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D1.5 – Data specification requirements framework Part 2

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Executive summary

The deliverable *D1.5 – Report on data specification requirements framework Part 2* is the second version of the report on the data specification requirements for the RETIME project.
It integrates the information provided in the report *D1.3 – Report on data specification requirements framework Part 1* submitted to the European Commission through the official portal in Month 12 of the project (April 2025).
D1.3 and D1.5 cover data protocols, data schemas, and user interfaces to enable accurate object-related digital information exchange, specifically tailored to the needs of the key stakeholders and users of the tools developed within the project scope across the RETIME pilot sites. They also outline adaptation solutions for data collection, usage, and management, defining key parameters such as source, volume, format, frequency, privacy, and security, to ensure scalability, effective model monitoring, and evaluation within the project framework.
The deliverable D1.5 presents the refined data requirements framework established in the deliverable D1.3, co-designed with stakeholders across the three pilot sites. It also incorporates refinements (covering 3D data semantics, OGC-based API integration, time-enabled spatial datasets, and CityGML extensions) to ensure RETIME solutions meet local needs while supporting scalability.
This report is intended for a diverse audience, including RETIME consortium members, the research community, industrial stakeholders, and representatives of SMEs.

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List of acronyms and abbreviations

ABAC	Attribute-Based Access Control
AEC	Architecture, Engineering and Construction
ADE	Application Domain Extension
API	Application Programming Interface
BIM	Building Information Model
BRP	Building Renovation Passport
CAP	Common Alerting Protocol
CDE	Common Data Environment
CI	Continuous Integration
CityGML	City Geography Markup Language
CityJSON	JSON encoding of CityGML
CML	Câmara Municipal de Lisboa | Lisbon City Council
CO_2	Carbon Dioxide
COG	Cloud-Optimised GeoTIFF
CPU	Central Processing Unit
DBT	Digital Building Twin
DMP	Data Management Plan
DPIA	Data Protection Impact Assessment
DOI	Digital Object Identifier
DSS	Decision Support System
EIF	European Interoperability Framework
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
FR	Functional Requirement
GDPR	General Data Protection Regulation
GIS	Geographic Information System
HVAC	Heating, Ventilation and Air Conditioning
HTTP	Hypertext Transfer Protocol
IBS	Institute of Baltic Studies
ICT	Information and Communication Technology
IdP	Identity Provider
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Classes
ISCTE	University Institute of Lisbon | Instituto Universitário de Lisboa
ISO	International Organization for Standardization
ISTAR	ISCTE - Information Sciences, Technologies and Architecture Research Centre

IT	Information Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCA	Life-Cycle Assessment
LDM	Local Desk Member
LoRa	Long Range (radio technology)
LoRaWAN	Long Range Wide Area Network
MFA	Multi-Factor Authentication
MQTT	Message Queuing Telemetry Transport
NbS	Nature-based Solutions
NFC	Near Field Communication
NFR	Non-Functional Requirement
NTP	Network Time Protocol
OASIS	Standards consortium publishing
OGC	Open Geospatial Consortium
PM	Particulate Matter
PostGIS	Spatial extension to PostgreSQL
QA	Quality Assurance
QR	Quick Response
RBAC	Role-Based Access Control
REST	Representational State Transfer
RPO	Recovery Point Objective
RTO	Recovery Time Objective
SBOM	Software Bill of Materials
SD	Secure Digital (memory card)
SME	Small and Medium-sized Enterprise
SSH	Secure Shell
SSO	Single Sign-On
TLS	Transport Layer Security
UI	User Interface
UPS	Uninterruptible Power Supply
UV	Ultraviolet
VOC	Volatile Organic Compounds
WCAG	Web Content Accessibility Guidelines
Wi-Fi	Wireless Fidelity (radio technology)
WP	Work Package
ŽSK	Žilina self-governing region

1. Introduction

This report, *D1.5 – Report on data specification requirements framework Part 2*, integrates the information provided in the report *D1.3 – Report on data specification requirements framework Part 1*, which was submitted to the European Commission through the official portal in Month 12 of the project (April 2025).

D1.3 and D1.5 outline all data specification requirements related to RETIME solutions, tools, and services to ensure that feasibility, interoperability, privacy, security, and inclusiveness are guaranteed across the three pilot areas (Lisbon, Žilina, and Tartu).

This report is organised as follows: *Section 2* outlines the main stakeholders and users who will benefit from the RETIME design solutions, with particular attention to the needs of vulnerable groups across the three pilot sites.[1] *Section 3* provides information on RETIME sensor installation that integrate the information provided in the deliverable D1.3. *Section 4* outlines the key functional and non-functional requirements of the four RETIME solutions:

- Hardware Totem;
- Digital Building Twin;
- Building Renovation Passport;
- Resilience Knowledge Hub and Decision Support Platform.

Section 5 focuses on advanced 2D/3D geospatial modelling, including the integration of modern OGC APIs and the incorporation of temporal and quality aspects. It highlights the use of CityGML Application Domain Extensions (ADEs) to enhance hazard, energy, and resilience modelling by linking Geographic Information System (GIS) and Building Information Modeling (BIM) data. The section also presents integrated 2D–3D workflows that connect hazard maps with detailed 3D models, expanding exposure and vulnerability databases to support indoor–outdoor continuity, evacuation modelling, risk-aware routing, and semantic extensions with linked ontologies for resilience modelling.

[1] as part of task *T2.2 - Design of the stakeholder engagement and co-design strategy*.

1.1. RETIME Data Requirement Framework

This report integrates the data requirement framework established in *D1.3 – Report on data specification requirements framework Part 1*. In D1.3, requirements for adaptation solutions, covering source, volume, format, frequency, privacy, and security are defined for data collection, usage, and management that ensure scalability, monitoring, and evaluation. D1.5 defines requirements for human-centric solutions in the three pilot sites and at building level, for ensuring semantic depth, interoperability, and long-term reusability. Figure 1 introduces the RETIME data requirement framework used across D1.3 (Part 1) and D1.5 (Part 2), identifying the related deliverables. By integrating the information provided in D1.3, the report D1.5 aims to ensure that RETIME solutions and services effectively respond to local stakeholders' needs and priorities, while remaining broadly scalable at European level. The RETIME data requirement framework is identified in both D1.3 and D1.5. Other content related to data management, risks, mitigation measures, and the co-design mapping of current and emerging end-user needs for RETIME solutions is also detailed in other RETIME deliverables.

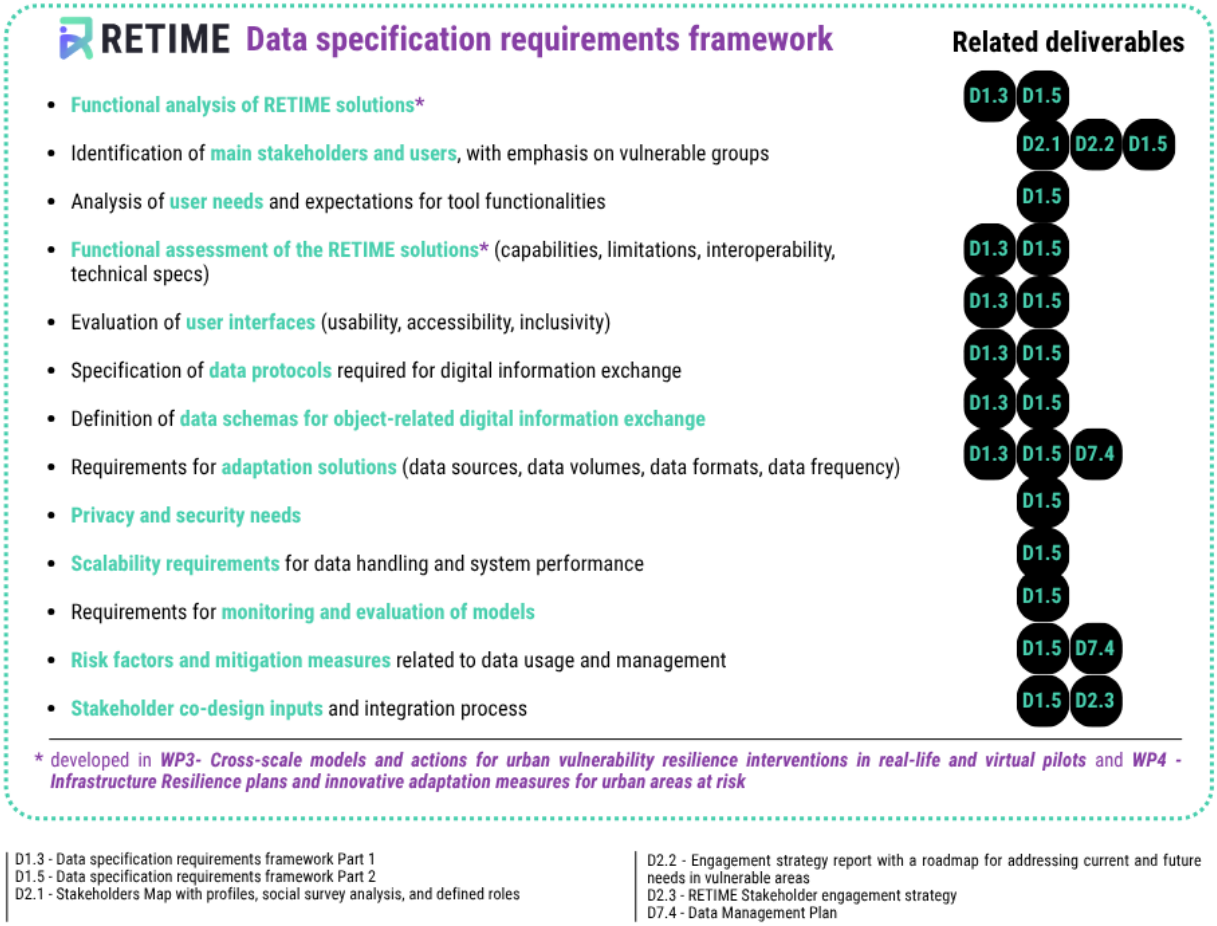


Figure 1. RETIME data requirement framework and RETIME related deliverables.

2. Key stakeholders and needs

Since people are at the centre of this project, RETIME solutions are tailored to meet current and emerging needs of key stakeholders in the pilot sites (Lisbon, Žilina, and Tartu), with results feeding into and shaping the development of activities. The information related to the main stakeholders and users are preliminary discussed with RETIME Local Desk Members (LDMs) during bilateral meetings and then will be validated and refined through co-design workshops with stakeholders and other activities planned during task *T2.3 – Implementation and coordination of the stakeholder engagement strategy*.

While each pilot has distinct hazards, building characteristics and sensor setups, the RETIME digital platforms (e.g., Building Renovation Passport, Digital Building Twins, Resilience Knowledge Hub) are deliberately designed as shared, multi-tenant services. RETIME solutions will be adapted through location-specific settings (for physical components), configuration adjustments, and customisation of data sources (such as languages, thresholds, roles, and local data feeds), rather than by creating pilot-specific forks of the software. This keeps tools coherent and maintainable across sites while still reflecting local needs through content and integrations. The more pilot-specific differentiations are handled close to the hardware (e.g., sensor networks and on-site displays/totems). This approach follows good practice for multi-tenant systems (treat differences as configuration/data and avoid forking) and aligns with EU interoperability principles and open standards, such as OGC APIs for data exchange, European Interoperability Framework (EIF) for re-use (European Commission, 2017). Accessibility remains a cross-cutting requirement so that the same platform works for all user groups (e.g., Web Content Accessibility - WCAG 2.2).[2]

RETIME solutions meet the needs of people with special requirements and buildings of particular interest across the three pilot sites, as shown in Table 1. Except for the Tartu pilot site, where end-users have received training before this project began[3] and demonstrate high levels of digital and climate-related literacy, end-users at the other two RETIME pilot sites are less familiar with both digital devices and data. Therefore, the communication interface must be tailored to their specific needs.

[2] https://www.w3.org/WAI/standards-guidelines/wcag/
[3] Additional info is provided in *section 3.2*.

Table 1. Overview of the needs and key end-users of RETIME solutions.

RETIME solutions	Description and Location	Key end-users	Specific needs of end-users
Hardware Totem *(fed by sensor-based Information Technology (IT) automated alert system)*	***Bairro da Boavista, Lisbon:*** Outside, Atrium of school Arquitecto Gonçalo Ribeiro Telles	Students of the school Arquitecto Gonçalo Ribeiro Telles (3-9 years), family members, local inhabitants	***Design:*** Height-appropriate, robust materials ***Integration with other alert system protocols:*** The totem should give signals that children already know from practice at school, so they understand what action to take right away. ***Type of communication:*** Symbol-based communication, use of universal pictograms, clear colour coding, and animated lights and not text-based instructions ***Language:*** Portuguese
	Zástranie (Žilina): Inside, in staff-only-accessible rooms in Social Services Centre Straník	Working staff and building managers (direct users); patients/residents (indirect beneficiaries)	***Different end-users:*** Diverse vulnerable groups living in the Straník building (e.g., individuals with various medical conditions) require tailored support and individualised evacuation procedures and early warning systems. ***Language:*** Slovak
	Tartu: Two devices can be installed in the areas where there are the postal boxes. This is because there does not exist just one common area (e.g., a foyer) in the apartment building, rather multiple.	Residents and the building manager of Tähe 2 apartment building	***Design:*** Simple devices, yet equipped with advanced information (e.g., outdoor temperature, CO2, staircase door open), as end-users have a high level of digital proficiency. ***Data integration framework:*** Residents may receive information from existing sensors on individual smart screens within each of the 32 apartments of the Tartu pilot house. The hardware totem should not reflect information which would duplicate the information that residents in Tartu already receive from those smart screens. Some more empathetic approach can be adopted to inform the residents about climate-related actions. ***Language:*** Estonian and Russian/English

A Digital Building Twin (DBT)	Digital replica of the pilot buildings that integrates sensor data, Life-Cycle Assessment (LCA), simulations, BIM, and related datasets to monitor, assess, and forecast building performance under relevant hazards. Delivered as a digital service.	Building users, owners, and managers; municipal authorities and emergency planners; Architecture, Engineering and Construction (AEC) practitioners; research and innovation partners, IT developers.	***Data integration framework:*** Consistent data ingestion from sensing/alerting, links to BIM and analytical models, privacy-respecting access control, and clear outputs (dashboards, reports, and Application Programming Interfaces (APIs).
A Digital Building Renovation Passport (BRP)	Digital tool/document that compiles building data and sets out a staged renovation roadmap, integrating relevant assessments and dynamic information from the pilots	AEC practitioners, building/flat owners, building managers, building investors, and building design professionals	***Usability:*** Multilingual User Interface (UI) and outputs across pilots ***Access and compliance:*** clear, step-by-step flows and plain-language summaries; role-based access and General Data Protection Regulation (GDPR) compliant handling ***Language:*** official national languages of the three pilot sties and English, where needed
A Resilience Knowledge Hub and Decision Support platform	Web-based platform that aggregates data, maps and learning resources, with profiles/views tailored to different user groups	Vulnerable groups, policy- and decision-makers, industrial stakeholders; Small and Medium-sized Enterprises (SMEs).	***Usability:*** Multilingual interface in official national languages, accessible, user-friendly navigation and plain-language content; easy discovery of GIS maps and Nature-based Solutions (NbS) case studies; use-case-guided flows; seamless links to DBT/BRP and hazard information; interactive self-assessment tools plus clear glossaries; design that accommodates low digital literacy and supports capacity building.

3. Sensor installation across the RETIME pilot sites

Sensor installation is tailored to the climate- and structure-related risks and building typologies in each RETIME pilot (Lisbon, Tartu and Žilina), at both building and district/municipal scales.[4] The objective is to capture the parameters needed for monitoring, early warning and decision support across buildings and public spaces.
The deliverable *D1.3 - Report on data specification requirements framework Part 1* defined the sensor-based alert system foundations: the communication and transmission architecture, the use of open and interoperable data models/protocols, and a preliminary list of indoor/outdoor parameters to be monitored. This section complements those foundations by detailing the site- and device-level installations per pilot.

3.1. Lisbon Pilot Site

Some of the sensors were not fully described and it was missing the specifications of the sensors to be installed on the dwellings in *Bairro da Boavista*.

3.1.1. Seismic sensors in elementary school in Bairro da Boavista (Lisbon)

The sensors to be installed in the elementary school building in Lisbon pilot site (EB Gonçalo Ribeiro de Telles) were specified in the deliverable D1.3. The main objective of installing seismic sensors in the elementary school building in Lisbon pilot site (*Bairro da Boavista*) is to achieve early detection and transmission of relevant three-dimensional acceleration data generated at the site by a moderate-to-strong earthquake affecting Lisbon. These data are also critical for post-earthquake assessment and decision support regarding the structural integrity of the school building. Each sensor unit is equipped with an integrated backup power supply to ensure uninterrupted operation during power outages or an earthquake. The sensors will collect acceleration data at a sampling frequency of 50 Hz, with event-triggered recording that starts once the ground motion acceleration exceeds a predefined threshold. A total of four sensors are planned for installation, based on the preliminary architectural and structural layout of the school. Their exact locations and configuration parameters will be documented within BIM environment. The data will be collected in case of an earthquake of significant intensity, i.e., which leads to a ground acceleration of 0.2g or above. Event

[4] Information on vulnerability, stakeholder analysis, and hazardous hotspots is outlined respectively in deliverables *D1.1 – Report on urban vulnerability and risk assessment (multi-risk resilience) methodologies and tools, D2.2 – Stakeholders Map with profiles, social survey analysis, and defined roles,* and *D3.1- Map of urban vulnerable hotspots in three pilot areas Part 1*.

data are transmitted to the municipal civil protection headquarters and is also stored locally on a Secure Digital (SD) card. Low-level acceleration data and other continuous background acceleration recordings are not retained by default. The transmitted datasets include the time-history of the recorded event which consists of four primary columns: timestamp and acceleration components along the three orthogonal axes (X, Y, Z). Additional derived parameters such as peak acceleration values, derived velocity, displacement, and response spectra may also be computed and transmitted. As referred, event-related data will be transmitted to a central database hosted by the Lisbon municipal civil protection and will then be integrated into their information system to support rapid assessment and decision-making. Data transmission is supported via the LoRa (Long Range radio technology) network (LoRa Alliance, 2020), ensuring reliable communication even under emergency conditions. These specifications are indicated in Table 2, while an example of the seismic sensors is shown in Figure 2.

Table 2. Specifications of the seismic sensor installation in elementary school in Bairro da Boavista (Lisbon).

Component	Feature	Specification
Sensor outer box	External dimension	12.5 cm × 8 cm × 6 cm
	Material	Aluminium or Polycarbonate housing
	Protection Rating	IP68 – dust-tight and protected against continuous immersion in water
	Durability	Suitable for outdoor environmental conditions
Sensor	Type	Triaxial accelerometer
	Brand / Model	Analog Devices – ADXL355
	Dynamic Range	± 2 g
	Resolution	20-bit analog-to-digital converter
	Acquisition Rate	Programmable
	Bandpass Filter	Programmable
Connectivity	Internet module	ESP32 with Xtensa 32-Bit LX6 Dual Core Processor (Espressif Systems, 2025)
	Wireless Standard	IEEE 802.11 b/g/n
	Frequency	2.4 GHz Wi-Fi
	Maximum Data Rate	150 Mbps
Power Supply	Source	Connection to the electrical network
	Backup battery	18650 type lithium battery
	Power continuity	Battery ensures operation during power outages



Figure 2. Photograph of a seismic sensor (by Carlos Moutinho, 2025).

3.1.2. Wildfire detection in Monsanto Forest Park (Lisbon)

RETIME will deploy Dryad Silvanet Wildfire Sensors (Dryad Networks, n.d.) for ultra-early detection of smouldering fires in the forested area adjacent to the school. The sensors use a gas 'electronic nose' (including hydrogen, carbon monoxide and other gases) with on-device AI to identify combustion in the smouldering phase and record micro-climate (temperature, humidity, air pressure). Detection is designed to occur within minutes to enable rapid response and minimise spread. The solution is composed by small autonomous sensors/detectors, autonomous gateways and a cloud platform. Connectivity is provided by Dryad's Long Range Wide Area Network (LoRaWAN)-enabled Silvanet mesh network: sensors relay to a Silvanet Mesh Gateway, which aggregates traffic to a Silvanet Border Gateway and forwards events to the Silvanet Cloud Platform that provides an API to access data and alerts.

The integration into RETIME will involve ingesting events from the Silvanet platform into the RETIME alerting pipeline and mapping them to the project's Common Alerting Protocol (CAP)-based alert model (including hazard category, severity, urgency, certainty, affected area, and instructions) to enable distribution through downstream channels such as building totems and city systems**.** This approach keeps the wildfire subsystem loosely coupled while ensuring standards-based

dissemination alongside other hazards. The parameters of sensors for wildfire detection are indicated in Table 3.

Table 3. Parameters of sensors for wildfire detection.

Component	Feature	Specification
Detector device	External dimensions	19 cm x 9.2 cm x 1.2 cm
	Weight	136 g
	Ingress Protection	IP67
	Material	Plastic (Weather, UV-proof)
	Operational Temperature	-40°C to +85°C
	Operational Humidity	0% to 100% Condensing
	Maintenance	Maintenance-free (10 - 15 years)
	Distance between Sensors (Radius)	100m radius for 60-min detection of 2 x 2 meter fire
	Sensor to Mesh Gateway (Ratio)	Typically, 100 sensors per Gateway, depending on topology
	Power source	Solar-powered
	Energy storage	Supercapacitors, battery-free
	Installation	Tree- or pole-mounted (3 meter height recommended)
	Data transmission	LoRa EU868 (LoRa Alliance, 2020), AS923, Tx Power: 14 dBm
	Maintenance and configuration	Near Field Communication (NFC)
Sensor inside detection device	Model	BOSCH BME 688
	Sensitive to	CO, CO2, H2, VOC, Temperature, Humidity, Air Pressure
	Operation range	Pressure: 300 to 1100 hPa; Humidity: 0 to 100%; Temperature: -40 to 85°C
Gateway	External dimensions	82 cm x 34 cm x 10 cm
	Weight	6.8 kg
	Ingress Protection	IP67
	Material	Plastic (Weather, UV-proof)
	Operational Temperature	-40°C to +85°C
	Operational Humidity	0% to 100% Condensing
	Maintenance	Maintenance-free (10 - 15 years)
	Max distance between Mesh Gateways	2 - 10 km, depending on topology and placement
	Power source	Solar-powered
	Energy Storage	Supercapacitors, battery-free
	Installation	Tree- or pole-mounted
	Provisioning	NFC for local debugging and configuration

3.1.3. Indoor Environmental Quality Sensors in Bairro da Boavista

The sensors related to IEQ installed in EB Arquiteto Gonçalo Ribeiro de Telles were specified in D1.3. However, due to power source limitations for the devices inside the dwellings in *Bairro da Boavista*, an alternative solution was developed. Sensors with long-lasting battery life and long-range communication protocols will be installed. An Airthings Space Hub will be installed on the roof of EB Arquiteto Gonçalo Ribeiro de Telles to receive the data from the sensors installed inside the dwellings. The indoor sensors are the Airthings Space Pro, that measures CO2, VOCs, PM2.5, radon, temperature, relative humidity, and atmospheric pressure.

3.2. Tartu Pilot Site

In Tartu, sensors already installed during the SmartEnCity project,[5] collect data on air quality weather, indoor environment, and consumptions. The parameters are indicated in Table 4. Sensors are installed in 32 apartments in the building.

Table 4. Parameters of sensors in Tartu Pilot Site.

Sensor	Parameters	Quantity
Eurotronic Spirit Z-Wave Plus (smart radiator thermostat)	Room temperature	104 (one per heated room)
Heiman HS1SA-Z	Smoke/fire alarm state	32 (apartment living-room ceilings)
Impulse counters – water meters	Water consumption	32
Impulse counters – gas meters	Gas consumption	19
Impulse counters – electricity meters	Electricity consumption	32
CO_2 probe (exhaust duct)	CO_2 level (building-level, aggregated)	-
Main water meter	Water consumption (building)	1
PV production meter/inverter telemetry	Current PV production; total PV production (month)	-
Outdoor temperature probe	Outdoor air temperature	1
Heating water temperature sensors – radiators / tap water / ventilation	Heating water temperatures for radiators, domestic hot water, and ventilation	-

[5] https://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects/smartencity

3.3. Žilina Pilot Site

Besides the data sources already detailed in D1.3, local sensors have been installed to monitor IEQ and weather, as indicated in Table 5.

Table 5. Parameters of sensors in Žilina Pilot Site.

Sensor	Parameter(s)	Quantity
Netamo Smart Indoor Air Quality Monitor	CO2, sound level, temperature, and humidity	3
Netamo Smart Home Weather Station	Temperature, humidity, CO2, noise, pressure	2
Netamo Smart Rain Gauge	Precipitation	1

4. Functional and non-functional requirements of RETIME solutions

4.1. RETIME Hardware totem

RETIME hardware totem is a public-facing interface that informs citizens/occupants about extreme climatic events and other natural disasters in a timely way. It is not intended to serve as a full sensor dashboard. It builds on the sensor-based monitoring (task *T4.3 – Sensors for IT automated alert in three pilot areas*) and the alerting strategies (triggers) developed in task *T3.2 – Design of impact-based triggers for automated monitoring and management systems*, and shows concise instructions tied to site-specific emergency protocols (task *T4.1 – Development of site-specific emergency protocols to improve safety and resilience*). The Resilience Knowledge Hub (developed within *T4.6 - Resilience Knowledge Hub and Decision Support platform*) and related tools may provide the rich/interactive content off-totem.

4.1.1. Key contents and principles

The RETIME hardware totem should be tailored to address key emergency communication needs in Lisbon, Žilina, and Tartu. Local Desk Members from Lisbon Town Council (CML, Câmara Municipal de Lisboa) and Žilina self-governing region (ŽSK) indicated that the totem should provide detailed instructions for evacuation coordinators, while Institute of Baltic Studies (IBS) (Tartu) did not consider this immediately necessary, given the limited number of exits in the building, but further discussions will be held on the topic for full confirmation. Regarding general messaging, CML and IBS preferred simple and accessible information, whereas ŽSK opted for more specific content.

- **Real-time Environmental Alerts:** RETIME hardware totem will display live alerts as soon as the upstream alert system publishes an event. It will show a short alert message along with concise action instructions.
- **Risk Maps and Hotspots:** RETIME hardware totem will not host complex interactive maps. Instead, it will show a simple daily risk tile (e.g., 'Today: Heat Stress Risk = Moderate') and provide a Quick Response (QR) code linking to the RETIME Resilience Knowledge Hub, where users can explore detailed urban risk maps, hotspots, and vulnerable groups.[6]

[6] RETIME hardware totem will not display future scenarios simulations. Future scenarios will be available in the DBT/Knowledge Hub, with QR codes on the totem directing users there when relevant.

- **Adaptation Measures / Building Renovation Passports (BRP):** RETIME hardware totem will not present full BRP content since this information is not relevant for the foreseen end-users. Instead, it can display brief call-to-actions (e.g., 'see your BRP recommendations') with a QR code linking to the BRP tool, keeping the screen focused on alerts and key instructions.
- **Accessible and Inclusive Interface:** The interface will use large, high-contrast fonts, clear iconography, and audio cues where possible. Even considering the display serves only a visual function, accessibility requirements will be met by ensuring that screen size and height are appropriate for the intended viewing distance. RETIME hardware totem will be mounted at a height accessible to wheelchair users, and pictograms will follow the 'no one left behind' principles (United Nations, 2015). The design will ensure that information is accessible to vulnerable groups across the three RETIME building pilot sites.

Functional and non-functional requirements of the RETIME Hardware totem are identified in Table 6 and 7, respectively.

Table 6. Functional requirements of RETIME Hardware totem.

Code	Description	Justification	Technical Information
FR01	The totem shall support multiple predefined operating modes (e.g., Normal Mode, Warning Mode) that determine its visual behaviour, displayed information, and communication patterns according to system status and contextual conditions	Structured operating modes ensure consistent interpretation of alerts and environmental data by end-users. They also enable controlled transitions between states (e.g., from normal operation to emergency display).	The operating mode shall be determined automatically based on inputs from knowledge hub and decision support system
FR02	In Normal Mode, the totem shall display real-time Indoor Environmental Quality (IEQ) status per monitored zone and outdoor public sensor data at municipal/district level, using a simple colour-coded indicator (Green/Amber/Red) and short text guidance	Supports occupant comfort and proactive behaviour (e.g., ventilation). Helps visualise selected sensor data in an accessible way.	Local IEQ sensor network (Carbon Dioxide (CO_2), Particulate Matter (PM), Volatile Organic Compounds (VOC), temperature, humidity) aggregated via the site monitoring system
FR03	In Warning Mode, the totem shall switch automatically from normal information mode to a full-screen alert mode upon reception of a validated hazard event	Ensures rapid and unambiguous communication of emergencies to all occupants	Upstream event broker (Message Queuing Telemetry Transport (MQTT) or Representational State Transfer (REST) feed)

			publishing validated alert messages
FR04	The totem shall display clear, site-specific action instructions (text + pictograms) for each alert, aligned with emergency procedures	Guarantees message consistency across media and supports inclusive communication ("no one left behind")	Central emergency protocol database / configuration file maintained by school or city authority
FR05	The totem shall maintain visibility and access to static emergency information (e.g., evacuation plan) during power or network outages	Provides resilience and continuity of information in crisis conditions	Locally stored static emergency plan (offline media)
FR06	The totem shall confirm alert receipt and display status (e.g., "Alert received," "Display active," "Connection lost") to the upstream system for monitoring and reliability tracking	Ensures operational reliability, allows remote supervision, and supports audit of whether alerts were successfully shown to users	System health telemetry and message acknowledgment between the totem and central alerting platform
FR07	The totem shall be able to subscribe to and parse standardised alert messages (e.g., Common Alerting Protocol – CAP) from external Decision Support Systems or municipal feeds	Enables interoperability with official hazard alert sources and supports integration with existing early-warning networks	External CAP-compliant feeds, city Decision Support System (DSS), or Knowledge Hub event stream
FR08	The totem shall display only alerts originating from trusted and approved sources, using a configurable list of validated data providers	Ensures the credibility of displayed information and prevents confusion from unverified or irrelevant alerts	Approved source registry managed by the central system or pilot administrator
FR09	The totem shall support secure remote maintenance and configuration updates (e.g., alert templates, icons, translations) through Secure Shell (SSH) based access or equivalent secure channel	Allows centralised and safe administration without on-site intervention, ensuring consistent content and cybersecurity compliance	Central management console / SSH interface with authenticated access

Table 7. Non-functional requirements of RETIME Hardware totem in Lisbon.

Code	Description	Justification	Technical Information
NFR01	The totem shall be installed in a location protected from direct sunlight, rain, and wind exposure.	Direct exposure to sunlight, rain, or wind can negatively affect both the visibility of displayed information and the operational effectiveness of the device.	Bright light conditions may cause glare or reduce screen readability, while rain and wind can interfere with sensors or cooling systems. Ensuring a protected installation environment therefore improves usability, reliability, and long-term performance.

NFR02	The totem shall be designed and installed with appropriate anchoring	The totem shall be anchored to the supporting infrastructure (e.g., floor or wall) to ensure mechanical stability under normal operating conditions and accidental external forces. The location must be also free from potential impact zones, such as sports areas or spaces where balls or other objects could strike the screen	Anchoring the totem to a fixed structure prevents tipping, displacement, or vibration that could compromise safety, alignment, or the integrity of internal components
NFR02	Electrical power supply	Ensures that the totem can operate reliably under normal conditions with a stable and safe energy source	The totem shall be installed near a standard electrical outlet or connected to a dedicated power line equipped with an Uninterruptible Power Supply (UPS) to provide continuous and conditioned power in compliance with safety and building regulations
NFR03	Operational resilience and power autonomy	The totem must remain functional and visible during power or network disruptions to ensure continuous availability of emergency information	The system shall include or be connected to a backup power solution that guarantee uninterrupted operation during short or medium-term outages
NFR04	High availability and fault tolerance	To ensure alerts are always displayed, the totem shall recover gracefully from hardware or network faults	The software shall implement automated recovery and continuous self-monitoring, reporting status to the central system
NFR05	Automatic Recovery after Power or Network Failure	The totem shall automatically restart and restore its normal operation after a power outage or network interruption, ensuring that alerts are displayed as soon as the system becomes available again	The software shall include a watchdog service and startup scripts configured to restore normal operation automatically after a reboot or connection loss
NFR06	Monitoring, logging and status reporting	The software shall periodically report its operational status to the central system and immediately send alerts if faults, disconnections, or	A background monitoring agent shall periodically report system status and transmit event-based notifications to the central platform when faults, disconnections, or abnormal conditions are detected. Logged data shall be synchronised with the central

		abnormal conditions are detected	monitoring system once connectivity is restored
NFR07	Interoperability with third-party systems and Decision Support Services	Enables the totem to receive validated alerts and contextual data from different systems and services	The system shall use open and widely adopted communication standards to exchange information with external platforms
NFR08	Secure remote administration	Allows authorised operators to maintain and update the totem remotely in a controlled and secure way	Remote access shall use encrypted connections and authenticated sessions - e.g., SSH or equivalent, following least-privilege principles. On-site deployments shall ensure that network configurations and firewall rules allow secure and continuous remote access for maintenance and monitoring.
NFR09	Accessibility and inclusive communication	Ensures that emergency information is understandable and reachable by all user groups, following principles defined within deliverable *D7.2 – Quality plan*	The interface shall follow accessibility design principles, using high-contrast visuals, intuitive icons, and multiple language and sensory modalities
NFR10	Data protection and privacy compliance	Protects operational and communication data handled by the totem and backend systems	Data shall be transmitted and stored securely, respecting privacy and regulatory frameworks for public information systems as defined in *D7.2 – Quality plan* and *D7.4 – Data Management Plan*
NFR11	Continuous connectivity and communication reliability	Ensures that the totem maintains a stable connection with the central system under varying network conditions	The totem shall remain continuously connected with the central system through a primary Wi-Fi, wired network and/or cellular connection (4G/5G), guaranteeing uninterrupted data exchange and alert delivery
NFR12	The device's display shall be exclusively for visual information output	The absence of a touch interface ensures protection of the display surface from physical wear, environmental contamination (e.g., dust, moisture), and vandalism.	

4.1.2. Operating concept

Default/Idle mode (no active alerts): The totem cycles through short status tiles at a regular interval:

- **Indoor comfort by zone** (e.g., classrooms, canteen, admin office): simple green/amber/red per zone for aggregated Indoor air quality (IEQ), with a one-line hint (e.g., 'Poor indoor air quality → consider opening windows'). Source: IEQ sensors; thresholds finalised via co-design activities.
- **Outdoor 'now & next'**: temperature, precipitation (if any), Ultraviolet (UV) index, and an outdoor air-quality summary (e.g., PM2.5 'Good/Moderate/Unhealthy'), using the outdoor meteorologic and air quality sensors, optionally fused with short-term RETIME Resilience Knowledge Hub layers where relevant.

Alert mode (when a trigger fires): On an active trigger, the totem switches to a full-screen panel showing: Hazard type and Severity / Urgency / Certainty (CAP fields); Plain-language action steps; Trigger timestamp and last updated time.
If multiple alerts occur, they are queued, and the highest-severity alert remains pinned until expiry. Action text and icons are taken from site-specific emergency protocols (task *T4.1 - Development of site-specific emergency protocols to improve safety and resilience*), with attention to low Information and Communication Technology (ICT) literacy and inclusive communication.
Examples of alerts:

- **IEQ breach:** Source: IEQ sensors; Triggering: task *T3.2 - Design of impact-based triggers for automated monitoring and management systems* thresholds for CO_2/PM/VOC/thermal comfort; Action: 'Open windows / switch on ventilation / alert staff if symptoms persist'.'
- **Storm / high winds / intense rain:** Source: local weather station + T3.2 forecast layers with local station confirmation; Action: "Shelter indoors, keep away from windows; delay outdoor activities; follow staff guidance."
- **Outdoor air-quality degraded (e.g., smoke):** Source: outdoor air quality sensors + T3.2 layers; Action: 'Close windows/doors; reduce outdoor activity; consider masks for sensitive groups'.
- **Seismic activity detected:** Source: local seismic sensor and/or authoritative feed via T3.2/DBT; Action: 'Drop, Cover, Hold On; after shaking stops, follow evacuation route if instructed'.
- **Wildfire detected nearby:** Source: forest detection sensors + city/regional layers; Action: 'Close windows/Heating, Ventilation and Air Conditioning (HVAC); shelter from smoke; prepare for possible evacuation per protocol'.

4.1.3. Other aspects



Interoperability: Triggers should follow existing standards when available (e.g., Common Alerting Protocol) and may be interoperable with other existing systems; alerts and thresholds are to be codesigned with stakeholders and validated in pilots.



Security: All communications between the totem and upstream services (alert/event feed, content/config updates, health telemetry) must use encrypted transport with authenticated sessions and least-privilege access (e.g., Hypertext Transfer Protocol (HTTP)/ Message Queuing Telemetry Transport (MQTT) over Transport Layer Security (TLS) for data; SSH or equivalent for administration). The device only accepts alerts from trusted, approved sources and acknowledges receipt/display to the central platform for auditability. Operational logging is limited to non-personal telemetry; logs are synchronised to the central monitor when connectivity is restored. Static emergency content is stored locally to remain available during outages. These controls implement the non-functional requirements on secure remote administration, data protection/privacy, continuous monitoring, and interoperability already defined for the totem.



Scalability: The totem operates as a thin subscriber to a single upstream event feed (no per-sensor polling), using either MQTT, with hierarchical topics per pilot/site or an authenticated REST webhook. Alert concurrency is handled by a simple queue, with the highest-severity alert pinned until expiry; static assets (e.g., emergency plans, icon sets, translations) are cached locally to minimise bandwidth. Fleet-level scale is supported by centralised content governance, health telemetry/acknowledgements, and standards-based message formats for interoperability with external decision-support systems. This architecture allows many displays to be added across pilots with minimal device-side complexity.

Installation in Lisbon pilot site: High traffic lobby near main entrance (articulate with school staff); ambient light readable; emergency power to keep static emergency plan available during outages (Static plans sourced from deliverable *D4.1 - Site-specific emergency plans*)
Content governance: action texts and icons centrally validated from the emergency protocol set (during task *T4.1 - Development of site-specific emergency protocols to improve safety and resilience),* to guarantee central data control, consistency, and integration with other official communication channels.

Installation in Žilina pilot site: The totem will be placed in a staff-accessible room, primarily for Stranik employees, and will display different colours to indicate various situations. Displays can be

installed for Stranik staff, while the weather station display should already be in place, initially, in only one employee office. Visible displays will ensure constant visibility in areas where staff work and circulate.
Technical functionality, device maintenance, and ownership responsibilities will be clarified with the building director and staff. The objective remains to deliver a scalable prototype that can be reused in similar facilities while addressing local requirements.

Installation in Tartu pilot site: Each flat already has smart screens providing weather and room temperature in addition to allowing residents to track their energy consumption. Given that the sensors in Tartu have been installed during a previous project (SmartEnCity), they will not be removed in the foreseeable future and will remain functional in the building to regulate indoor climate. However, the totem must not duplicate this information relayed to residents on existing smart screens and should instead focus on risk-related guidance and actionable, empathetic messages.
The building lacks a single common foyer and instead the two building entrances along with two spaces for mailboxes are the most trafficked areas, where people also regularly stop. The preferred placement is near the postal boxes, to maximise visibility for residents entering/exiting.

4.2. RETIME Digital Building Twin

RETIME Digital Building Twin (DBT) is a virtual replica of the pilot buildings that integrates live and historical sensing, hazard forecasts, structural and hygrothermal models, BIM, and LCA indicators to monitor, assess and forecast building performance under relevant hazards. This section consolidates data requirements and interfaces defined in deliverable D1.3 and refines them here for interoperability, semantic depth, and long-term re-use.

4.2.1. Key contents and principles

- **Scope and boundary:** The DBT is a building-level twin. It processes sensor data alongside BIM/Industry Foundation Classes (IFC) data into building simulations and indicators. City-scale maps/rasters/3D context live in the Resilience Knowledge Hub / exposure–vulnerability database. The DBT consumes those services when needed and publishes building-level results back to them.
- **Standards:** The DBT exposes building features and indicators through OGC API – Features and, where modelling workflows are published, via OGC API – Processes. All endpoints are described with OpenAPI and validated with JavaScript Object Notation (JSON) Schema, with clear semantic and versioning rules to keep changes backwards compatible.

- **Time-enabled data and quality:** All core data are time-stamped and indexable for analysis/replay. Provenance and quality are captured using ISO-style metadata; uncertainty is recorded where relevant so decisions can reflect confidence.
- **Data model and semantics:** BIM/IFC is the authoritative source for geometry, systems and materials at building level. The DBT maintains stable identifiers for spaces/zones/components to support cross-queries with sensor streams, simulations, and Hub layers.
- **Ingestion and harmonisation:** Validated streams from the sensor-based IT system, hazard/exposure services and modelling tools are harmonised to the DBT schema, linked to building objects and stored with minimal, necessary attributes for performance.
- **Analytics and scenarios:** The DBT runs building-level assessments (e.g., structural/hygrothermal/comfort) and 'what-if' scenarios using hazard/exposure inputs. Where outputs drive advisories, they align with the project's CAP-style alert parameters.
- **Outputs and re-use:** Results are delivered as dashboards, reports, and APIs for the Knowledge Hub (exploration/visualisation in 2D/3D and map context), and the Building Renovation Passport (BRP) (staged renovation roadmaps and evidence).
- **Privacy and security by design:** Role-based access, encrypted transport, least-privilege administration, and privacy-preserving handling of any person-related data (e.g., logs). The DBT stores only what it needs.
- **Operational fitness:** Lightweight, query-filtered services and caching of frequently used results keep the DBT responsive. Health telemetry and audit logs support monitoring, troubleshooting and acceptance testing across pilots.

Functional and non-functional requirements of RETIME Digital Building Twin are identified in Tables 8 and 9, respectively.

Table 8. Functional requirements of RETIME Digital Building Twin.

Code	Description	Justification	Technical Information
FR01	Ingest real-time and historical building sensor observations and external hazard inputs into the DBT using open, standards-based interfaces.	The DBT must fuse time-varying building and hazard data for monitoring, analytics and alerts; standards-based ingestion ensures reliable, low-coupling integration across pilots.	Accept OGC SensorThings API for observations; MQTT v5.0 (TLS) for events/alerts; HTTP/OpenAPI for batch/metadata; harmonise to the DBT schema and time-index by building/zone IDs.
FR02	Integrate BIM models (IFC; LOD 300+) to anchor geometry, systems and	*A building-level twin needs authoritative geometry/systems and stable identifiers to bind*	IFC 4/4.3 (ISO 16739-1) ingestion; maintain IFC GUIDs for spaces/elements; sensor-to-space binding via IFC spatial

	space usage, enabling sensor-to-space mapping.	*sensors and analyses to spaces and elements.*	structure; Common Data Environment (CDE) naming/status per ISO 19650-1/-2 to keep traceable links to BIM artefacts.
FR03	Link the DBT to the exposure & vulnerability database for building- and neighbourhood-scale risk simulations.	Risk-aware assessments depend on contextual exposure/vulnerability data at multiple scales.	Consume spatial layers from the exposure DB (PostGIS) via web services and use them as inputs to DBT analytics.
FR04	Support structural/hygrothermal scenario simulations, integrating hazard forecasts and Eurocode-based models.	Needed for testing mitigation strategies and building response under forecasted hazards.	Eurocodes for actions/response (EN 1991 wind/snow, EN 1998 seismic); hygrothermal per EN 15026 and interstitial/surface condensation checks per EN ISO 13788; persist inputs/outputs for traceability.
FR05	Provide IEQ scenario simulations at room/zone level (CO_2, PM, VOC, temperature, humidity), including 'what-if' mitigation (ventilation/window opening/filtration) under external hazard conditions (e.g., heatwave, smoke).	The DBT must plan how to maintain healthy indoor conditions during events and renovations; IEQ scenarios provide evidence for advisories and BRP decisions.	Dynamic mass-balance/comfort modelling; sensor-baseline assimilation; occupancy and ventilation/filtration set-points; Key Performance Indicators (KPIs) (time-in-target, exceedance hours, degree-hours); reference EN 16798-1 (categories), EN 16798-7 (ventilation), EN ISO 7730 (thermal comfort); expose runs via OGC API – Processes; persist parameters/results for audit and re-use.
FR06	Consume CAP-compliant alerts and translate them to building-specific advisories and DBT state changes.	RETIME alerting adheres to CAP; building tools must stay interoperable with its core fields (e.g., category, severity, urgency, certainty).	Support OASIS CAP v1.2 (also profiled as ITU-T X.1303); map CAP messages to DBT entities (building/zone); keep CAP identifiers/fields for provenance and audit.
FR07	Provide time-enabled storage and querying (4D: space+time) for all DBT data and results.	DBT unifies time-varying sensor, hazard and model data; time-enabled queries are needed to analyse trends, compare baseline vs events, and reproduce evidence for advisories and renovation planning.	Time-indexed tables for sensors/simulations; optional TimescaleDB over PostGIS for high-frequency series.

FR08	Interoperate via modern, standards-based APIs.	DBT outputs must be consumed by the Knowledge Hub, BRP and city systems across pilots; open, standards-based APIs enable consistent, low-coupling integration with clear versioning/discoverability and avoid bespoke connectors or vendor lock-in.	Provide OGC API – Features for vector features and OGC API – Processes for server-side workflows; document REST with OpenAPI.
FR09	Generate building-level indicators and exports for the Building Renovation Passport (BRP).	The BRP relies on DBT evidence to define staged renovation roadmaps and compliance with policy.	Export KPIs/attributes aligned with directive (EU) 2024/1275 - Energy Performance of Buildings Directive (EPBD) and national Energy Performance Certificate (EPC) contexts; map semantics to CityGML Energy ADE / BRP-compatible structures for reuse.

Table 9. Non-functional requirements of RETIME Digital Building Twin.

Code	Description	Justification	Technical Information
NFR01	Security	Protect data in motion/at rest and reduce attack surface	Controls and policies aligned to ISO/IEC 27001:2022 (ISMS), with security controls implemented per ISO/IEC 27002:2022; TLS for all APIs/streams; server-side encryption for stores; endpoint hardening; secure secrets management; least-privilege service accounts; vulnerability & patch management (incl. dependency/ Software Bill of Materials (SBOM) scanning).
NFR02	Privacy & data protection (GDPR)	Protect occupants and partners, meet legal/contractual duties, and enable trusted data sharing/re-use across pilots	Apply data minimisation and purpose limitation; classify data per the Data Management Plan (DMP); define lawful bases; perform Data Protection Impact Assessment (DPIA) where applicable; provide privacy notices and data-subject rights handling; use pseudonymisation/anonymisation when feasible; follow retention rules and records of processing; exclude personal data from logs; maintain breach response procedures.
NFR03	Access control & identity	Ensure only authorised users/services can access DBT resources and keep	OAuth 2.0 / OpenID Connect with Role-Based Access Control (RBAC)/ Attribute-Based Access Control (ABAC) and per-building scoping; Single Sign-On (SSO) with trusted Identity Providers (IdPs); Multi-Factor Authentication (MFA) for privileged roles; least-

		access auditable across organisations	privilege service accounts; short-lived tokens & session timeout; joiner–mover–leaver user lifecycle; immutable auth/authz audit logs and continuous monitoring; secure secrets management.
NFR04	Availability & continuity	Keep building services usable during incidents and maintenance	Redundant components where feasible; graceful degradation; maintenance windows; health/ready endpoints; clock sync with Network Time Protocol (NTP) for consistency; documented continuity objectives (Recovery Point Objective (RPO)/Recovery TimeObjective (RTO) at a system level.
NFR05	Performance & responsiveness	Support interactive analysis and API consumption without lag	Targeted p-percentile latencies defined in Quality Assurance (QA); query optimisation and caching; asynchronous jobs for long-running simulations.
NFR06	Scalability	Operate across pilots/buildings without re-architecture	Stateless services where possible; horizontal scaling; partitioning by building/site; caching of frequently requested results.
NFR07	Interoperability & standards conformance	Plug-and-play with other RETIME tools and external systems	Conform to OGC API – Features/Processes (and Tiles where applicable), OpenAPI 3.1 (OpenAPI Initiative, 2021) + JSON Schema 2020-12 for contracts, OASIS CAP v1.2 / ITU-T X.1303 for advisories; maintain schema/conformance tests and publish endpoint docs.
NFR08	Observability & logging	Diagnose issues quickly and verify behaviour	Structured logs with correlation IDs; metrics and traces (use OpenTelemetry (OpenTelemetry Project, n.d.) where feasible); central log/metric collection; no personal data in logs; time-synchronised entries.
NFR09	Auditability	Provide evidence of access/configuration changes and data lineage	Immutable audit logs of auth events and admin actions; data provenance recorded with each dataset/result; signed releases where appropriate.
NFR10	Data quality & provenance	Enable trustworthy analysis and reuse.	ISO 19115/19157 metadata; OGC/ISO 19156 for observations; schema validation on ingest; uncertainty/quality flags stored alongside values; provenance retained to support Findable, Accessible, Interoperable, Reusable (FAIR).
NFR11	Versioning & backwards compatibility	Avoid breaking dependent tools and workflows.	Semantic versioning (SemVer 2.0.0) (Preston-Werner, 2013); documented deprecation policy; migration scripts; API compatibility windows; contract tests in Continuous Integration (CI).

NFR12	Accessibility & inclusive UX for the DBT web interface	The DBT must be usable by diverse user groups across pilots and comply with EU accessibility obligations	Conform to Web Content Accessibility Guidelines (WCAG) 2.2 AA; align with EU EN 301 549 (harmonised ICT accessibility standard); use WAI-ARIA 1.2 patterns; ensure keyboard navigation, focus order, forms/labels, error prevention, and sufficient contrast.
NFR13	Internationalisation & localisation	Serve pilot languages and local conventions	UI and exports in PT/SK/ET/EN (where needed); locale-aware dates, numbers, and units; content externalised for translation.
NFR14	Maintainability & modularity	Reduce cost of change and defects	Modular services; clean interfaces; automated unit/integration tests; coding standards; up-to-date technical docs.
NFR15	Portability & deployment	Deploy consistently across environments	Containerised services; infrastructure-as-code; 12-factor configuration; support for on-prem/cloud as required by pilots.
NFR16	Backup & disaster recovery	Prevent data loss and enable timely restoration	Regular backups of databases/config; off-site/immutable copies; documented restore runbooks; periodic restore drills.
NFR17	Data retention & archiving	Align storage with governance and reuse goals	Archive in open, well-known formats (e.g., GeoPackage, J SON encoding of CityGML (CityJSON), JSON/CSV, Cloud-Optimised GeoTIFF (COG) for rasters (Cloud Optimized GeoTIFF, n.d.)); purge/anonymise on schedule; where public, assign persistent identifiers (e.g., DOI- Digital Object Identifier via trusted repositories.
NFR18	Legal & ethical compliance	Avoid legal/ethical risk and align with project commitments	Licence clarity on datasets/code; ethics approvals where required; terms of use; third-party dependency compliance tracking.
NFR19	Fail-safe behaviour	Reduce user impact when components fail	Last-known-good indicators for read-only views; clear fallback messages; queued retries; circuit-breaker/timeouts to protect dependencies.
NFR20	Testability	Make quality verifiable before pilot rollout	Dedicated test environments and datasets; API contract/performance/accessibility tests; OGC/CAP conformance checks; reproducible scenario test packs.
NFR21	BIM information management	Consistent, cross-organisation handling of building information across the project lifecycle	Use a CDE aligned to ISO 19650-1/-2 (organisation & delivery) and ISO 19650-5 (security-minded BIM): information container metadata, naming, status/revision states (e.g., WIP/Shared/Published/Archived), transmittals and responsibility roles. Maintain stable IDs linking CDE items to IFC elements; record handover/milestones.

4.3. RETIME Building Renovation Passport

As a stand-alone web application accessible from the RETIME Resilience Knowledge Hub (RKH) and Decision Support Platform (DSP), the Building Renovation Passport (BRP) will be built on a Digital Building Logbook (DBL). The tool will be leveraged by multiple end-user groups: (i) building or flat owners and (ii) tenants, (iii) building managers, (iv) utility or service providers (v) design studios, construction companies and certification bodies, (vi) financial or insurance institutions and (vii) municipalities or other public authorities. Some stakeholders will have the opportunity to simulate building renovation scenarios, the main functionality of the BRP, outlining step-by-step renovation actions over a long-term time roadmap (e.g., 20 years) and registering into a digital repository (the DBL) the new building data (e.g., performance, emissions, maintenance) once a specific mitigation or adaptation measure is implemented.

4.3.1. Key components and functionalities

The key BRP components are summarised below.

- **Server**: as a software tool, the BRP will feature a web-based server configured by ONE.[7]
- **Web application**: end-users will access the BRP through a web link, logging in with their own user-credentials and navigating through a user-friendly menu.
- **Database**: built on the DBL database, the BRP will act as a digital building data repository, where, following a BIM-based approach, each parameter is categorised under a specific object matched with three UI hierarchy levels.
- **Interoperability layer**: the BRP will be a modular web platform that will communicate with other software components through APIs, gathering inputs to simulate renovation scenarios and sharing building information to a Digital Ledger Technology (DLT) when a specific renovation action is carried out. Additionally, KRH and DSS end-users, enabled on RETIME pilot areas, will be redirected to the BRP.

The list below briefly explains which BRP functionalities could be developed in the forthcoming months, compared to those preliminary identified in deliverable D1.3.

- **Administration**: multiple building projects can be fitted into the BRP. Each project will feature a main administrator managing end-users, user groups and data access permissions.

[7] https://www.oneteam.it/en/

- **BIM data**: by uploading a BIM model, the BRP will collect and show building data, following the SECCLasS[8] classification system, about its identity, levels, units, spaces, and equipment – including energy, Operation and Maintenance (O&M) and sustainability-related information.
- **EPC**: the full building and flat scale EPCs will also be stored in the BRP. Old certificates will be kept in the database to track the asset(s) energy efficiency evolution through the years.
- **Performance**: some relevant building indicators will be grouped together (subjected to each pilot data availability) and provided to specific end-users, e.g., energy consumption, CO_2 emissions, ventilation, Indoor climate, and Air Quality (IAQ).
- **Roadmap**: the BRP heart will be the renovation scenario set-up, in which staged renovation works are simulated to consider the installation of mitigation and adaptation measures – improving the building energy performance class and reducing the building vulnerability for higher likelihood hazards respectively.
- **Doc & cert**: apart from the EPC, end-users will be permitted to store and download any other building document or certificate through the BRP (e.g., sustainability, compliances).

Metered data, concerning energy, resources or IEQ, will be ingested by the BRP and be made accessible to some key end-users, if technically feasible (due to data availability dependency). Functional and non-functional requirements of RETIME Building Renovation Passport are outlined in Tables 10 and 11, respectively.

Table 10. Functional requirements of RETIME Building Renovation Passport.

Code	Description	Justification	Technical Information
FR01	The BRP system administrator will create or delete new projects and will appoint the project's building owner(s) and administrator	All the BRP user groups must be controlled by a main administrator, who is the only one permitted to set up new projects.	The BRP front-end will allow the system administrator to carry out the management tasks.
FR02	End-users will register themselves on the BRP through the log-in interface. Otherwise, they will be invited by the system administrator	If the end-user is not invited by the BRP system administrator, then he or she will be temporarily assigned to a guest role with limited functionalities.	To complete the registration, the end-user will be associated to specific credentials. Once signed-in the BRP, the system administrator will assign him or her to a project and user group.
FR03	An end-user will log-in the BRP landing page with his or	Credentials must include a client ID and secret ID	The BRP web application-user connection will be ensured

[8] https://secclass.pt/

	her credentials (e.g., https://retime.oneteam.it/)	(associated to an e-mail address).	thanks to the HTTP over Transport Layer Security (TLS) protocol, while data will be encrypted thanks to a symmetric-key block cipher (e.g., Triple Data Encryption Standard).
FR04	The building owner(s) and administrator will assign each end-user to a group (role), while also managing each group's data permissions (write or read-only mode)	Private data must be protected: while some information can be publicly accessible (e.g., to all user groups), some other must be restricted (e.g., to owners or tenants) for privacy.	Managing data permissions means that each BRP functionality will be or will not be associated to a specific user group. The building owner(s) and administrator can edit permissions through the UI.
FR05	The following BRP features will concern the project's resources: upload, delete, download, share, edit, share, sort, permission access, check-in/out (temporary write protection), status (work in progress, shared, published, archived), versioning (historic versions), change history (who, when, what), approval workflow (from work in progress to share)	Acting as a CDE, the BRP front-end must allow end-users to store, share and manage the project's resources. Specifically, resources are a set of information such as BIM models, drawings, documents.	Resources will be fully compliant with the ISO 19650 standard.
FR06	The BRP will feature the "roadmap" functionality, where an end-user (e.g., owner or construction companies) will simulate the building long-time term renovation scenario	Through a guided procedure on the BRP UI, the end-user will set up the renovation roadmap in multiple steps – each considering the installation of one or more measures.	Mitigation and adaptation measures will be gathered by the BRP from RETIME catalogue through API.
FR07	Leveraging the same "roadmap" functionality, the end-user will also compare, edit or delete the previously simulated renovation scenarios	The end-user must have the possibility to compare which simulated roadmap is the most effective (in terms of costs, energy and CO_2 savings or target EPC class).	The process will be managed through the BRP front-end.
FR08	A section will gather all the main indicators depicting the building performance	This interface will help the end-users be aware of the building's status.	This section will feature mainly static data. If applicable, dynamic data will be displayed in charts and gathered from

			external RETIME components via API.
FR09	The end-user will store, access, update and download any building document or certificate	The BRP relevant documents must be kept in the BRP database (as a building digital data register).	These files will be uploaded manually to the BRP, but DLT-provided certificates about undertaken renovation actions will be supplied digitally (e.g., API).

Table 11. Non-functional requirements of RETIME Building Renovation Passport.

Code	Description	Justification	Technical Information
NFR01	The BRP, including the web application and APIs, will be developed using the Microsoft .NET technology	The BRP programming must leverage a robust and reliable code throughout all the platform development areas.	Microsoft NET Framework is a runtime execution environment offering system services, memory management and an extensive class library.
NFR02	The BRP hardware configuration will consist of an all-in-one or a distributed architecture	Without a physical architecture the BRP cannot be implemented.	The infrastructure's services will include a web server (Internet Information Services – Microsoft IIS) and a database (MySQL).
NFR03	Users and external applications will connect to or will communicate with the BRP, respectively	The BRP must allow users and software components to browse its functions.	The user connection will happen via browser in HTTPS. Applications will communicate with the BRP in HTTPS through API.
NFR04	The BRP will consist of an interoperable web application, developed with a multi-level architecture	The BRP must act as a CDE, where APIs (e.g., REST) also ensure data exchange with other components.	The architecture will be made up of UIs (e.g., ASP.NET, HTML 5, CSS – Bootstrap, JaveScript – jQuery), business logics (e.g., Microsoft .NET Framework, VB.NET – C#) and data access protocols (e.g., ADO.Net driver for MySQL).
NFR05	The BRP will be developed within an Information Security Management System (ISMS) framework	The method will ensure compliance with GDPR, while also preventing all risks related to information security. Data availability, confidentiality and integrity will be guaranteed as well.	This framework will follow the best practises and control objectives outlined by ISO/IEC 27001:2022.

4.4. RETIME Resilience Knowledge Hub and Decision Support Platform

Functional and non-functional requirements of RETIME Resilience Knowledge Hub and Decision Support Platform are outlined in Tables 12 and 13, respectively.

Table 12. Functional requirements of RETIME Resilience Knowledge Hub and Decision Support Platform.

Code	Description	Justification	Technical Information
FR01	Interactive dashboard	Enables users to explore building adaptation and mitigation KPIs in an intuitive way.	React SPA interface providing dashboards with KPIs like energy savings, CO_2 reductions, investment cost, return period.
FR02	Hazard Informer	Visualises hazard datasets and risk exposure.	GIS-based layer viewer using WMS/WFS; connects to static and future dynamic hazard datasets from deliverables D1.1 and D3.1.
FR03	Catalogue of mitigation and adaptation measures	Provides actionable insights for building upgrades.	Structured by building components and levels of intervention; filters by hazard type, cost, co-benefits; includes sufficient granularity (e.g., cost, co-benefits, hazard-specific filters) to support actionable decision-making.
FR04	Citizen Stories crowdsourcing	Collects user stories and lived experiences for platform enrichment	Crowdsourced tool integrated from GeoIKP; links stories to map points; supports co-design.
FR05	Policy Catalogue	Provides relevant governance context for NbS adoption	Searchable interface for policy documents; filters by level (EU, national, local); links to case studies.
FR06	User registration and profile	Enables saving, revisiting, and customising platform use	Django backend with user authentication, linked to BRP and dashboard scenarios.

Table 13. Non-Functional requirements of RETIME Resilience Knowledge Hub and Decision Support Platform.

Code	Description	Justification	Technical Information
NFR01	Interoperability	Ensures system components and external data sources work together	REST APIs and OGC-compliant geospatial services (WMS, WFS, WMS-T); integration with Copernicus, Risk Data Hub.

NFR02	Modularity	Facilitates independent deployment and scaling of components	Microservice architecture with Docker containers for backend, frontend, GeoServer.
NFR03	Performance & scalability	Supports increasing users and datasets without performance degradation	Asynchronous tasks via Celery and Redis; GeoWebCache used for efficient map rendering.
NFR04	Maintainability & Continuous Integration and Continuous Delivery/Deployment. (CI/CD)	Allows rapid updates and testing across platform versions	Automated build, test, and deployment pipelines; image versioning and rollback enabled.
NFR05	Security	Protects user data and platform integrity	Django-based authentication, HTTPS via Nginx reverse proxy; optional RBAC for future versions.
NFR06	Usability	Enables intuitive use across user types (citizens, SMEs, decision-makers)	Responsive design; scenario builder wizard in BRP; default settings and templates for ease of use.
NFR07	Data reliability and updateability	Supports integration of new hazard and building data over time	Static hazard datasets with planned update functionality; PostGIS storage, GeoServer distribution.

4.6. Quality Monitoring of RETIME solutions

The key set of criteria and related indicators for guaranteeing RETIME solutions quality assurances are shown in Table 14.

Table 14. RETIME Solution Quality Assurance.

Criterion	Indicator(s)	Monitoring Procedure
Functionality	*Functional and Non-functional Requirements Coverage:* Percentage of implemented requirements compared to the total planned. *Functional Error Rate:* Number of functional failures detected per test cycle. *Compliance with Specifications:* Degree to which the system adheres to specifications identified within task *T1.3 – Data specification requirements of adaptation solutions in three pilot areas*.	*Test Case*
User Satisfaction	*Net Promoter Score:* Measures the likelihood of a user recommending the solution. *Customer Satisfaction Score:* Direct user rating on a scale (e.g., 1 to 5). *User Retention Rate:* Percentage of users who continue using the system over time.	*Survey form*

Scalability	*Response Time Under Load:* Measures the impact of increasing concurrent users. *Resource Usage Under Load:* Central Processing Unit (CPU), memory, and network usage at different load levels. *Maximum Concurrent Users Supported:* Highest number of users the system can handle without significant degradation.	*Script test*
Usability	*Average Task Completion Time:* Time users take to complete common tasks. *User Error Rate:* Number of errors made during system use.	*Automatic test*
Reliability	*Mean Time Between Failure:* Average time between system failures. *Failure Rate Over Time:* Number of failures within a specific time frame. *System Availability:* Percentage of time the system is operational.	*Test software*
Performance Speed	*Average Response Time:* Average time the system takes to respond to a request. *Page/Screen Load Time:* Time required to display an interface to the user. *Processing Latency:* Time between input and output of an operation.	*Test software*
Adaptability	*Time to Implement Changes:* Time needed to adapt the system to new requirements. *Compatibility with Different Environments:* Number of supported operating systems. *Ease of Integration with Other Systems:* Effort required to integrate with external APIs or services.	*Reported by: Software architect, developer, and Quality Assurance engineer.*
Acceptance by user testing	*Overall Efficiency Index:* Combination of response time, resource usage, and throughput. *Process Success Rate:* Percentage of operations completed successfully. *Benchmarking Against Similar Systems:* Performance comparison with competitors or market standards.	*Reported by: UX Designer, System Analyst, and Quality Assurance Engineer (Or similar roles)*
Accuracy	*Predictive Models Coefficient of Determination (R^2):* A comparison of predicted parameters with actual observed values. *Forecast Data Accuracy:* The accuracy of external data feeds (e.g., weather forecasts) used as inputs for the models will be evaluated by comparing forecasted values against real-world data measured by on-site sensors (task T4.3).	*Test software*

5. Advanced 2D/3D Geospatial and Semantic Integration Framework

This section consolidates the data-model, integration, and semantic concepts that underpin the RETIME platform architecture. It builds on the requirements established in deliverable D1.3 and refines them through the recent technical discussions and workshops amongst project partners.
The framework links 3D geospatial information, BIM data, and hazard or environmental layers across the three pilot sites. It ensures that data collected or produced in RETIME are interoperable, quality-controlled, and semantically coherent for analysis, simulation, and decision support within the Digital Building Twin (DBT), Building Renovation Passport (BRP), and Resilience Knowledge Hub (RKH).

The subsections below describe:

- the **spatio-temporal and quality management approach** for 2D/3D data (*section 5.1*);
- the **linked-data-driven BIM–GIS integration workflow** (*section 5.2*); and
- the **semantic and ontological alignment** mechanisms that connect datasets for resilience modelling (*section 5.3*).

5.1. Spatio-temporal and quality management in 2D/3D geospatial models

To support multi-hazard and building-scale analyses across the RETIME pilots, the geospatial database integrates **3D geometries with temporal attributes**. This allows the evolution of building states, hazard layers, and sensor observations to be recorded and compared between baseline, event, and post-event conditions. Temporal information is attached through **timestamp fields and metadata elements** within **PostGIS 3D / 3DCityDB**, providing sufficient traceability without adding unnecessary system complexity. If higher-frequency monitoring or replay functionality becomes relevant in later stages, **TimescaleDB** may be explored as a complementary option for managing time-series data.
Data quality is tracked at the **metadata level**, following **ISO 19115** and **ISO 19157** principles. Where upstream sources such as Copernicus EMS, national meteorological services, or EU hazard hubs include accuracy or confidence indicators, these are preserved and linked to the corresponding datasets. When such information is missing, **qualitative quality tags** (e.g., *authoritative*, *modelled*, *indicative*) communicate the relative trust level of each layer. This pragmatic approach ensures transparent quality communication without the need for probabilistic uncertainty propagation.
All semantic and geometric data are stored and managed in **3DCityDB** and published through **OGC API – Features**, **OGC API – Tiles**, and **OGC API – Processes**. This guarantees standards-based

access to multi-scale spatial data and supports incremental updates and interoperability across the DBT, BRP, and RKH.

5.2. Linked data-driven BIM–GIS integration workflow

The RETIME BIM–GIS integration approach, refined during the September 2025 technical workshop with THK, focuses on a **linked-data-based framework** that connects 3D city and building models without requiring heavy one-to-one format conversions. The architecture couples **3DCityDB** (for urban-scale semantic 3D data) and **BIMserver** (for IFC-based building models) with a **graph database layer**, such as **Apache Fuseki** or **OnSpatial**, that exposes data as RDF triples. Spatial and semantic relationships between datasets are represented through **GeoSPARQL** and, where relevant, complementary ontologies such as **IfcOWL** and **OntoCityGML**.
The workflow comprises four main steps:

1. **Ingestion and validation** – IFC and 3DCityDB datasets are validated and uploaded to their respective repositories.
2. **RDF conversion and linking** – Persistent identifiers (building IDs, element GUIDs, spatial URIs) are expressed as RDF resources. Links between building elements, sensors, and hazard layers are defined via GeoSPARQL predicates such as *geo:sfWithin* or *geo:hasGeometry*.
3. **Query and federation** – Applications query the federated knowledge graph through SPARQL endpoints, retrieving integrated information without duplicating or converting complete models.
4. **Integration with RETIME tools** – Query results feed directly into the DBT, BRP, and RKH via OGC APIs and lightweight REST interfaces.

This linked-data strategy ensures semantic transparency, modular scalability, and compatibility with open web standards. It aligns with the **European Interoperability Framework (EIF)** and the FAIR data principles, allowing RETIME to integrate BIM, GIS, and sensor data efficiently.

While **CityGML Application Domain Extensions (ADEs)** remain a valuable mechanism for semantic enrichment, RETIME treats them as **optional, complementary avenues** for future exploration, particularly where stable and widely supported ADEs (e.g., Energy ADE v1.0) could enhance thematic consistency.

5.3. Semantic extensions and linked ontologies for resilience modelling

Building on the linked-data foundation, RETIME applies a **modular semantic integration strategy** that combines RDF-based ontologies with selected, mature CityGML ADE concepts. Linked data provides a flexible mechanism to connect heterogeneous datasets, BIM objects, sensor observations, hazard layers, and energy indicators, through URIs and GeoSPARQL relations. This allows cross-domain reasoning and spatial querying without enforcing strict schema conversions.
Where existing ADEs add proven value, RETIME may reference them conceptually, notably the **CityGML Energy ADE v1.0** for energy-related attributes and, where relevant, elements from the **Emergency Response ADE (OGC draft 2022)** to describe evacuation routes and safety facilities. Rather than fully implementing these ADEs, RETIME focuses on **semantic alignment through ontologies** such as **IfcOWL**, **OntoCityGML**, and RETIME-specific vocabularies exposed via the graph database. This approach enables the project to integrate RDF-based and relational data, maintain clear provenance, and remain compatible with evolving OGC standards.
At pilot level, semantic links between the DBT, BRP, and RKH datasets are maintained within RDF graphs and accessible through GeoSPARQL queries. Where deeper thematic detail is required, e.g., for representing energy systems or safety zones, attributes may draw conceptually on Energy ADE structures or equivalent ontological terms. This combined **linked data + selective ADE** approach provides RETIME with a realistic, extensible path toward full interoperability, ensuring scientific robustness while keeping the implementation lightweight and maintainable within the existing 3DCityDB–BIMserver–Fuseki infrastructure.

5.4. Summary and outlook

The integrated 2D/3D geospatial and semantic framework described in this section establishes the foundation for RETIME's digital architecture. By combining 3DCityDB, BIMserver, and linked-data technologies such as Fuseki and GeoSPARQL, the project ensures that spatial, structural, and hazard information interoperate seamlessly across scales and pilot sites.
This framework enables the Digital Building Twin, Building Renovation Passport, and Resilience Knowledge Hub to share consistent, quality-controlled data, supporting modelling, simulation, and decision-making activities in subsequent work packages.
It also provides a scalable basis for future extensions (such as integration of additional pilots, semantic enrichment through mature ADEs, or the connection of RETIME outputs to European data-space initiatives) ensuring technical continuity toward deliverables *D1.6 – Analysis of economic and social feasibility of the adaptation strategy and associated business model Part 2* of the RETIME platform and *D3.7 – A set of alerting strategies (impact-based triggers) for automatic monitoring and management systems Part 3*.

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