceed further after the submission of D4.4.

4.2.1.2. Deployment using MATLAB Production Server

Considering that applied research work of RFSAT in use of Deep Learning techniques for ARCH have been performed using MATLAB, in order to sped up the delivery of the operational services for detection of cracks and biological growths, the MATLAB Production Server™ [28]has been selected for short terms integration into ARCH workflow.

Such an approach offers an opportunity to avoid translation of MATLAB code to C/C++ and thus custom analytics developed in the original environment can be integrated into WEB applications, THIS/HArIR databases and/or other production enterprise applications running on dedicated servers or in the cloud by other partners like INGV. This creates an opportunity for RFSAT to run algorithms in MATLAB, package them using MATLAB Compiler SDK™, and then deploy them to proprietary RFSAT instance of the MATLAB Production Server without recoding or creating custom infrastructure. In this way the latest versions of RSFAT analytics can be automatically made available to other partner to be accessed.

The advantage of such a solution is also in that the MATLAB Production Server can manage multiple MATLAB runtime versions simultaneously. This means that algorithms developed in different versions of MATLAB, also by other partner, could be incorporated into one application. The server can operate on multiprocessor and multicore computers, thus providing even lower-latency processing of concurrent work requests. In the case of RFSATY deployment, it will initially run on the in-house industrial server, alongside other services built for ARCH to acquire, process and transmit sensor data to THIS platform of INGV. When the need arises for additional capacity and redundancy, extra computing nodes shall be deployed and operated to scale up such extra needs.

From the point of view of client applications, access to analytics and models published to MATLAB Production Server can be achieved from applications written in various programming languages, RESTful APIs, and MATLAB apps. Furthermore, enterprise applications can take advantage of lightweight client libraries to call functions in MATLAB analytics deployed to MATLAB Production Server from desktop, server, or database applications developed in languages such as C#, Java®, C/C++, or Python®. Similarly, WEB and mobile applications that access deployed MATLAB analytics may invoke functions via RESTful APIs using JSON for input and output. Service discovery API helps also such apps to discover functions that are available and required input/output parameters.

The concept diagram of the proposed architecture of the RFSAT crack and biological growth identification services deployed using MATLAB Production Server is shown in Figure 20 This is currently the most application approach for providing services to ARCH Decision Support System (DSS) offering a faster translation of research results produced using MATLAB into production services. On the other hand, a full translation into C/C++ would require extensive amount of time and would risk delaying provision of such services for trials.

[28] MATLAB Production Server™: https://www.mathworks.com/products/matlab-production-server.html

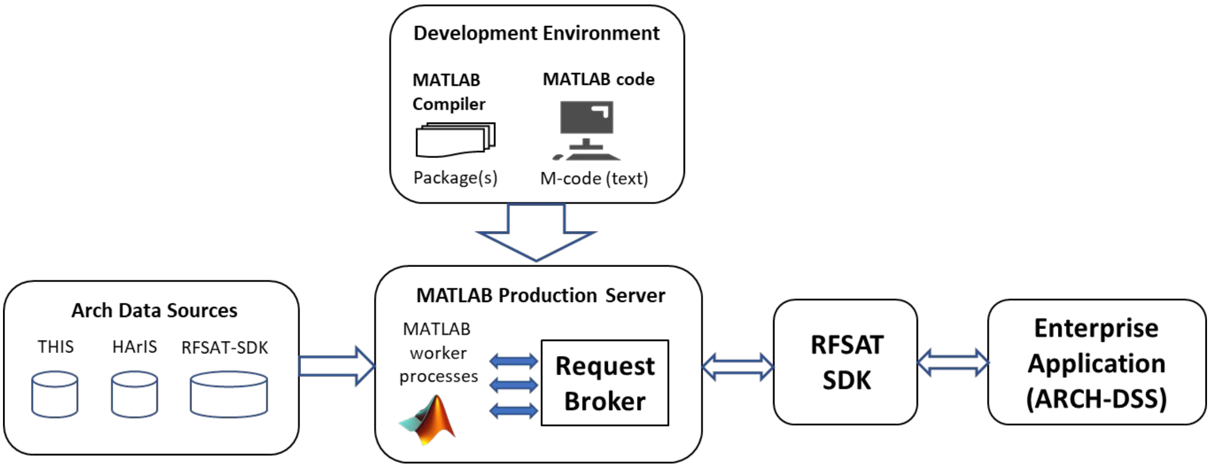

Figure 20. Architecture for crack and biological growth detection services deployed using MATLAB Production Server and integrated with RFSAT SDK.

The proposed architecture assumes the MATLAB Production Server deployed at RFSAT premises on its industrial server alongside other services deployed on it for providing weather, pollution and earth observation data to THIS server deployed at INGV. Algorithms mentioned earlier are thus compiled automatically using MATLAB Compiler and deployed on the Production Server. The RFSAT SDK makes requests to the Request Broker of the Production Server, passing them into separate packages compiled earlier. In this way, the usage of the MATLAB Production Server is fully invisible to 3rd-party applications, which need only to make use of the RFSAT-SDK to perform required types of data analysis. Note that ARCH Data Sources mainly refer to images and models available in THIS and HArIS databases as well as images acquired from automated surveillance part of the RFSAT-SDK. However, those can be also accessible from the level of the RFSAT-SDK if required. The main advantage of placing those databases behind the MATLAB Production Server is the inherent capability of such a server to manage load among multiple processors and cloud computing capabilities, should those be available.

At the time of writing this deliverable, the MATLAB Production Server has been deployed and is operational. However, full integration with custom Deep Learning services and full integration with RFSAT-SDK has not been completed yet. This development is expected to be continued with provisional full operational capability expected within the next two months.

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Annex A. Definition of Metadata and Ontology

Metadata is data about information. Metadata includes descriptive summaries and high-level categorization of data and information. Metadata is information about the context in which information is used. That is, **knowledge** is a combination of metadata and an awareness of the context in which the metadata can be applied successfully.

An **ontology** defines a common vocabulary for researchers who need to share information in a certain domain. Ontology includes machine-interpretable definitions of basic concepts in the domain and relations and hierarchy among them.

A domain ontology (or domain-specific ontology) **represents concepts which belong to a realm of the world**, such as politics, or disaster resilience. Each domain ontology typically models domain-specific definitions of terms.

Figure 21 exemplifies in a schematic way the relationship between Data, Metadata and Ontology and their respective role i.e. Data provides the content, Metadata the terms and Ontology the Vocabulary.

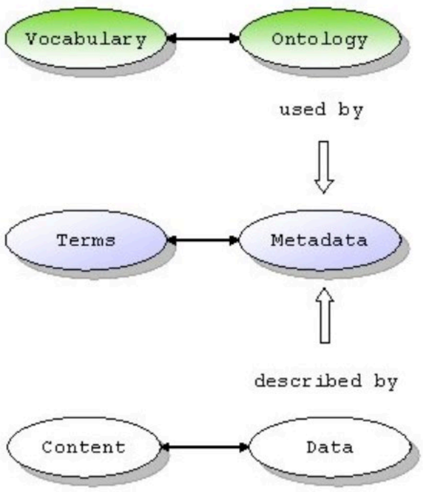


Figure 21. Relationship between Data, Metadata and Ontology.

Annex B. ARCH tools for visualizing and accessing information

To make relevant *Data* and *Information* accessible to the pilot cities and other users interested to browse *Data* and *Information* of their historic area, specific web-tools were designed by partner INGV. In particular, as already described previous deliverables (i.e. [8][9]), three tools have been developed, namely:

- **GIS Dashboards** enable users to obtain information by location-based analytics, using intuitive and interactive data and maps to be viewed on a single screen.
- **Building/Object Sheets** to query and visualise structured data included in the databases, for example providing information about assets and objects in the historic areas; these web-sheets will be used also for editing and data entry performed by authorised users.
- **3D model viewer** to visualise the three-dimensional models of assets and objects, also enabling users to extract a subset of three-dimensional data.

The web tools are integrated into the same web-platform to show the data and information included in both HArIS and THIS; specific GIS dashboards have been developed whose details can be found in D4.1[10].

This document illustrates the way to recover metadata and link to the data\services by means of the Geocatalog, that is a tool integrated in the same web-platform.

In this section, the Geocatalog (version v1.2021) is presented and a quick user manual is illustrated. Currently, the landing page of the information systems can be reached (Figure 22) at the web link http://www.cs.ingv.it/ARCHPortal/.

The access way to the web-platform, as reported in this document, is the same as that already described in D4.2 [8] and D4.3 [9].

After clicking on the button at the top right in the landing page, the user can login (Figure 23), if registered, otherwise they can request the registration of a new account (Figure 24), that will be managed by INGV before granting it. This control process is necessary as the authorised user has access to all functionalities; with the possibility also of modifying information concerning the assets of their own historic area. However, the unregistered user can have access in consultation mode to all public information contained in the systems.

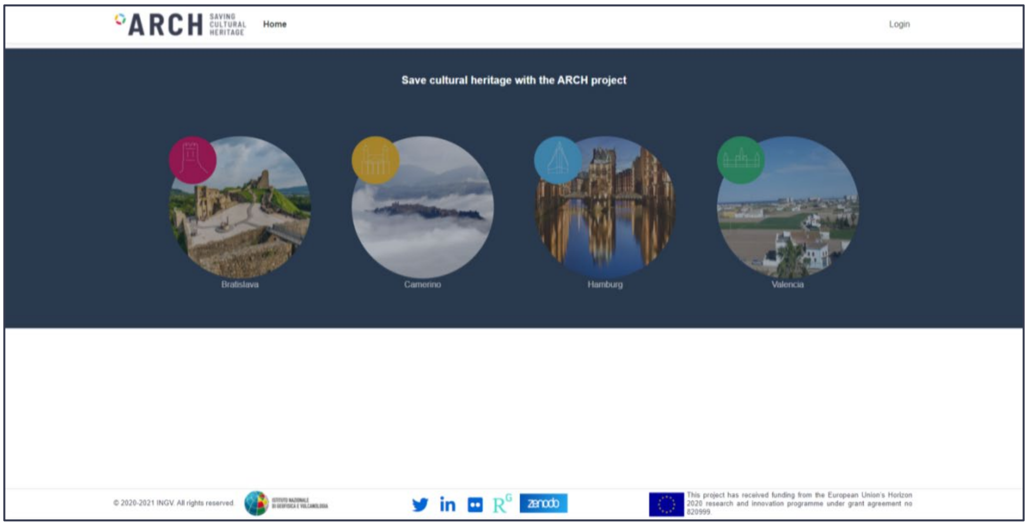


Figure 22. Landing page of the Information System platform

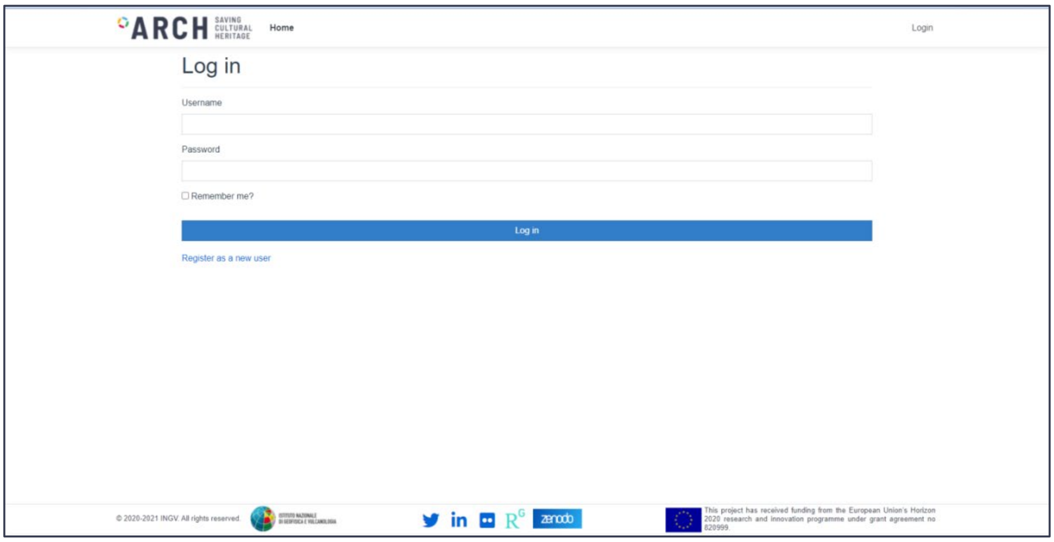


Figure 23. Login to the information systems

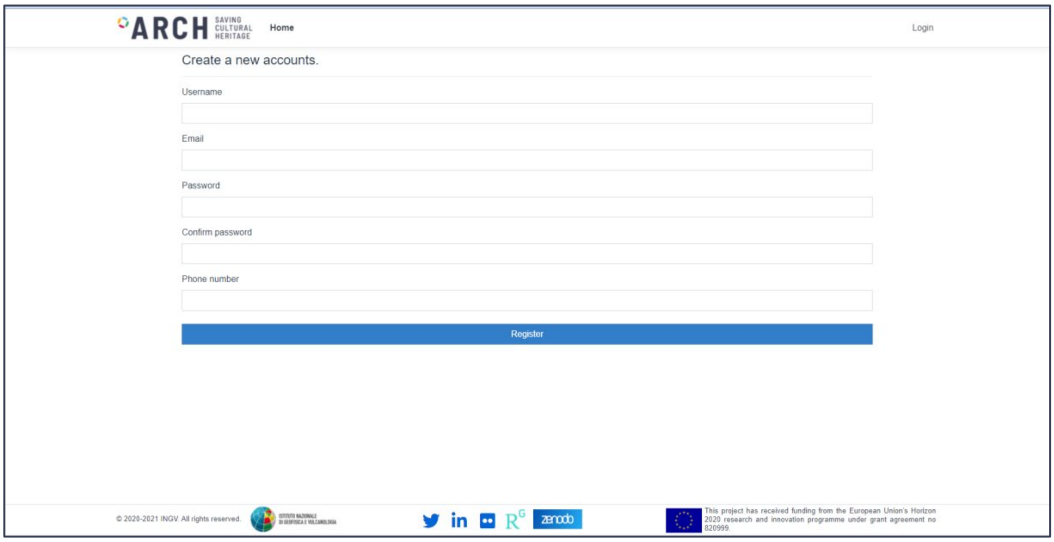


Figure 24. Registration of new account

On the landing page, the image of the city lights up when the mouse pointer is positioned over it and, at this point, the corresponding GIS dashboard (Figure 25) is loaded with a simple click. Once this new page has been loaded, a menu in the header (orange frame in Figure 8) allows accessing to the tools of the information platform, always remaining available so that the user can easily change their choice. This menu reports the follow link:

- “Home” to return to the landing page and choose another city;
- “GIS dashboard” to obtain the tool to query the cartographic layers both in HArIS (cf. Section 4.2 in D4.2 [8]) and THIS (cf. Section 7 in D4.3 [9]);
- “Construction\Object Sheet” to consult the information on the assets (cf. section 4.3 in D4.2 [8]);
- “*Geocatalog*” to browse and search metadata and link related to GIS web-services and datasets in HArIS and THIS.

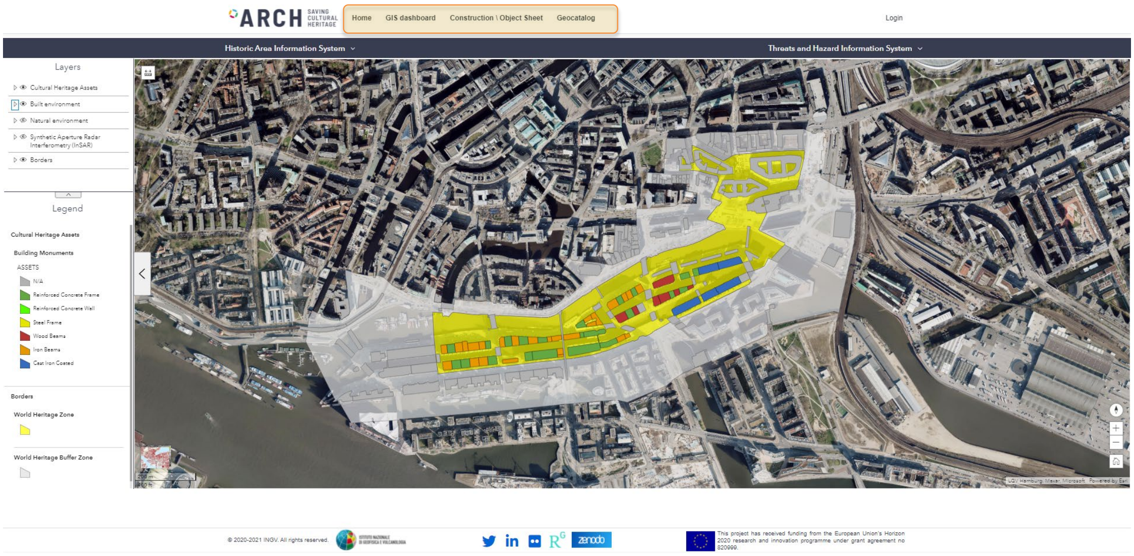


Figure 25. Example of web page of the platform relating to the information system. From this page it is possible to reach the Geocatalogue by clicking the link in the header menu (orange frame).

Geocatalog

By clicking on "Geocatalog" in the header menu (Figure 25) , three tools become available:

- **“Search in the Catalog”** (Figure 26), that allows performing a query related to the name and keywords to filter available datasets\service. Moreover, on the left of the page different other filters can be set to skim potential datasets of interest. A submenu for each dataset\service allows obtaining:
    - the metadata in different formats, by clicking on “HTML”, “XML”, “JSON”, respectively;
    - the “Links” to the resource, if available;
    - the “Preview” of the dataset\service (cf. map pane in **.**)
    - the download of the dataset (or the HTTP web-page relating the service) by “Download (HTTP)”
    - the information reported on the map by “Add to map”, which can be explored in detail as well as it is possible through the link below.

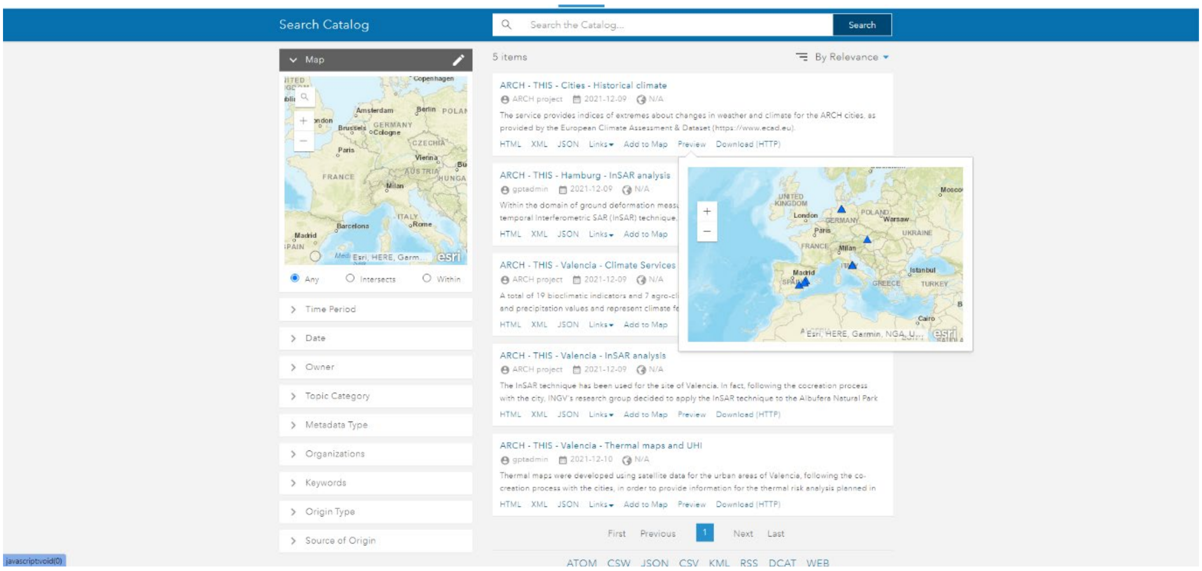
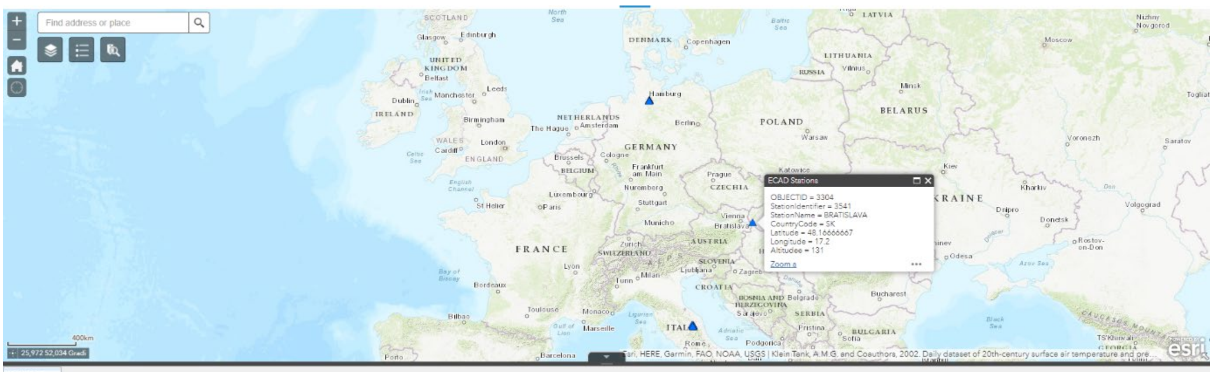


Figure 26. "Search in Catalog" web-page

- **"Explore on Map"** (Figure 27) allows exploring one or more datasets and/or services, which can be added by search button and activated\deactivated by layer button . Legend of the active layers can be viewed by the legend button . Fields and values included in the dataset\service can be obtained in table by clicking on the arrow in the bottom centre of the map. The other buttons in the upper-left also permit to manage the zoom or to find a specific place on the map.

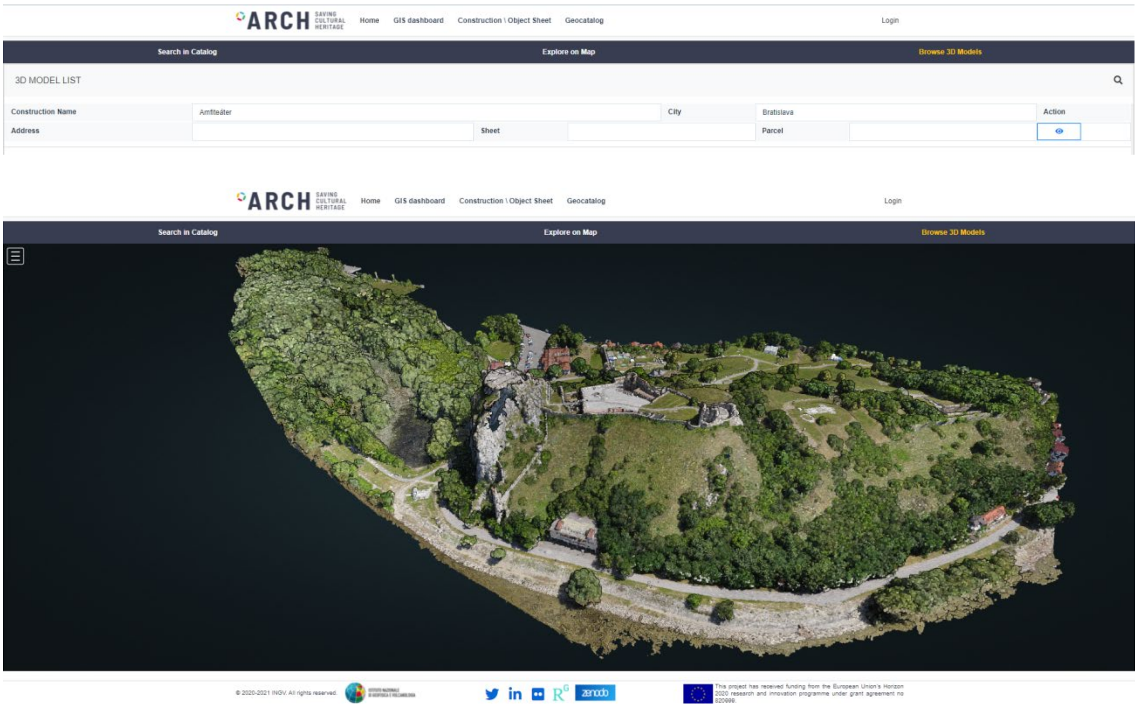


OBJECTID	StationIdentifier	StationName	CountryCode	Latitude	Longitude	Altitudee	SHAPE
3304	3541	BRATISLAVA	SK	48,16666667	17,2	131	
3801	4180	HAMBURG-BOTANISCHER GARTEN	DE	53,56138889	9,98833333	14	
3805	4184	HAMBURG-SANKT PAULI	DE	53,54805556	9,97027778	35	
10772	11781	HAMBURG (DEUTSCHE SEEWARTE)	DE	53,54666667	9,97138889	2	
12188	13197	HAMBURG-ELLERHOLZKANAL	DE	53,51666667	9,96666667	0	
15770	16878	CAMERINO	IT	43,14	13,06777778	582	

10 feature 0 selezionate

Figure 27. "Explore on Map" web-page

- **"Browse 3D Models"** allows to directly open a 3D object stored in the ARCH repository by clicking the button on the related row of the list (Figure28.a), thus the web-viewer application opens for a realistic view of the asset (as point cloud or mesh) in the three-dimensional space (Figure 28.b) - cf. Section 4.4 in D4.2 [8] for details on the 3D viewer tool.



(b
)

Figure 28. List of the 3D objects in ARCH repository (a) and 3D viewer to navigate the object (b).

Annex C. Metadata of the ARCH Information System

Overall information

Metadata:
File identifier:
1639422125167r18752737530874009
Language:
Language Code:
eng
Hierarchy level:
Scope code:
service
Hierarchy level name:
service
Metadata author:
Responsible party:
Organisation name:
Istituto Nazionale di Geofisica e Vulcanologia
Contact info:
Contact:
Address:
Address:
Electronic mail address:
antonio.costanzo@ingv.it
Role:
Role code:
pointOfContact
Metadata author:
Responsible party:
Organisation name:
TECNALIA
Contact info:
Contact:
Address:
Address:
Electronic mail address:
nieves.pena@tecnalia.com
Role:
Role code:
author
Date stamp:
2021-12-09
Metadata standard name:
INSPIRE Metadata Implementing Rules
Metadata standard version:
Technical Guidelines based on EN ISO 19115 and EN ISO 19119 (Version 2.0)

Reference System Information

Reference system info:

Reference system:

Reference system identifier:

RS Identifier:

Code:

Anchor: xlink: http://www.opengis.net/def/crs/EPSG/0/3045

ETRS89-TM33N

Identification Information

Credit:

The indicators have been produced by Tecnalia (https://www.tecnalia.com/) by combining daily gridded ground observation data over Valencia, derived from the e-OBS dataset (https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe%20?tab=overview) and the regional EURO-CORDEX (https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cordex-domains-single-levels?tab=overview) projections data on single levels available at Copernicus Climate Data Store. The Datasets are processed in cartographic mode by INGV (https://www.ingv.it/). "We acknowledge the E-OBS dataset and the data providers in the ECA&D project (https://www.ecad.eu). Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200"

Identification info:
Service Identification (19119):
Citation:
Citation:
Title:
ARCH - THIS - Bratislava - Climate Services
Date:
Date:
Date:
2021-12-09
Date type:
Date type code:
publication
Abstract:
A total of 7 extreme precipitation indexes and daily and monthly climatological information related to temperature are provided. These indicators are derived from daily and monthly temperature and precipitation values and represent climate features.

They list of extreme precipitation indexes are:
· RR1 = Number of wet days, with precipitation higher than 1mm
· RR2 = Number of wet days, with precipitation higher than 2mm
· RR10 = Number of wet days, with precipitation higher than 10mm
· RR20 = Number of wet days, with precipitation higher than 20mm
· RX1DAY = Maximum amount of precipitation in 1 day (in mm)
· RX2DAY = Maximum amount of precipitation in 2 day (in mm)
· RX5DAY = Maximum amount of precipitation in 5 day (in mm)

For future periods 2011-2040, 2041-2070, 2071-2100, the same information is available as and average of the ensemble of CORDEX models as well as the standard deviation.

These final subset if indicators was based on a co-creation process with stakeholders in Bratislava.
Purpose:
A total of 7 extreme precipitation indexes and daily and monthly climatological information related to temperature are provided. These indicators are derived from daily and monthly temperature and precipitation values and represent climate features.
Credit:
This product is developed in the framework of the WP4 "Hazard & Object Information Management System" of the H2020-ARCH. The "Advancing Resilience of Historic Areas against Climate-related and other Hazards" (ARCH) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 820999.

Credit:

The indicators have been produced by Tecnalia (https://www.tecnalia.com/) by combining daily gridded ground observation data over Valencia, derived from the e-OBS dataset (https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe%20?tab=overview) and the regional EURO-CORDEX (https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cordex-domains-single-levels?tab=overview) projections data on single levels available at Copernicus Climate Data Store. The Datasets are processed in cartographic mode by INGV (https://www.ingv.it/). "We acknowledge the E-OBS dataset and the data providers in the ECA&D project (https://www.ecad.eu). Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200"

Credit:

Point of contact:
- ***Responsible party:***
  - ***Organisation name:***
    Istituto Nazionale di Geofisica e Vulcanologia
  - ***Contact info:***
    - ***Contact:***
      - ***Address:***
        - ***Address:***
          - ***Electronic mail address:***
            antonio.costanzo@ingv.it
  - ***Role:***
    - ***Role code:***
      resourceProvider

Descriptive keywords:
- ***Keywords:***
  - ***Keyword:***
    thematicProcessingService
  - ***Keyword:***
    thematicChangeDetectionService
  - ***Thesaurus name:***
    - ***Citation:***
      - ***Title:***
        ISO 19119 service taxonomy
      - ***Date:***
        - ***Date:***
          - ***Date:***
            2003
          - ***Date type:***
            - ***Date type code:***
              publication

Descriptive keywords:
- ***Keywords:***
  - ***Keyword:***
    ARCH

Descriptive keywords:

- ***Connect Point:***
  - ***Online Resource:***
    - ***Linkage:***
      - ***URL:***
        https://www.cs.ingv.it:6443/arcgis/rest/services/ARCH/ARCH_THIS_BRA_CLSERV/MapServer
    - ***Function:***
      - ***Online function code:***
        information

Distribution info:
Distribution:
Distribution format:
Format:
Name:
ARCH_THIS_BRA_CLSERV
Version:
MapServer
Transfer options:
Digital transfer options:
Online:
Online Resource:
Linkage:
URL:
https://www.cs.ingv.it:6443/arcgis/rest/services/ARCH/ARCH_THIS_BRA_CLSERV/MapServer

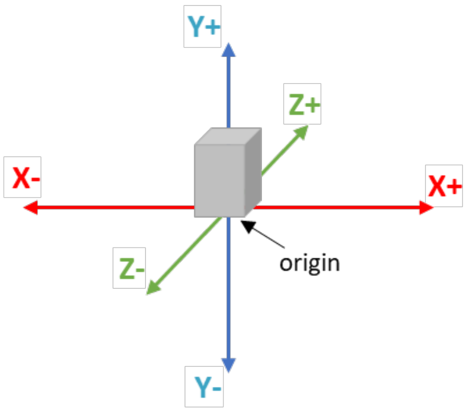
Data Quality Information

Data quality info:
Data quality:
Scope:
Scope:
Hierarchy level:
Scope code:
service
Level description:
Scope description:
Other:
Service
Report:
Domain consistency:
Result:
Conformance result:
Specification:
Citation:
Title:
COMMISSION REGULATION (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services
Date:
Date:
Date:
2021-12-09
Date type:
Date type code:
publication
Explanation:
Data-processing validated by TECNALIA
GIS service validated by INGV
Pass:
true
Lineage:
Lineage:
Statement:
These indicators have been produced by Tecnalia by combining daily gridded ground observation data over Bratislava, derived from the e-OBS dataset and the regional EURO-CORDEX projections data on single levels available at Copernicus Climate Data Store. The NetCDF files have been reported in shapefile by INGV.

Annex D. Automated 3D Scanning Module SWSCAN user manual

Annex D. Automated 3D Scanning Module SWSCAN user manual

Coordinate system



X-Y-Z coordinate system is used.

Camera is placed along Z axis (back from origin)

Object is centred at origin (X=0, Y=0, Z-=0)

When looking through camera lens:

- X axis increases to the right
- Y axis increased in up direction
- Z axis increases away from the camera

Units of measurements

ALL measurements used in the SWSCAN object are given in **METERS**.

Integration approach

Version 1.5 of SWSCAN API allows providing the control to the main application for controlling the arm and performing the image capture. This means that the SWSCAN object can be used to provide ALL the camera positions at which images should be captured.

NOTE: refer to section $**Errore. L'origine riferimento non è stata trovata.**for instructions how to capture images with SWSCAN API.

SWSCAN module initialization

The RFSAT API needs to be first declared and initialised:

```
SWSCAN     RFSAT;
```

Then declare UI variables:

```
int CameraType = SWSCAN_Camera_Canon5DS_EF70;  // Camera type
int ImageOverlap = ImageOverlap_75;    // Image overlap
int ScanType = 0;                      // Flat/3D object
int ModelQuality = Model3D_Optimal;    // Model quality
char[256]  FileName = “”;              // Path to an images
char[256]  PathToImages= “”;           // Path to image folder
char[256]  PathToModel= “”;            // Path to FBX model
```

Passing object size from core application to SWSCAN module

Subsequently the rough size of the object needs to be passed from main application to SWSCAN module. As confirmed by CERTH, such an information is available from the rough san with Asus/Kinect scanner.

NOTE: the SWSCAN API assumed that the object is centred with respect to the origin (i.e. centre of the rotary stage) and for icons/paintings aligned along the X-axis. In case that it is not centred, then you need to pass values corresponding to double the maximum extent along X, Y, Z axis respectively and NOT the actual object size.

The object size can be passed to SWSCAN object with the following command:

```
RFSAT.SetCHSize(CHmaxX, CHmaxY, CHmaxZ);
```

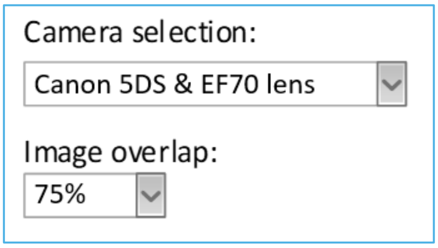
Where: CHmaxX, CHmaxY and CHmaxZ are double variables.

User Interface Elements

The following user interface elements should be integrated into core application by CERTH.

NOTE: SWSCAN object must be initialised before executing commands related to UI elements

Camera selection



Camera selection should be performed using a drop-down list, populated with:

- "Canon 5DS & EF70 lens" (to be selected by default)
  `CameraType = SWSCAN_Camera_Canon5DS_EF70;`
- "Canon 5DS & EF50 lens"
  `CameraType = SWSCAN_Camera_Canon5DS_EF50;`
- "Canon 5DS & EF35 lens"
  `CameraType = SWSCAN_Camera_Canon5DS_EF35;`
- "Canon 5DS & EF24 lens"
  `CameraType = SWSCAN_Camera_Canon5DS_EF24;`
- "DJI X3 camera"
  `CameraType = SWSCAN_Camera_DJIX3;`
- "DJI X5 camera"
  `CameraType = SWSCAN_Camera_DJIX5;`
- "Parrot Sequoia (multispectral)"
  `CameraType = SWSCAN_Camera_ParrotSequoia;`

Camera selection can be passed to SWSCAN module as follows:

```
RFSAT.SetCameraType(CameraType);
```

Note that additional cameras can be additionally defined.

Image overlap

Following the selection of the camera, image overlap needs to be selected. This can be done using a drop-down list next/under the camera selection list. The list of options includes:

- "75%" (to be selected by default)
  `ImageOverlap = ImageOverlap_75;`
- "50%"
  `ImageOverlap = ImageOverlap_50;`
- "33%"
  `ImageOverlap = ImageOverlap_33;`
- "25%"
  `ImageOverlap = ImageOverlap_25;`
- "0%"
  `ImageOverlap = ImageOverlap_00;`

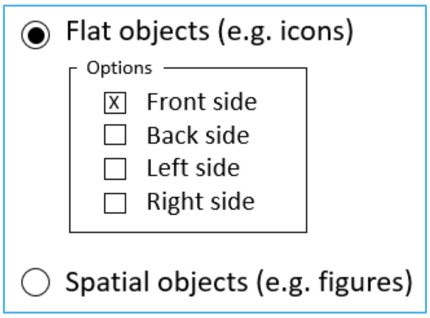
Image overlap selection can be passed to SWSCAN module as follows:

```
RFSAT.SetImageOverlap(ImageOverlap);
```

Scan Types

Two types of image capture strategies can be used, either matrix-like for flat objects like icons and paintings or semi-spherical one for 3D spatial objects. Therefore, first you ned to choose between a flan and spatial object, and in case of the latter one additional multi-selection menu can be used to choose sides (front, back, left side, right side).

The figure below shows example user interface for selecting scan type options:



Main scan options should be mutually exclusive (radio buttons or a drop-down list).

When "*Flat objects*" is selected then additional multi-choice option selection is enabled.

When "*Spatial objects*" is selected then multiple options groups should be disabled.

Default options are shown selected in the figure.

Operations to be executed when selecting various options (SWSCAN object already created):

- “*Flat objects (e.g. icons)*” selected:
  `ScanType = 0;`

  When “*Options*” are selected/deselected:

  - “*Front side*” selected:
    `ScanType = ScanType | Scan_Flag_Front;`
  - “*Front side*” de-selected:
    `ScanType = ScanType - Scan_Flag_Front;`
  - “*Back side*” selected:
    `ScanType = ScanType + Scan_Flag_Back;`
  - “*Back side*” de-selected:
    `ScanType = ScanType - Scan_Flag_Back;`
  - “*Left side*” selected:
    `ScanType = ScanType + Scan_Flag_Left;`
  - “*Left side*” de-selected:
    `ScanType = ScanType - Scan_Flag_Left;`
  - “*Right side*” selected:
    `ScanType = ScanType + Scan_Flag_Right;`
  - “*Right side*” de-selected:
    `ScanType = ScanType - Scan_Flag_Right;`

- “Spatial objects (e.g. figures)” selected:
  `ScanType = Scan_Flag_3D;`

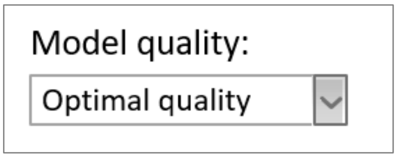
NOTE: at least one option MUST be selected when selecting “Flat objects (e.g. icons)”.

Type of scan selection can be passed to SWSCAN module as follows:

```
RFSAT.SetScanMethod(ScanType);
```

Model quality

The model quality can be chosen between High, Optimal and Low ones (new in API v. 1.3).



Operations are executed when selecting various options (SWSCAN object already created):

- “*Low-quality*” selected:
  `ModelQuality =Model3D_LowRes;`

- “*Optimal-quality*” selected (to be selected by default):
  `ModelQuality =Model3D_Optimal;`

- “High-quality” selected:
  `ModelQuality =Model3D_HighRes;`

The model quality selection can be passed to SWSCAN module as follows:

- `RFSAT.SetModelQuality(ModelQuality);`

NOTE: High quality models may take several hours to process, especially on computers with average processor speeds. Memory below 32GBytes may also prevent producing the highest quality models. Therefore, for demonstration purposes it is advisable to select low-quality setting that should under normal condition produce a model within tens of minutes.

Currently selected model quality can be queried with the following command:

```
ModelQuality = GetModelQuality(void);
```

Performing image capture directly from core application

Calculating all camera positions

Following the user selection of capture options, all required camera positions can be calculated with the following command (new in API v. 1.5):

```
RFSAT.CalculateCameraPositions();
```

This function fills the content of the following internal SWSCAN variables:

- int ImagesToCapture;// Number of images to capture
- double *CamX; // Camera X positions w.r.t. table centre [meters]
- double *CamY; // Camera Y positions w.r.t. table centre [meters]
- double *CamZ; // Camera Z positions w.r.t. table centre [meters]
- double *CamA; // Camera Azimuth for each image [degrees]
- double *CamE; // Camera Elevation for each image [degrees]

For verification purposes, camera positions are also saved into a Matlab file that displays 3D locations of cameras and their orientations on a 3D graph. This program is saved in the same directory where images are expected to be captured.

Capturing individual images

After calculating the camera positions, the individual images need to be captured in a loop within the main application using previously calculated positions, by placing the camera at specified locations with respect to the object (in meters) with given rotation and elevation/tilt. Individual images can be captured using the following function (available since API v. 1.2):

```
RFSAT.CanonSnaphot(FileName);
```

Where FileName is a char[256] variable providing the full path to the file.

NOTE: images filenames for each complete set MUST follow the following format:

image_xxx.jpg, where XXX are numbers in sequence, e.g. 000, 001, 002 etc.

The ImageCapture function is a C++ wrapper for executing a command line program "*ControlEOS.exe*" developed by RFSAT for controlling the Canon EOS cameras. Refer to the help embedded in this program for usage syntax.

Pass a path to images from core application to SWSCAN module

In order for SWSCAN module to have a correct reference to image files, a path to the directory where images captured by core application will be stored needs to be provided. This can be done with the following command (available since API v. 1.2):

```
SetPathToImages(PathToImages);
```

Where PathToImages is a char[256] variable terminated with a path separator ('\\').

The path can be queried with the following command:

```
PathToImages = GetPathToImages(void);
```

Specifying a path to the produced FBX model file

The SWSCAN module will copy the FBX file produced by 3D modelling algorithm to a pre-defined directory. It can be defined and passed to SWSCAN module with the following command (available since API v. 1.2):

```
SetPathTo3DModel(PathToModel);
```

Where PathToModel is a char[256] variable terminated with a path separator ('\\').

The current path to FBX model can be queried using the following command:

```
PathToModel = GetPathTo3DModel();
```

Launching 3D modelling

5.1.1.1. Executing modelling process with Pix4D engine

In the final step the 3D modelling should be executed using the following commands:

NOTE: remove the previously processed 3D model before processing a new model.

```
char SysCom[256] = "";
sprintf(SysCom, "rmdir /S /Q %s", "ARCH_Project");
system(SysCom);
```

Start Pix4D to produce a model in a separate process:

```
PROCESS_INFORMATION my_pi;
int counter = 2000; // Chose your timeout
my_pi = RFSAT.Pix4D_Start(Model3D_LowRes);
while ((RFSAT.Pix4D_Progress()!=3) && counter) {
Sleep(1000);
```

```
counter--;
if (!counter) cout << Timeout, terminating Pix4D\n";
}
```

Terminate Pix4D if processing complete or on timeout

```
if (!RFSAT.Pix4D_Terminate(my_pi))
cout << Pix4D process failed to terminate\n";
else
cout << Pix4D process terminated OK\n";
```

Check how far Pix4D has progressed

```
result = RFSAT.Pix4D_Progress();
switch (result) {
case 0: cout << "No progress\n"; break;
case 1: cout << "Initial processing complete\n"; break;
case 2: cout << "Point cloud ready\n"; break;
case 3: cout << "Created 3D model\n";
}
```

The 3D model is by default located at:

.\\ARCH_project\\2_densification\\3d_mesh\\ARCH_project_simplified_3d_mesh.fbx

It can be loaded by the man application and displayed/processed as required.

NOTE: processing models in HIGH quality may take several hours. Hence, for demonstration purposes it is advisable to use low-quality modelling, which may take up to tens of minutes.