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Contact: projects@libelium.com

D4.1 SENSE Scenarios

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Lead Partner	LIBE	**Lead Author**	Juan Francisco Inglés
Contributors		**Reviewers**	Katharina Volpp (KIELM) Arnauld Verstraete (OASC)

Document Information

List of Contributors	
Name	Partner
Juan Francisco Inglés	Libelium Lab

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Table of Contents

List of Figures

Executive Summary

This deliverable (D4.1) is part of the SENSE project, funded by the European Commission under the Digital Europe Programme (DIGITAL). It defines the use cases selected for the pilot cities of Cartagena and Kiel and describes the foundational models and enabling technologies that will be deployed to implement them, providing the basis for subsequent design, integration, and validation activities across the pilots.

D4.1 documents four scenarios, covering both operational/decision-support needs and public-facing engagement experiences:

- **Cartagena – Smart Urban Mobility**, focused on real-time mobility awareness, routing support, and city management workflows (e.g., commuter optimisation, visitor routing, event preparation, and air-quality communication).
- **Cartagena – Public Space, Environment and Quality of Life**, extending mobility foundations with neighbourhood profiling, quality-of-life indicators, and hotspot identification to support planning and equity-oriented analysis, while also enabling a simplified public view.
- **Kiel – Hidden World**, a cultural and heritage scenario built around an interactive 3D “cultural twin” and guided tours that reveal historical layers and narratives embedded in the contemporary city.
- **Kiel – SEALEVEL**, extending the SEALEVEL exhibition into a persistent digital experience, connecting curated “stations” and narratives with a land–sea 3D twin and marine/environmental indicators for ocean literacy and public communication.

Across all scenarios, the deliverable adopts a common technical framing based on three core components connected through a simple interaction chain: (A) SENSE User Application, (B) Scenario Service Layer, and (C) Data & Knowledge Layer connected to the SENSE Data Space. This decomposition supports reuse across pilots (shared frontend and governed data access) while allowing each scenario to implement its own logic, content orchestration, and interaction behaviour in dedicated services.

To make the scenarios actionable for implementation, D4.1 provides representative user journeys and corresponding interaction flows (sequence diagrams) that describe the expected end-to-end behaviour from user action to data retrieval and visual rendering. In addition, it outlines key underlying models and datasets needed for each scenario, including 3D representations, thematic/indicator layers, and narrative/content models (notably for the Kiel SEALEVEL exhibition integration).

Finally, the deliverable proposes an incremental development pathway organised into four phases, ranging from early demos and architecture/tool experimentation, to professional-grade scenario capabilities, public-facing adaptations, and operational improvements.

The document also includes illustrative mock-ups demonstrating how the SENSE interface could be experienced in practice for Cartagena and Kiel.

1. Introduction

1.1 Purpose of the Document

This deliverable (D4.1) defines and documents the SENSE pilot scenarios to be implemented in the two frontrunner cities, Cartagena (ES) and Kiel (DE). It describes the selected use cases and the foundational models and enabling technologies that will be used to deliver them, providing a shared reference point for subsequent design, integration, and validation activities across the pilots.

More specifically, the document aims to:

- **Describe the scenario context and rationale**, including the relevant urban/policy setting and the expected impacts for each use case.
- **Identify stakeholders and user roles** (e.g., municipal professionals, operators, citizens/visitors, and content curators) and relate them to realistic tasks and needs.
- **Define the functional scope** of each scenario as a target solution (key features, interaction patterns, and the role of the 3D twin and thematic layers).
- **Provide representative user journeys and interaction flows** that guide requirements and prioritisation and help validate end-to-end behaviour.
- **Outline the underlying models and data sources** required to support the scenario logic and visualisations, and how these connect to the SENSE Data Space and scenario services.
- **Set an incremental development plan** describing how prototypes will evolve into professional-grade pilots and later public-facing adaptations.

In this way, D4.1 acts as a scenario-level blueprint: it aligns partners on "what will be built and why", and supports the broader SENSE objective of delivering a CitiVerse orchestrator with concrete use case implementations and reusable patterns.

1.2 Structure of the Document

This deliverable is structured as follows:

- **Section 1** introduces the document, including its purpose and structure.
- **Section 2** describes the Cartagena - Smart Urban Mobility scenario, covering context, objectives, stakeholders, functional description, user journeys, and technical foundations.
- **Section 3** describes the Cartagena - Public Space, Environment and Quality of Life scenario, following the same scenario template (context → objectives → roles → functionality → journeys → technical foundations).
- **Section 4** describes the Kiel - Hidden World scenario, including the cultural context, functional concept and user journeys.

- **Section 5** describes the Kiel - SEALEVEL scenario, detailing how the SEALEVEL exhibition is extended into a persistent digital experience within the SENSE twin and supported by relevant data and models.
- **Section 6** presents the development plan, outlining the phased approach from first demos and technical validation to professional pilots, public adaptations, and operational hardening.
- **Section 7** concludes the deliverable and summarises the main outcomes and next steps implied by the scenario definitions.

2. Cartagena - Smart Urban Mobility

2.1 Scenario overview

In Cartagena, the *Smart Urban Mobility* scenario can be illustrated through the daily routine of María, a 32-year-old nurse. Every morning before leaving home, she opens the SENSE city twin on her phone and sees an intuitive 3D view of the city displaying live traffic conditions, expected travel times, real-time bus and tram arrivals, the low-emission zone clearly highlighted around the historic centre, and colour-coded air quality indicators along the main corridors she might use. Her usual car commute appears in red: the corridor is congested and the air quality panel warns of "poor" conditions for the next hour. The system automatically proposes an alternative, combining a short walk, a tram connection and a bus. This route is shown in green, with a brief explanation indicating that it has a similar travel time but significantly lower emissions and "moderate" air quality along most of the way. With a single tap, María inspects the multimodal route in 3D, identifying where she will park or leave her bike, where she will change from tram to bus, and how crowded the main stops typically are at that time of day. Confident that she will arrive on time while avoiding the worst congestion, she chooses the cleaner option. The app confirms the expected arrival time at the hospital and displays a small "impact" summary showing the emissions avoided and the minutes saved compared to her usual car route.

Later that week, a local festival takes place in the city centre. In the evening, María again consults the SENSE twin, this time activating an "event" view in which temporary street closures and pedestrianised areas are clearly displayed, detours and recommended access routes are highlighted, and additional public transport services as well as extended operating hours appear directly on the 3D network. She quickly realises that her normal bus stop will be out of service during the festival, but that another stop two blocks away will offer reinforced service. She shares a link to the same 3D view with her friends so they can adjust their routes and meeting point accordingly. For María, the city suddenly feels easier to understand: it is clear where she can drive, when it makes sense to leave the car at home, and how the system is adapting to events.

This fictional story illustrates the intended role of the *Smart Urban Mobility* scenario in Cartagena. Through SENSE, the city will offer an interactive 3D digital twin that consolidates real-time information relevant to mobility, environmental quality and regulatory enforcement in one coherent environment. Citizens and visitors will be able to explore the city virtually, plan multimodal routes, consult public transport itineraries and immediately see where restrictions such as low-emission zones, pedestrian areas or temporary closures apply at any given moment. At the same time, city managers and operators will gain a shared operational picture of mobility and environmental conditions, allowing them to monitor patterns and key indicators in real time, anticipate pressure points such as rush-hour build-ups, cruise ship arrivals or large events, and prepare targeted measures in advance. The same platform supports direct, visual communication with the public, making guidance accessible and traceable to underlying data. The use case is therefore not limited to a static map or informational dashboard; it is conceived as an operational tool embedded in everyday mobility management and public communication.

The expected impact is twofold: to improve understanding of and compliance with low-emission and traffic regulations by making them visible, contextualised and easy to interpret; and to promote a modal shift towards cleaner and more efficient transport options by making sustainable routes more discoverable, comparable and practically usable in citizens' daily routines.

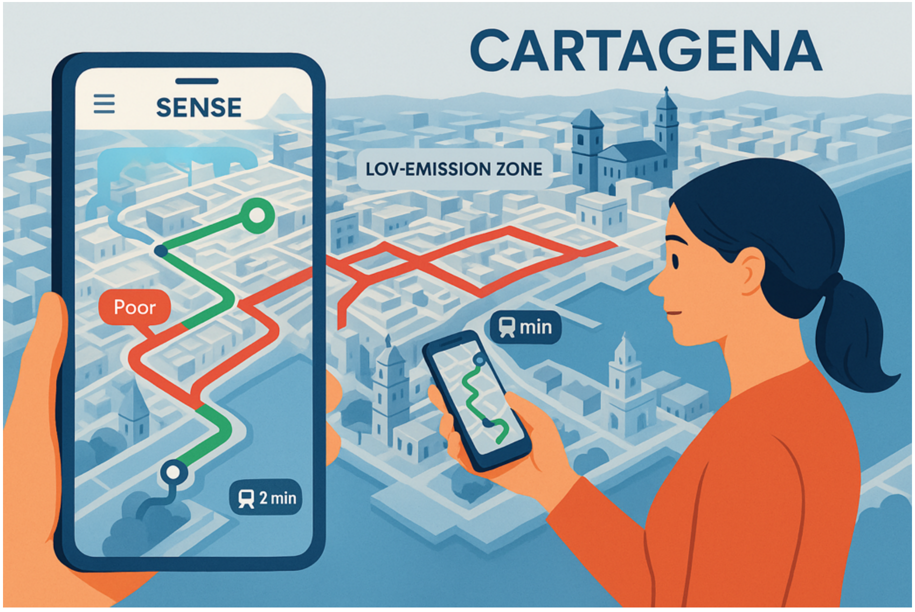

Figure 1. Cartagena - Smart Urban Mobility

2.2 Urban and policy context in Cartagena

Cartagena is a medium-sized coastal city in the Region of Murcia, in south-eastern Spain, with a population of around 215,000 inhabitants in the municipality and a wider metropolitan area that attracts many additional commuters and visitors. The city combines a major commercial and naval port, university and technology campuses, residential neighbourhoods and a highly valued historic centre characterised by narrow streets, heritage buildings and an active cultural life. Its Mediterranean climate, coastal setting and touristic appeal generate strong seasonal variations in population and mobility, while the presence of port, industrial and logistics activities adds further pressure on the transport network and on local environmental conditions.

Over the last years Cartagena has invested significantly in digital transformation and smart city initiatives. The city operates a FIWARE-based data platform that integrates information from multiple domains, including air quality indices, weather conditions, parking occupancy, people-counting systems and traffic data, as well as broader environmental datasets (temperature, humidity, noise, public affluence and data from green zones). The platform is designed for real-time data collection, storage and analysis, and is complemented by an open data portal that exposes selected datasets for public reuse. Interoperability is a core design principle, with the platform adhering to common standards and protocols (such as MIM1, MIM2 and MIM6) and aligning with EU data space requirements on privacy, security and data governance. This provides a solid technical and policy foundation on which SENSE can build the *Smart Urban Mobility* scenario.

Against this backdrop, Cartagena faces a set of mobility and environmental challenges that the scenario aims to address:

- **Congestion and unreliable travel times** on main access routes and within the inner city, especially at peak hours and during events.
- **Local air pollution** (e.g. NO_2, particulate matter) influenced by road traffic, port activities and industrial sources.
- **Need for a clear and understandable ZBE/LEZ scheme**, so that both residents and visitors know where and when restrictions apply, and on what basis.
- **Need for a more comprehensive and unified representation of mobility and environmental data,** so that users can easily access information from different sources and obtain a holistic, up-to-date view of conditions and available options.
- **Need for effective two-way communication channels**, where citizens can easily provide feedback, report issues and share their mobility experiences, and where the city can respond and incorporate this input into planning and operational decisions.

2.3 Objectives and expected impacts

The *Smart Urban Mobility* scenario pursues the following overarching objective:

> To support safer, cleaner and more efficient urban mobility in Cartagena by providing an accessible, real-time 3D environment where citizens and city managers can understand, anticipate and influence mobility and environmental conditions.

This overarching objective is articulated into the following specific objectives:

O1. Visibility and transparency of rules and conditions

- Make low-emission zones, traffic regulations, parking rules and other mobility constraints clearly visible and understandable within a single 3D environment.
- Provide real-time views of traffic density, congestion and air quality at street level.

O2. Support for informed mobility choices

- Enable citizens and visitors to compare route options in terms of travel time, reliability, environmental impact, comfort and accessibility, and to base their travel decisions on this information.
- Promote multimodal journeys combining public transport, walking, cycling and shared mobility.

O3. Operational support for city managers

- Offer mobility and environment teams a unified situational picture that allows them to monitor current conditions, detect incidents and anticipate problems such as recurrent bottlenecks or event-related pressures.

- Facilitate coordination between departments (mobility, environment, police, emergency services and others) during planned events and unplanned incidents by providing a common, data-driven visual reference.

O4. Evidence-based planning and evaluation

- Provide aggregated indicators and spatial analytics to evaluate the effects of measures such as LEZ deployment, new bus lanes, traffic-calming interventions or changes in signal plans.
- Support the iterative improvement of the Sustainable Urban Mobility Plan (SUMP) and climate action plans by making it easier to test, visualise and communicate different policy scenarios.

O5. Citizen engagement and behaviour change

- Use gamification, storytelling and narrative elements to encourage more sustainable mobility choices and recurrent use of the platform.
- Foster a sense of shared responsibility for air quality, climate and street safety by making the links between individual choices, collective patterns and environmental outcomes more visible.

The expected impacts of the scenario can be grouped into two broad categories:

Short-term operational impacts

- Improved incident detection and response, for example by more quickly identifying bottlenecks, diversions, abnormal congestion or emerging hot spots.
- Reduced information asymmetry between the city and citizens, leading to fewer misunderstandings about rules, restrictions and temporary measures.

Medium- to long-term behavioural and policy impacts

- Increased use of public transport and active modes for everyday journeys, supported by better information, improved perceived convenience and more attractive multimodal options.
- Increased compliance with LEZ and traffic regulations, as rules become more visible, understandable and easier to follow in practice.
- Stronger political and public backing for mobility and environmental measures, thanks to clear, shared visual evidence of existing problems and the benefits of implemented solutions.

2.4 Stakeholders, user groups and roles

The scenario is designed around several primary user groups (based on the engagement mapping in D6.1), each with distinct needs and usage patterns:

- **Citizens and commuter**

  Daily users who require reliable information on travel times, congestion, parking availability and applicable restrictions. They typically interact with the platform via mobile devices or standard web browsers, in short sessions focused on pre-trip planning or quickly checking current conditions.

- **Visitors and tourists**

  Occasional users with limited familiarity with local rules, geography and public transport options. They mainly need simple, intuitive visual cues showing where they can drive or park, how to reach key attractions, and which public transport lines or interchanges connect the places they want to visit.

- **Municipal mobility and traffic departments**

  Professional users who operate the platform in a control-room or office environment, often on large screens or dashboards. They are responsible for traffic management, signal plans, event planning, parking policies and coordination with the police, and use the tool to obtain a unified operational picture.

- **Environmental and climate departments**

  Users focusing on air quality, emissions and noise indicators, including long-term exposure patterns and regulatory compliance. They rely on the platform to correlate traffic and mobility measures with environmental impacts and to support reporting and communication.

- **Public transport operators and mobility service providers**

  Bus and regional rail operators, shared mobility providers and taxi dispatch services. They use aggregated information on congestion, passenger flows and service reliability to adjust planning, optimise operations and communicate disruptions or changes to users.

- **Security forces and emergency services**

  Police, emergency services and civil protection units that use the platform during incidents, evacuations or large events. They require clear visualisations of closures, recommended routes, priority corridors and safe gathering points to support decision-making under time pressure.

- **Technical teams and researchers**

  City IT departments, local SMEs, universities and research groups working with SENSE data, models and services. They use the scenario as a testbed to integrate new data sources, develop and validate analytics and optimisation algorithms, and explore innovative human–digital interfaces for urban mobility.

For each of these user groups, specific roles and permissions are defined:

- **Public users**

  Anonymous or lightly authenticated users with access to the main 3D visualisation, route planning functions and a core set of indicators (e.g. traffic, air quality, basic service information).

- **Professional users (city staff and operators)**

  Authenticated users from municipal departments and service operators with access to extended functionality, including operational dashboards, historical data exploration, configuration of alerts, and the ability to define and manage scenario views (e.g. event configurations).

- **Administrators**

  Users responsible for managing accounts and roles, defining and adjusting access rights, configuring available data layers, and maintaining integrations with external systems and services.

2.5 Functional description of the use case

2.5.1 Interactive 3D digital twin

The core of the scenario can be conceived as an interactive 3D digital twin of Cartagena that acts as the main entry point for both citizens and professionals. Functionally, the 3D twin could include the following capabilities:

- **City coverage and performance:** it could cover the relevant urban area with sufficient detail to distinguish buildings, the street network, squares, parks, major port facilities and key landmarks, while maintaining good performance on standard devices.
- **Navigation and orientation:** it could provide intuitive navigation (pan, rotate and zoom), potentially complemented by “fly-through” or follow-the-route modes, and a simple minimap/overview for orientation and quick repositioning.
- **Time control:** it could include a time control allowing users to switch between the current situation, historical replay and, where available, short-term predictions, so they can see how conditions change during the day, during specific events or under different scenario configurations.

From a functional perspective, the 3D twin could support at least the following interactions:

- **Layer switching:** users could toggle thematic layers on and off (e.g. LEZ boundaries, air quality, road traffic, pedestrian flows, public transport routes) to focus on the information most relevant to their task.
- **Contextual information on click/tap:** selecting a street segment, junction, parking area or point of interest could open an information panel showing key attributes such as current speed, typical travel time, applicable restrictions, emission levels or service status.

- **Bookmarks and perspectives:** preconfigured views (e.g. historic centre, main access corridors, port access, major interchanges) could be accessed with a single click, supporting rapid navigation for both citizens and operators.
- **Search and geocoding:** users could search for addresses or POIs (schools, hospitals, stations, tourist attractions, public facilities) and automatically centre the view on the selected location.

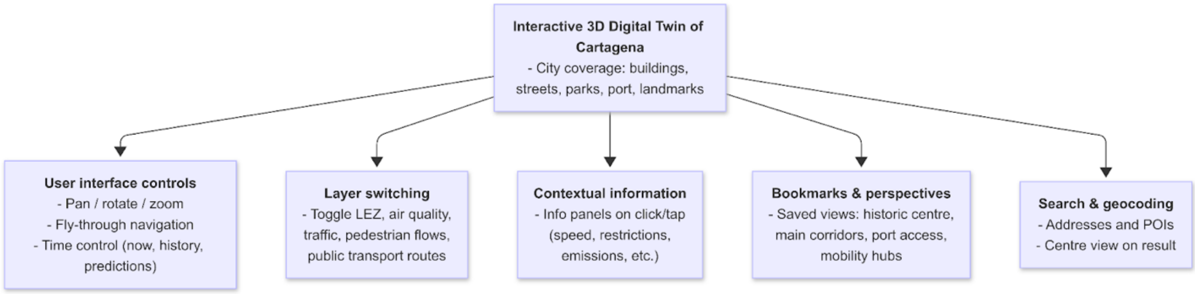

Figure 2. Basic features of the 3D Digital Twin of Cartagena

2.5.2 Real-time layers

The scenario will bring together a set of core data layers, some predominantly static and others dynamic or real-time. These could include:

Low-emission and restricted traffic zones

- **Static geometry** of LEZ/ZBE boundaries, pedestrian-only streets and restricted access areas (e.g. residents-only streets, time-limited loading zones).
- **Associated rules**, such as time windows, vehicle categories allowed, emission standards and permit requirements.
- **Visual representation** through coloured overlays on the 3D map, supplemented by clear legends and tooltips that explain the meaning of each colour and the applicable rule.

Road traffic conditions

- **Real-time or near-real-time indicators** for each relevant street segment, including level of service, average speed, travel time and a congestion index.
- **Data sources** such as fixed sensors (loop detectors, traffic cameras), floating car data or other city traffic data feeds.
- **Visual representation** via colour-coded segments (e.g. green–yellow–red) and, where appropriate, line thickness or glow effects to indicate intensity or volume.

Pedestrian flows and crowded spaces

- **Estimates of pedestrian densities** in key areas such as shopping streets, the waterfront, transport hubs and event venues.

- **Data sources** may include counting systems, Wi-Fi/Bluetooth probes or aggregated mobile positioning data, always managed under strict privacy-preserving conditions.
- **Visual representation** via heatmaps or animated dots overlaying squares, sidewalks and other public spaces, making crowded or calm areas immediately visible.

Air quality and environmental indicators

- **Point measurements and spatial interpolations** of relevant pollutants (e.g. NO_2, PM_{10}, $PM_{2.5}$) and, where available, noise levels and other environmental indicators.
- **Temporal dimension**, providing current values, recent history (e.g. last 24 hours) and daily or hourly averages to support interpretation of trends.
- **Visual representation** using colour gradients, vertical extrusions (e.g. “pollution columns”) and contextual pop-up panels explaining levels, thresholds and health implications in accessible language.

Public transport and mobility services

- **Static layers** describing lines, stops, stations and timetables for buses, trams and other relevant modes.
- **Dynamic layers** showing live vehicle positions, delays, disruptions, planned detours and reinforcement services (e.g. additional buses during events).
- **Visual representation** through moving icons for buses and trams, colour-coding of punctuality and clear highlighting of recommended interchanges and key nodes.

2.5.3 Citizen/visitor functionalities

For citizens and visitors, the platform behaves as a 3D mobility assistant that supports everyday decision-making. The following are funcitonalities that could be considered in this scenario.

Route planning

Users specify origin and destination via address search, map click or “current location”. They can express preferences such as fastest, most reliable, least emissions, least walking or “avoid LEZ”. The system returns one or more route alternatives, each visualised as a highlighted path in 3D, with associated information including estimated travel time, distance, cost (if available), emissions estimate and expected comfort (e.g. a qualitative indication of crowding).

LEZ-aware routing

Users can indicate their vehicle type and emission class so that routing respects LEZ/ZBE rules. If a proposed route would enter a restricted zone in a non-compliant way, the interface explicitly warns the user, explains the relevant rule and offers alternative routes that respect the restrictions.

Contextual explanations and “why this route?”

For each recommended route, the system provides a short textual explanation, such as “Best trade-off between time and emissions”, “Avoids congested corridor X” or “Uses bus line Y with frequent service”. Users can explore the route step by step, viewing expected conditions along the path (e.g. typical congestion points, segments with higher pollution, interchanges and walking segments).

Exploration and learning

Users can explore the 3D twin without necessarily planning a specific trip, for example to check “What is the air quality in my neighbourhood?” or “Where are the busiest streets during rush hour?”. A time slider allows comparison between different times of day or days of the week, helping users understand temporal patterns and how their own choices interact with peak periods.

Two-way communication and feedback

The platform also acts as an interaction channel between citizens and the city. Users can provide quick feedback on their travel experience (e.g. rating a route, indicating whether suggested options were useful), report issues encountered on the network (such as obstacles on sidewalks, malfunctioning traffic lights, missing or confusing signage), or comment on specific locations by placing geo-referenced notes on the map. Simple forms and predefined categories make reporting fast and accessible from mobile devices. Where appropriate, users can opt in to receive updates on how their reports have been handled (e.g. “issue acknowledged”, “maintenance scheduled”, “measure implemented”). Aggregated feedback is made available to municipal teams as an input for planning and operational decisions, closing the loop between observed conditions, citizen experience and policy response.

Accessibility features

Information on restrictions and conditions is presented using simple, consistent icons and concise text. The interface offers options for high-contrast modes, larger fonts and simplified views (with reduced layer complexity) to support users with different accessibility needs and device capabilities.

2.5.4 Municipal monitoring and decision-support features

For the municipality and other professional users, the platform could provide a “control-room” view that supports monitoring, coordination and evaluation.

Operational dashboards

Key performance indicators (e.g. congestion index by corridor, average travel times, bus punctuality, air quality indicators) are displayed in dashboard panels that are linked to the 3D view. Users can define configurable thresholds and alerts (for example, triggering a notification when congestion exceeds a given level on a critical corridor, or when pollution approaches regulatory limits in sensitive areas).

Scenario views for planned events

The system allows the predefinition of "event layers" for festivals, sports events, road works or demonstrations, including street closures, recommended routes, temporary parking areas and changes in public transport services. Operators can switch between "normal day" and "event day" configurations to check readiness, validate planned measures and communicate them consistently to the public and other stakeholders.

Historical analysis and evaluation

Professional users can access historical data for selected periods, enabling before/after comparisons (e.g. conditions before and after the introduction of an LEZ or new bus lane). The platform provides tools to generate maps, time series and summary charts that can be exported or embedded in reports, presentations and decision documents.

Collaboration and annotation

City staff can place annotations directly on the 3D map (e.g. "candidate location for new crossing", "recurrent illegal parking area", "potential PT interchange improvement") and attach comments, tags or links to external documents. These annotations can be shared across departments, forming a spatially organised knowledge layer that feeds into planning processes, internal coordination and future scenario refinement.

2.6 User journeys

The user journeys described in this section represent the desired target behaviour of the *Smart Urban Mobility* scenario in Cartagena once the solution is fully matured and integrated into city operations. They are therefore intentionally ambitious and include functionalities that may extend beyond what can be implemented within the timeframe and resources of the SENSE project.

Within the project, these narratives serve as a design compass: they guide requirements, prioritisation and technical choices. Therefore, the user stories should be read as aspirational target scenarios, not as a strict list of features guaranteed at project end.

2.6.1 Routing applications for citizens or visitors

Routing functionalities in SENSE are primarily aimed at helping citizens and visitors navigate Cartagena in a way that is efficient, environmentally responsible and compliant with local regulations. The following user journeys illustrate typical interaction patterns.

Daily commuter optimising the route

A citizen living in a residential neighbourhood and working near the city centre opens the SENSE mobility view on their phone before leaving home. In the search bar, they enter their home and work addresses, and the system immediately proposes a set of alternatives, for example a fastest car route and a multimodal route that combines a park-and-ride facility with a bus line. On the 3D map, the car route is highlighted in red, crossing a corridor with heavy congestion and poor air quality; the legend also indicates that part of the route passes through a low-emission zone where the vehicle is technically allowed but not particularly clean. The multimodal route appears in green and is annotated as slightly longer in time but substantially better in terms of emissions and reliability, while also avoiding the main congestion hot spots. A short explanation panel compares both options side by side in simple terms. The commuter decides to follow the recommended multimodal route and saves it as a favourite for future use. After completing the trip, they use the built-in feedback function to rate the route and briefly report, for instance, that one of the bus stops was more crowded than indicated, providing useful input for adjusting parameters and improving future guidance.

Visitor avoiding restricted areas and discovering public transport

A tourist arrives in Cartagena by car and wants to reach a hotel in the historic centre. On a hotel flyer and on the municipal tourism website there is a QR code linking directly to the SENSE mobility map. After scanning it, the visitor searches for the hotel name and the application centres the 3D view on the historic district, clearly showing the surrounding low-emission zone. From the main access road, the system proposes several options: driving as close as possible to the edge of the LEZ, parking in a peripheral car park and continuing on foot, or using a shuttle bus service. Because the visitor's car is older and does not meet the most stringent emission standards, SENSE flags that direct access to the central streets may be restricted and highlights the peripheral parking plus shuttle option as the most suitable and compliant route. The visitor can visualise the walking segment and bus route in 3D, including estimated travel times, stop locations and service frequency, which makes the multimodal option more understandable and less intimidating. After the trip, the visitor uses a simple feedback form in the app to confirm, for example, that the signage to the parking area was clear, providing a quick qualitative check that can be used by the city to refine information and signage.

2.6.2 Traffic planning and operations for city managers

Beyond individual routing, SENSE is intended to support municipal teams in planning, operating and communicating mobility and environmental measures at city scale. The following user journeys illustrate how traffic managers and environmental officers could use the platform for event preparation, day-to-day operations and policy communication.

Mobility manager preparing for a large event

The city plans a large cultural event in the historic centre that is expected to attract many visitors. Several weeks in advance, the mobility team creates a dedicated "event configuration": they define temporary street closures, extended pedestrian areas, priority corridors for public transport and emergency vehicles, additional bus services and recommended parking locations. Using the 3D twin, they simulate expected flows based on historical data from similar events, visually inspecting potential bottlenecks around key junctions and car parks. Once satisfied, they save this configuration as a named "event scenario" that can be activated with a single click.

On the day of the event, the control room displays the SENSE twin with the event scenario active and real-time data streaming in. Operators monitor congestion around access corridors and parking facilities and watch the evolution of pedestrian densities near the main venues. If a particular access route becomes saturated, they coordinate with communication teams to update public guidance, pushing alternative routes and parking suggestions through the city's web channels, social media and, where possible, directly through the SENSE interface.

Environment officer explaining air quality

After several days with unusually high pollution levels, the environment department needs to explain the situation and the response measures to citizens and decision-makers. Staff open the SENSE twin and select the relevant period on the time slider. The map replays the evolution of traffic volumes and air quality indicators, allowing them to compare the high-pollution episodes with more typical days. They identify specific corridors and time windows where the combination of heavy traffic and unfavourable meteorological conditions led to peaks in NO_2 and PM.

Using SENSE, they capture a series of illustrative views and short animations that overlay traffic patterns with pollution "plumes" over sensitive locations such as schools or health centres. These materials are used in public presentations, on the municipal website and in social media posts. During public meetings, the team uses the interactive "what-if" visualisation capabilities to show how different traffic management measures—such as restricting certain movements, strengthening public transport on key corridors or adjusting signal timings—could reduce exposure in targeted areas, helping citizens understand both the problems and the rationale for proposed interventions.

2.7 Technical foundations

This section outlines technical aspects that may be considered for implementing the scenario. Some elements are generic and applicable across SENSE scenarios, while others may be adapted or extended to address scenario-specific requirements.

2.7.1 Core components

Conceptually, the SENSE scenario can be understood as a tailored configuration built on three core components, connected through a simple interaction and data chain (A ↔ B ↔ C).

A. SENSE User Application (Frontend) is the main entry point for both public and professional users. This layer hosts the user experience: exploring the 3D twin, enabling thematic layers, selecting points of interest, consulting indicators, and interacting with content (e.g. information panels, multimedia assets, or lightweight visualisations). Depending on the scenario, it may also include authentication and role-based views, so that different user groups are offered different features and levels of detail.

B. Scenario Service Layer (Scenario Backend) represents the "scenario logic". It acts as an intermediary that translates user actions into concrete services: it composes views and content, applies scenario-specific rules, manages access rights, and orchestrates access to data and results. Where scenarios require processing or computation (for example, indicator aggregation, advanced filtered queries, or the generation of scenario configurations), this layer coordinates those operations and ensures consistent behaviour aligned with the scenario objectives.

C. Data & Knowledge Layer (connected to the SENSE Data Space) groups persistence and governed access to information assets. It includes base datasets, metadata and catalogues, time series, multimedia resources, and pre-processed outputs or versioned thematic layers. The Data Space provides the framework to publish, discover and reuse data in a controlled manner, ensuring traceability, consistency and appropriate access conditions for different institutions and user types.

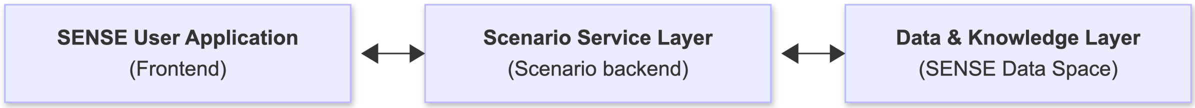

Figure 3. Scenario core components

2.7.2 Interaction flows

Overall, the interaction pattern is simple: the SENSE user application (**A**) communicates with the scenario service layer (**B**), which in turn reads from and/or writes to the data and knowledge layer (**C**). This separation allows different scenarios to reuse a common foundation (frontend and Data Space), while each use case implements its specific logic, content and configuration in the scenario backend. The following sequence diagrams describe the interaction flows associated with the user journeys, illustrating the expected end-to-end behaviour of the scenario.

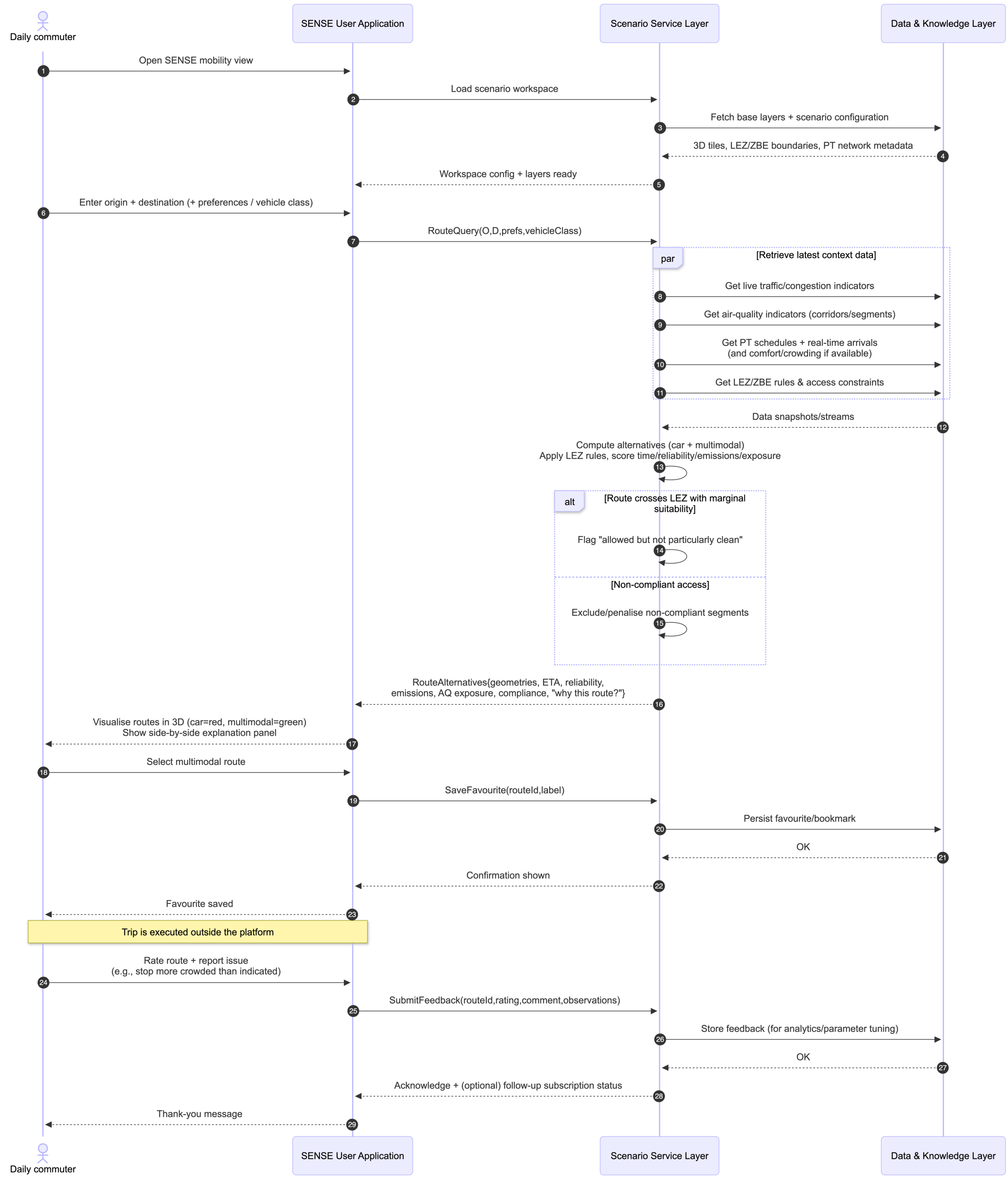

Figure 4. Sequence diagram for “Daily commuter optimising the route”

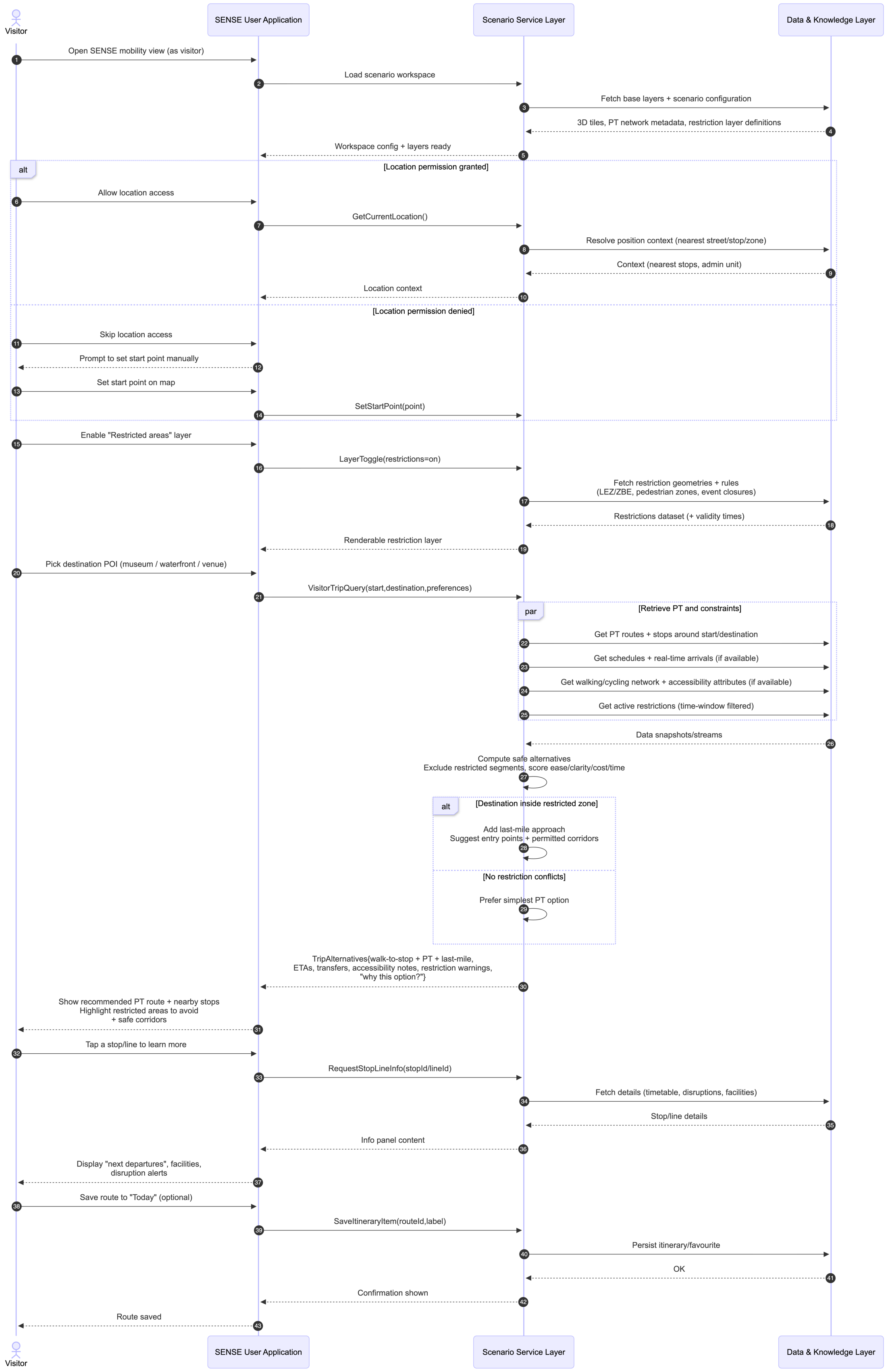

Figure 5. Sequence diagram for "Visitor avoiding restricted areas and discovering public transport"

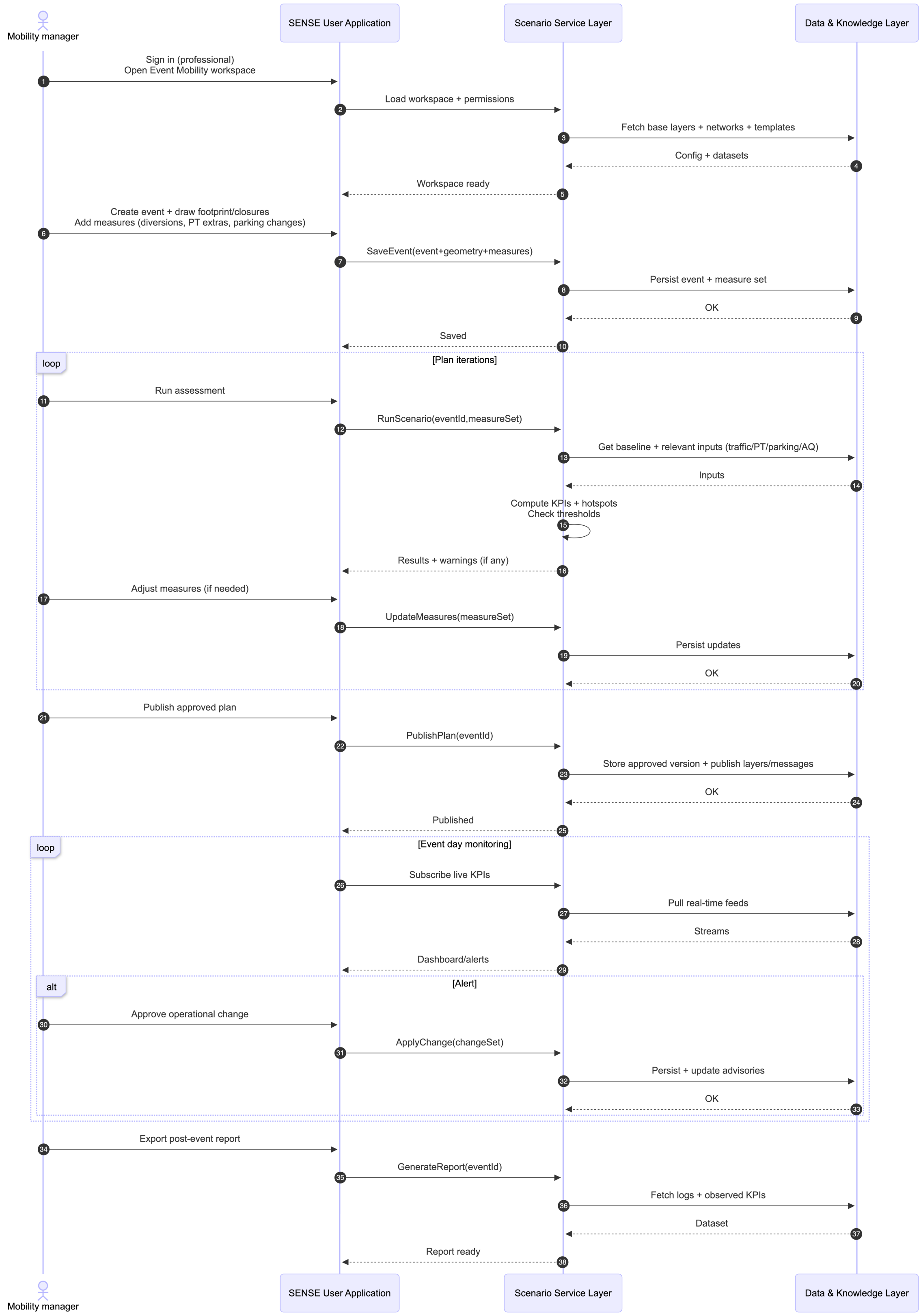

Figure 6. Sequence diagram for "Mobility manager preparing for a large event"

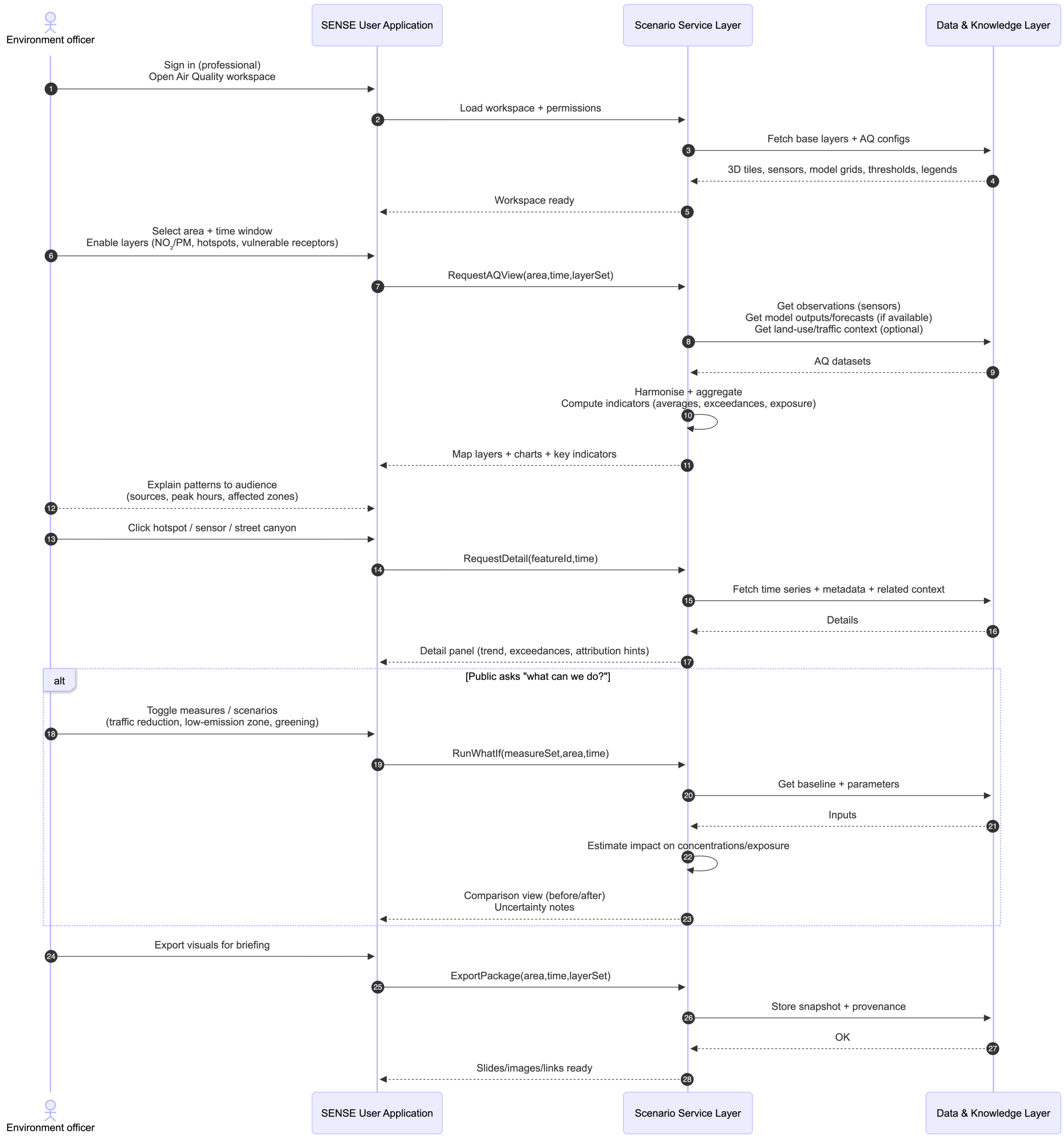

Figure 7. Environment officer explaining air quality

2.7.3 Input datasets

Below, we list the datasets published in the SENSE Data Space catalogue that are considered in the Smart Urban Mobility scenario. Together, they provide (1) the static geospatial context required to configure and render the scenario in the 3D twin, and (2) near real-time monitoring streams used to compute indicators, highlight hotspots and support routing and decision support.

City of Cartagena Geospatial Data

- **Type:** OGC GeoPackage (static / periodically updated).

- **Content:** Reference and thematic geospatial layers for the City of Cartagena, including Points of Interest (aligned with the OGC POI standard), vegetation cover, public transport timetable layers, and additional GIS layers used by the scenario (e.g., administrative boundaries and mobility-related layers where available).
- **Use in the scenario:** Basemap/overlay layers for the 3D twin, POI discovery, and the configuration of routing contexts (e.g., districts, key destinations, thematic layers). It also provides the spatial "anchors" used to join monitoring streams to neighbourhoods, corridors, or points of interest.

City of Cartagena Media Data

- **Type:** Media package (static / curated).
- **Content:** Multimedia assets related to the city, including images and 3D models. This package complements the *City of Cartagena Geospatial Data* dataset, which may include references (e.g. within POIs) linking to the corresponding media resources.
- **Use in the scenario:** Enriches user-facing panels and visualisations with contextual content (e.g., landmark images, illustrative media, 3D representations of selected urban spaces), improving interpretability and engagement.

City of Cartagena Crowd Flow Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Crowd/footfall measurements from 25 sensors in Cartagena.
- **Use in the scenario:** Supports the detection of crowding hotspots and temporal patterns (e.g., peak periods), and enables visitor/commuter guidance by indicating areas of high pedestrian pressure (as an operational signal and/or as a contextual indicator).

City of Cartagena Traffic Flow Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Traffic flow observations from 13 sensors in Cartagena.
- **Use in the scenario:** Provides the operational basis for congestion-aware routing, corridor performance indicators (speed/flow trends), and the identification of mobility bottlenecks that may affect both commuters and event operations.

City of Cartagena Weather Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Weather observations from 5 sensors in Cartagena.
Use in the scenario: Adds environmental context (e.g., temperature, humidity, wind)

to interpret mobility and air-quality conditions, and supports user-facing explanations (e.g., why pollution peaks may coincide with specific meteorological conditions).

City of Cartagena Noise Levels Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Noise level observations from 20 sensors in Cartagena.
- **Use in the scenario:** Enables noise exposure context for selected corridors/areas (useful for "quality-of-route" interpretation and for identifying potential nuisance hotspots relevant to urban mobility planning).

City of Cartagena Air Quality Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Air quality observations from 26 sensors in Cartagena.
- **Use in the scenario:** Supports air-quality-aware mobility guidance (e.g., route comparison or corridor highlighting) and provides evidence for explaining LEZ-related goals and expected impacts using near real-time indicators and trends.

City of Cartagena Parking Sensor Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models)**.**
- **Content:** Parking sensor observations from 20 sensors in Cartagena.
- **Use in the scenario:** Provides parking availability/occupancy signals to support parking search and demand management, and to contextualise mobility choices (e.g., encouraging park-and-ride or reducing cruising traffic where relevant).

2.7.4 Underlying models

In this section we list the main models that can be considered in the development of the *Smart Urban Mobility* scenario, covering (1) the 3D representation, (2) routing and optimisation, and (3) operational and analytical models.

- **Cartagena 3D City Model**. A high-resolution 3D representation of Cartagena, comprising mainly photorealistic 3D Tiles (3D mesh textured with high-resolution imagery) and supporting layers. This model provides the visual/spatial foundation for the scenario, enabling interactive navigation, layer switching and contextual inspection of streets, junctions, POIs and operational conditions within the 3D twin.

- **Cartagena street network model**. A graph-based representation of the mobility system, modelling streets and intersections (as edges and nodes respectivily) and, where applicable, public transport stops/lines/interchanges. The graph is enriched with attributes required by the scenario (e.g., accessibility constraints and connection rules for intermodal transfers), supporting the route planning interactions described for citizens and visitors.

- **Route planner and multi-criteria optimisation**. A routing model that operates on the street graph and supports dynamic edge weights driven by near real-time context (e.g., congestion levels, crowding, environmental conditions). The route planner can be implemented as a multi-criteria optimisation process (e.g., using a Dijkstra/A* family algorithm with dynamic costs), combining indicators such as time, reliability, emissions/exposure, walking effort, and rule compliance. In line with the scenario's "why this route?" requirement, the optimisation should produce both (a) ranked alternatives and (b) short, interpretable explanations of the trade-offs.

- **Traffic simulation and scenario assessment model.** A mesoscopic/microscopic traffic simulation model (e.g., using Eclipse SUMO[1]) built on the same network representation as the route planner. It is used primarily for professional workflows (e.g., event preparation, testing closures/diversions, assessing pressure points) by simulating expected flows based on historical baselines and configured measures. Outputs may include link travel times, queue lengths, congestion indices and hotspot maps, which can be visualised and compared across "normal day" vs "event day" configurations.

- **LEZ / restriction rule model.** A rules model describing LEZ/ZBE boundaries, pedestrian areas, restricted-access streets and temporary closures, including parameters such as time windows, vehicle categories, emission standards and permit requirements. This model is used to validate whether a route is compliant, to explain "why" a route is flagged, and to generate compliant alternatives.

- **Environmental exposure and impact estimation model**. A set of models translating environmental observations into route- and area-level indicators, e.g. (a) air-quality exposure along corridors (using point measurements and/or spatial interpolation), and (b) noise context where available. These models support both citizen-facing guidance (e.g., "avoid polluted corridor") and professional interpretation/communication of impacts.

[1] Eclipse SUMO, https://eclipse.dev/sumo/

Cartagena - Public Space, Environment and Quality of Life

3.1 Scenario Overview

In this scenario, the SENSE CitiVerse is used to understand how people live, move and interact in different neighbourhoods of Cartagena, and how public space, environment and social conditions combine to shape quality of life.

Imagine a resident opening the SENSE city twin and selecting their neighbourhood. On the 3D map, they see not only buildings and streets, but also a series of thematic layers: access to green areas and playgrounds, noise exposure from busy roads, proximity to schools and health centres, public transport stops, and basic socio-demographic indicators such as age structure and population density. By adjusting a set of simple filters, they can view how their area compares to others in terms of public space availability, environmental stress (e.g. noise, pollution proxies) and access to essential services.

At the same time, a city planner uses the professional view of the same twin to examine a cluster of districts where complaints about lack of amenities and poor maintenance have been increasing. With a few clicks, they overlay indicators of unemployment, educational attainment and housing tenure with mobility accessibility and environmental indicators. Patterns emerge: some areas show a combination of limited green space, higher exposure to traffic-related impacts and lower socio-economic resilience. The planner uses these insights to prioritise small-scale interventions such as new shaded seating areas, improvements to pedestrian routes, renewal of playgrounds and better public transport stops, and to justify larger investments in public space.

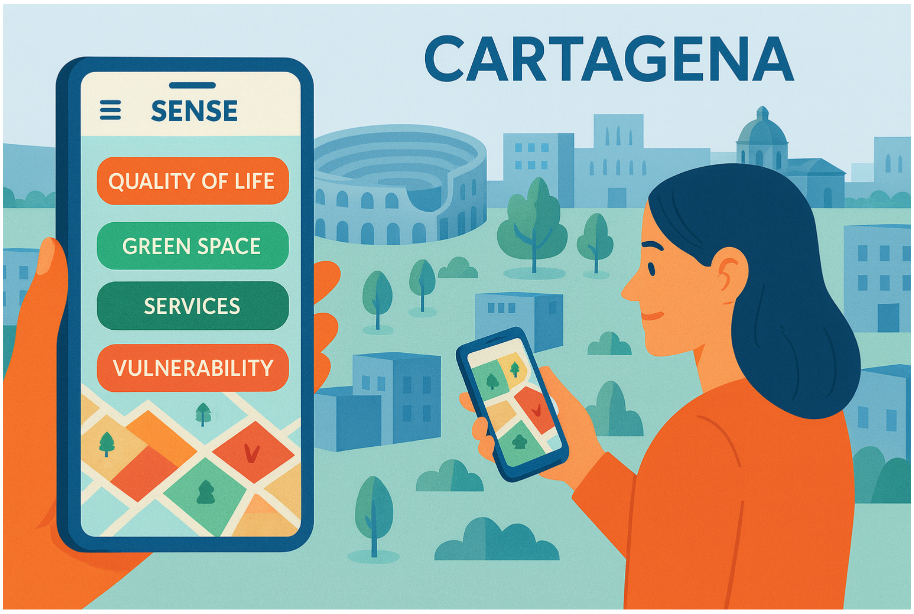

Figure 8. Cartagena – Public Space, Environment and Quality of Life

Social services teams can use the same environment to identify areas where socio-economic vulnerability and poor environmental conditions overlap, helping them focus outreach and community programmes. Citizen organisations and neighbourhood associations can use the public interface to communicate their experiences, validate or question the data and propose priorities. The overarching aim of this scenario is to make the spatial distribution of opportunities and stressors in Cartagena visible, understandable and discussable, in order to support more equitable, informed and participatory urban policy.

Overall, the scenario is designed to be used both internally (for evidence-based policy design, prioritisation and reporting) and externally (for communication and civic engagement), with the broader goal of supporting social cohesion and more equitable urban policy in Cartagena.

3.2 Urban and policy context in Cartagena

This use case aligns with Cartagena's broader strategic orientation towards a more environmentally, socially and economically sustainable city, as reflected in local frameworks such as the "Agenda Urbana" and the PACES strategy for a sustainable city model. In this context, addressing inequalities and improving quality of life is not treated as a purely "social policy" topic, but as a cross-cutting urban challenge where mobility, environmental conditions, public space, access to services and neighbourhood investment interact.

Cartagena is also positioned to build on an existing culture of digital innovation and data-driven approaches. The city has already engaged in multiple EU and national initiatives connected to sustainability, open data and urban transformation, such as BeOpen[2] (a Horizon Europe initiative aimed at developing an open-data framework to increase the availability and usability of high-value public sector datasets and enable new digital and AI-based services), as well as LIFE BAUHAUSING EUROPE[3] (a LIFE programme project that applies the New European Bauhaus approach to the renovation and reimagination of public buildings and neighbourhood spaces, with Cartagena included among the targeted municipalities). It is also involved in national investments and reforms linked to Spain's Plan de Recuperación, Transformación y Resiliencia (PRTR / NextGenerationEU)[4]. In SENSE, this scenario is framed as a cornerstone for community engagement and for strengthening the social fabric through more transparent, spatially grounded information about where disparities exist, how they intersect with environmental and accessibility factors, and how they evolve over time.

3.3 Objectives and expected impacts

This scenario pursues the following general objective:

> To support more inclusive, evidence-based and transparent urban policy in Cartagena by providing an accessible 3D environment where socio-economic conditions, access

[2] BeOpen Project, https://beopen-dep.eu

[3] LIFE BAUHAUSING EUROPE, reference: LIFE22-ENV-ES-LIFEBauhausingEurope/101113886

[4] https://serviciossociales.cartagena.es/proyectos_recuperacion.asp

to services, environmental stressors and public-space factors can be explored together at neighbourhood scale.

This objective is articulated into the following specific objectives:

O1. Integrated visibility of conditions and inequalities

- Provide an integrated view of socio-economic indicators, public space characteristics, environmental exposure and service accessibility at neighbourhood or district level.
- Make spatial inequalities and emerging vulnerabilities visible in a way that is understandable for both professionals and citizens.

O2. Support for planning and investment decisions

- Enable planners and policy makers to correlate socio-economic indicators with environmental stressors and accessibility gaps, helping them prioritise interventions and target resources where they are most needed.
- Provide empirical support for investment proposals (e.g. new parks, public space upgrades, service relocations), and for the evaluation of completed projects.

O3. Transparency and citizen understanding

- Offer a public interface where citizens can explore how their neighbourhood is evolving over time, understand the broader social fabric of the city and see how planned measures may affect them.
- Make underlying assumptions and limitations explicit, so that data and indicators are used as a basis for informed debate rather than as unquestionable “truths”.

O4. Support for social services and community programmes

- Help social services and community development teams identify areas where various forms of vulnerability overlap (e.g. high unemployment, low educational attainment, limited public space, higher environmental exposure).
- Support the planning and monitoring of outreach programmes, community initiatives and targeted support schemes.

O5. Citizen engagement and co-creation

- Provide a platform where neighbourhood associations, NGOs and citizens can leave structured feedback, identify places of concern or potential, and propose small-scale improvements in public spaces.
- Encourage co-creation of local priorities by combining data-driven insights with lived experience.

The expected impacts of the scenario can be grouped into two broad categories:

Short-term operational impacts

- Facilitate internal coordination between planning, environment, social services and mobility teams by providing a shared spatial reference.

- Improve the quality and clarity of communication materials used in public meetings and consultations.

Medium- to long-term impacts

- Contribute to a more balanced distribution of public investments in public space and services.
- Strengthen social cohesion by making inequalities visible and debatable in a constructive, evidence-based way.
- Support gradual improvements in environmental and quality-of-life indicators in the most vulnerable neighbourhoods.

3.4 Stakeholders, user groups and roles

The scenario is designed around several primary user groups (based on the engagement mapping in D6.1), each with distinct needs and usage patterns:

Primary user groups

- **Municipal planning and urban regeneration teams**: use the platform to understand neighbourhood profiles, justify investment priorities, and support integrated planning decisions.
- **Social services and inclusion units**: use the scenario to identify vulnerability patterns, locate service gaps, and support targeted programmes.
- **Public space / parks / neighbourhood management teams**: relate public-space provision and maintenance priorities to population needs and quality-of-life indicators.
- **Citizen associations and community organisations (e.g., federations of neighbourhood associations)**: consult and validate whether the mapped patterns reflect lived experience, and contribute feedback during participatory processes.
- **Citizens (residents)**: explore their neighbourhood context, understand city priorities, and follow how conditions change over time.

For each of these user groups, specific roles and permissions are defined:

- **Public users**: access an understandable subset of layers and explanations (with safeguards to avoid disclosure risks), and consult simple comparisons and time trends.
- **Professional users (city staff)**: access extended functionality such as advanced indicator selection, comparison tools, dashboards, and internal notes/annotations for planning workflows.
- **Administrators / data stewards**: manage data publication rules, access control, indicator metadata, and update cycles, ensuring governance and privacy constraints are respected.

3.5 Functional description of the use case

3.5.1 Interactive 3D digital twin as an "urban cohesion lens"

This scenario reuses the same 3D digital twin of Cartagena as the mobility scenario, but focuses on neighbourhood-scale conditions rather than individual routes. Functionally, the 3D twin could include the following capabilities:

- **Comprehensive spatial coverage:** represent all urban districts with sufficient detail to distinguish buildings, blocks, streets, parks, plazas, waterfronts and major public facilities.
- **Intuitive navigation and context:** support smooth navigation (pan, rotate, zoom, "fly to district") and offer a contextual overview map showing administrative units such as districts, neighbourhoods and census tracts.
- **Temporal exploration:** include time controls that allow users to move between different years or periods and compare the evolution of selected indicators (e.g. population change, increase in green space).

Key interaction features include:

- **Thematic layer selection**: users can activate thematic groups such as "Socio-economic profile", "Public space and services", "Environment and exposure", "Mobility accessibility".
- **Neighbourhood selection**: clicking on a district or neighbourhood boundary opens a summary card with selected indicators, while the map can shade all units according to a chosen indicator (e.g. unemployment rate).
- **Comparison tools**: simple tools allow users to compare two neighbourhoods side-by-side, or to view distribution charts for the whole city.

3.5.2 Socio-economic, public space and environmental layers

The scenario could combine several thematic families of indicators, delivered as spatial layers.

Socio-economic and demographic indicators

- Population density and structure (age groups, dependency ratios).
- Household composition (e.g. share of single-person households, families with children).
- Educational attainment levels.
- Employment and unemployment rates, perhaps by broad sector.
- Housing characteristics (tenure, building age, basic conditions where available).

Public space, services and amenities

- Surface and accessibility of green spaces, playgrounds and sports facilities.

- Distribution of public services: schools, health centres, social services offices, cultural facilities, libraries, community centres.
- Basic indicators of public space quality, where available (e.g. presence of shade structures, benches, playground equipment, maintenance status).

Environmental and exposure indicators (linked to the *Smart Urban Mobility* scenario)

- Noise exposure proxies derived from traffic volumes and road classification or from measurement campaigns.
- Air quality indicators at neighbourhood level (e.g. long-term averages interpolated from monitoring stations or model results).
- Heat exposure indicators derived from land surface temperature and land cover (e.g. share of impervious surfaces, tree cover).

Mobility and accessibility indicators (linked to the *Smart Urban Mobility* scenario)

- Public transport accessibility indices (e.g. distance to nearest stops, number of reachable jobs or facilities within a certain time by public transport).
- Walkability indicators (e.g. pedestrian network density, barrier effects from major roads).
- Simple “proximity scores” for key services (e.g. proportion of population within 10 minutes’ walk of a park, a primary school, a health centre).

All these layers are rendered in a way that balances richness with readability, avoiding too many indicators at once and providing clear legends and explanations.

3.5.3 Citizen-facing functionalities: exploration, transparency, feedback

For general users, the platform could focus on exploration and understanding:

- **Neighbourhood overview**: selecting “My neighbourhood” gives a concise overview card with a limited set of indicators (e.g. population, green space per inhabitant, access to services, generic socio-economic profile) and simple visual encodings (bars, icons).
- **City-wide comparison**: users can see where their neighbourhood sits in the city distribution for a given indicator (e.g. percentile rank for green space, unemployment).
- **Story-guided views**: for non-expert users, predefined “stories” lead them through a set of views, for example “Where are services located in Cartagena?” or “Understanding environmental exposure in your area”.
- **Feedback and local knowledge**: citizens can leave comments or structured feedback attached to specific locations or neighbourhoods, for example reporting under-used spaces, unsafe feeling locations, or suggesting micro-interventions (more shade, benches, better lighting). This complements top-down indicators with bottom-up experience.

3.5.4 Professional functionalities: planning, analysis and scenario comparison

For planners, social services and environmental teams, the professional view could offer:

- **Configurable dashboards** showing key indicators for selected neighbourhoods or the whole city.
- **Multi-layer overlays**, allowing users to view combinations such as "low green space + high heat exposure + high share of elderly population", or "high unemployment + poor public transport access".
- **Scenario comparison tools**, where planned interventions (e.g. adding a pocket park, upgrading a square, improving a bus line) can be represented and their approximate effect on accessibility or environmental exposure can be visualised at a high level.
- **Export capabilities** for maps, indicator tables and charts that are used in reports, funding applications and public presentations.

3.6 User journeys

The user journeys below illustrate how different actors might interact with the scenario once fully operational. As in other scenarios, these narratives are aspirational and may include functionalities that go beyond what can be implemented within the SENSE project timeframe.

3.6.1 Social policy analyst identifying vulnerability hotspots

A municipal analyst responsible for inclusion policy opens the SENSE 3D twin and activates a "Urban Cohesion" workspace. She selects a set of indicators (e.g., unemployment distribution, population structure and proximity to essential services) and asks the platform to highlight districts that score above a chosen threshold. The map updates to show a small set of neighbourhoods where multiple risk factors overlap. She then toggles an environmental overlay (e.g., an air-quality or heat proxy layer, where available) to see whether exposure patterns intensify the social vulnerability profile.

She captures a set of annotated screenshots and exports a short "neighbourhood comparison card" that summarises key indicator differences for an internal coordination meeting with planning and public space teams.

3.6.2 Public space manager targeting improvements for quality of life

A public space manager is preparing next year's maintenance and upgrade plan. Using SENSE, he selects a district and opens the contextual panel that summarises population density, age structure and proximity to parks and facilities.

By switching between layers, he identifies a set of streets and small squares where dense population coincides with low green access and poor service proximity. He places internal annotations ("candidate for pocket park", "priority shading corridor", "bench and lighting upgrade area") and shares a link to the same view with colleagues in environment and social services to validate whether planned measures align with broader cohesion objectives.

3.6.3 Citizen exploring neighbourhood evolution and public priorities

A resident hears about a new municipal programme linked to neighbourhood regeneration. On the public-facing SENSE portal, she searches for her district and opens a "Neighbourhood

profile" view showing a small set of accessible indicators and a brief explanation of what they mean.
She compares her area to the city average, then checks a "changes over time" slider (if available) to understand how key values have evolved. The platform also shows links to related municipal initiatives and offers an optional short questionnaire to capture perceived priorities (e.g., public space, services, environmental comfort), feeding into engagement processes planned for Cartagena.

3.7 Technical foundations

This section highlights the key technical aspects for implementing the scenario, including both common elements across SENSE scenarios and scenario-specific considerations.

3.7.1 Interaction flows

The sequence diagrams below define the interaction flows associated with the user journeys described in the previous section, illustrating the expected end-to-end behaviour of the scenario. The diagrams are based on the core components introduced in Section 2.7.1: (1) the SENSE User Application, (2) the Scenario Service Layer, and (3) the Data & Knowledge Layer.

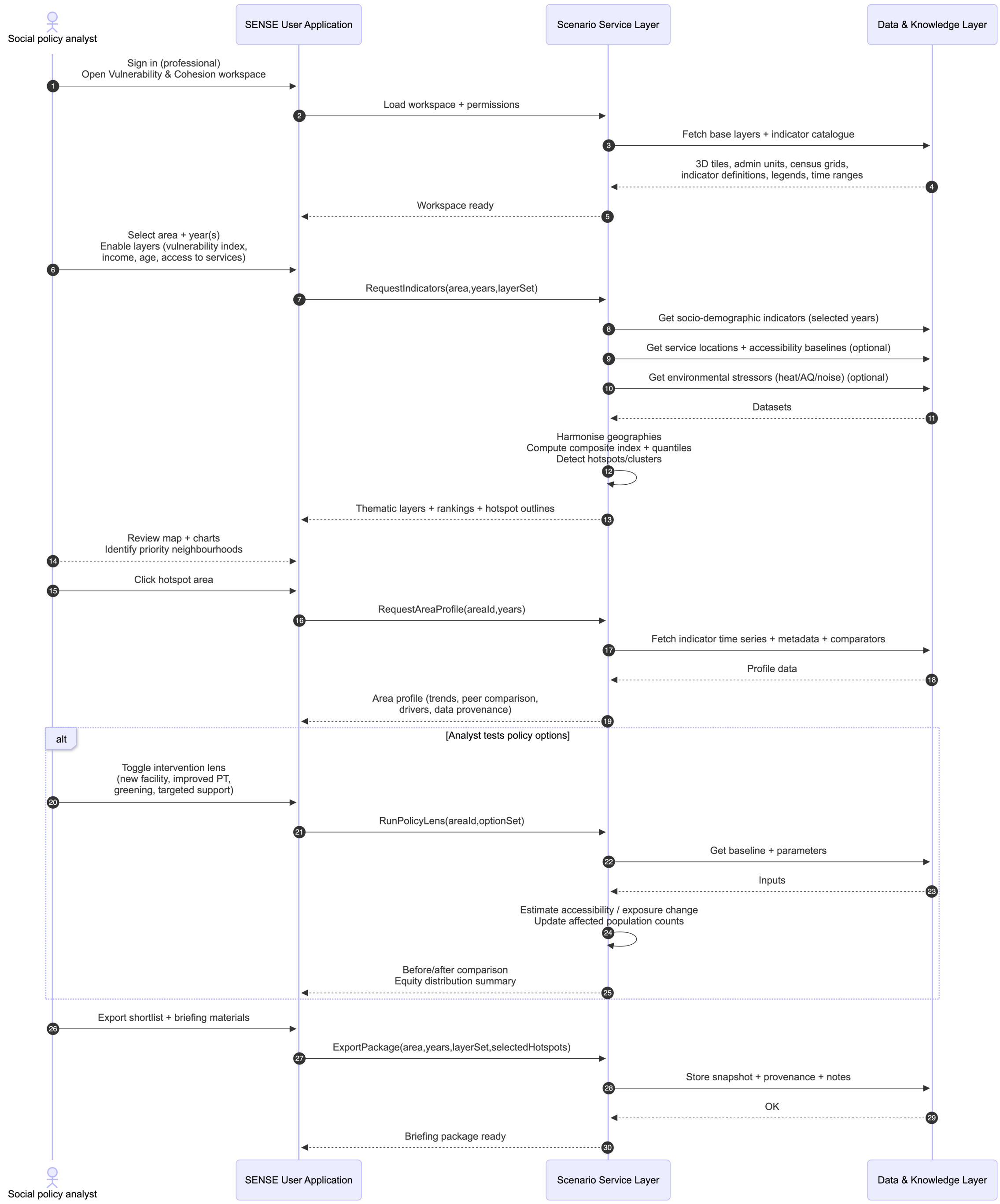

Figure 9. Sequence diagram for “Social policy analyst identifying vulnerability hotspots”

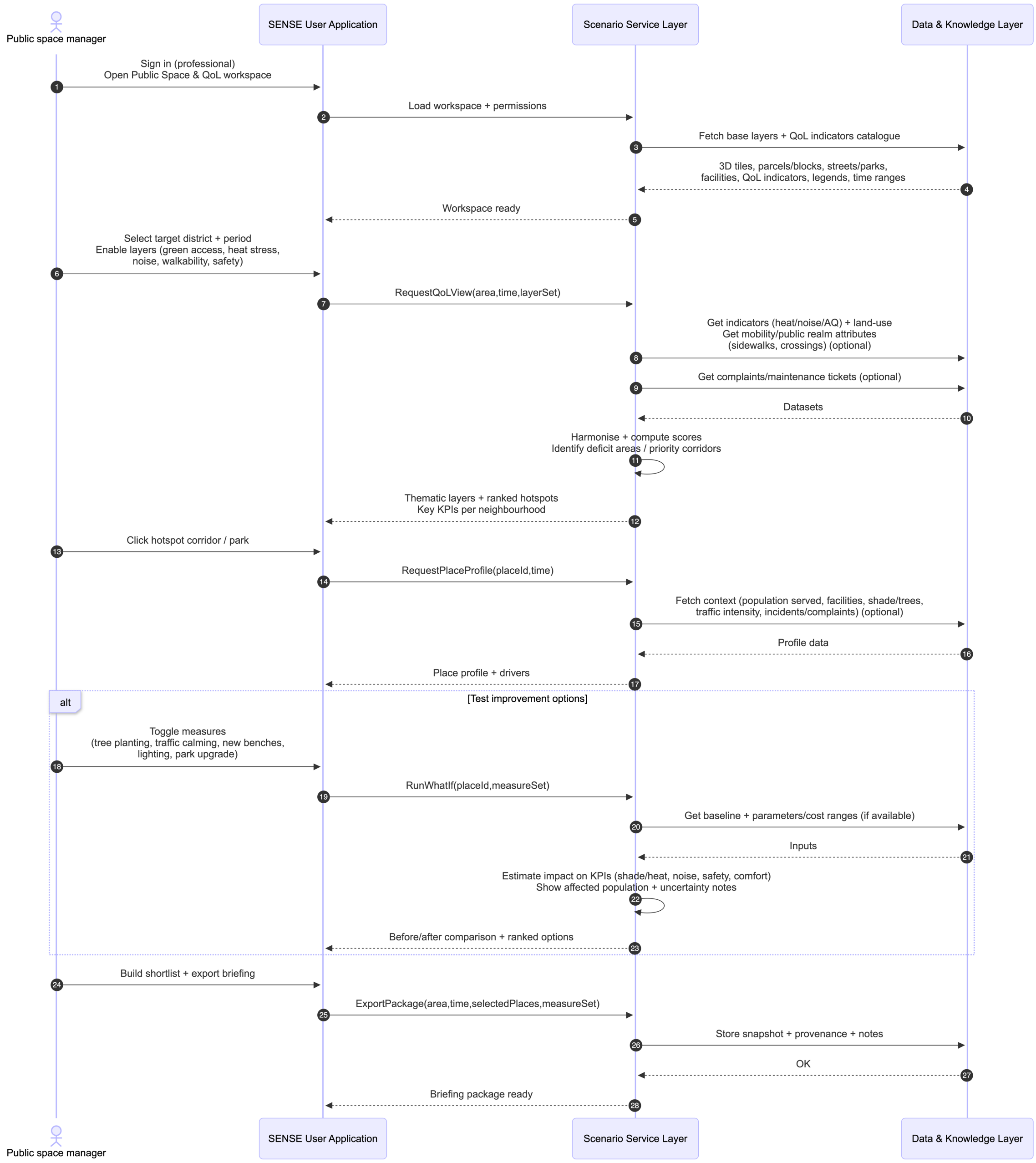

Figure 10. Sequence diagram for “Public space manager targeting improvements for quality of life”

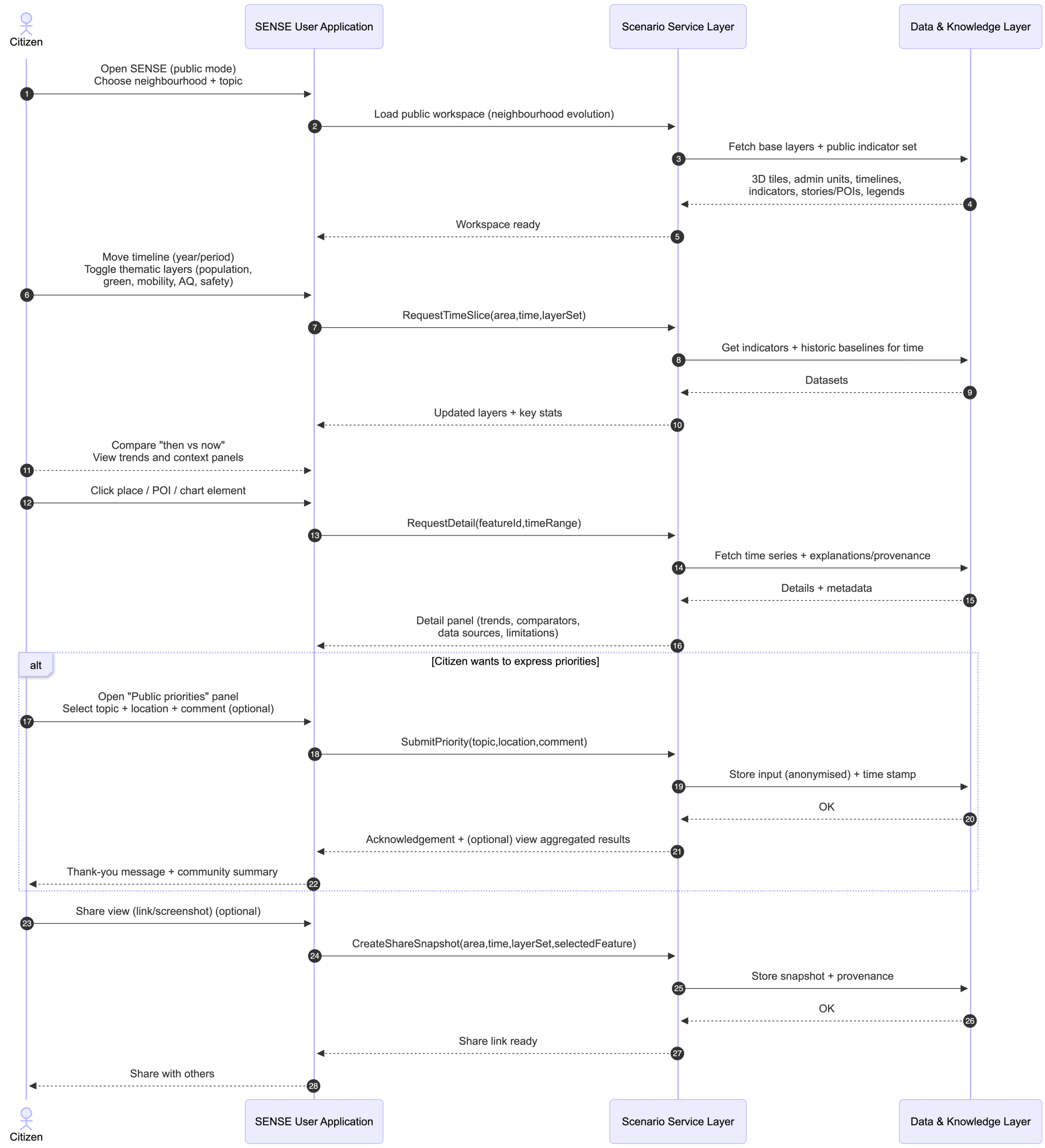

Figure 11. Sequence diagram for "Citizen exploring neighbourhood evolution and public priorities"

3.7.2 Input datasets

Below, we list the datasets published in the SENSE Data Space catalogue that are considered in this scenario. Since *Public Space, Environment and Quality of Life* extends the *Smart Urban Mobility* scenario, several datasets are reused in both. Together, the datasets provide: (1) the static geospatial context required to configure and render the scenario in the 3D twin, (2) near real-time monitoring streams used to characterise environmental conditions and urban pressure, and (3) socio-economic indicators enabling neighbourhood comparisons and equity-oriented analysis.

City of Cartagena Geospatial Data

- **Type**: OGC GeoPackage (static / periodically updated).
- **Content**: Reference and thematic geospatial layers for Cartagena, including Points of Interest (aligned with the OGC POI standard), vegetation cover, public transport timetable layers, and additional GIS layers used by the scenario (e.g., administrative boundaries and mobility-related layers where available).
- **Use in the scenario**: Provides the spatial backbone for the 3D twin (basemap/overlays), supports POI discovery and public space exploration, and supplies the spatial anchors to aggregate and interpret monitoring streams (e.g., by neighbourhood, district, corridor or selected places).

City of Cartagena Media Data

- **Type**: Media package (static / curated).
- **Content**: Multimedia assets related to the city, including images and 3D models. This package complements the *City of Cartagena Geospatial Data* dataset, which may include references (e.g. within POIs) linking to the corresponding media resources.
- **Use in the scenario**: Enriches user-facing panels and story-like explanations with contextual content (e.g., parks, plazas, landmarks, before/after illustrations), improving interpretability for both public communication and professional briefings.

City of Cartagena Socio-Economic Data

- **Type**: Package of CSV files (static / curated).
- **Content**:

  Core/reference layers
  - areas_geometry – geometries of areas (e.g., neighbourhoods, census tracts, districts).
  - areas_metadata – metadata on these areas (administrative hierarchy, latest population, etc.).
  - metadata_variables – variable dictionary with definitions, units, and scales.

  Zonal socio-economic datasets (by area and year)
  - demographics_zonal – population, age structure, households, migration.
  - economy_employment_zonal – employment, unemployment, income, poverty, businesses.
  - education_zonal – education level, illiteracy, education centres, accessibility.
  - health_zonal – life expectancy, mortality, insurance coverage, access to healthcare.
  - housing_zonal – housing stock, tenure, basic services, prices, vulnerability.
  - mobility_access_zonal – travel times, transport modes, accessibility to jobs and services.
  - environment_zonal – green areas, air quality, noise, climate risk.
  - safety_social_zonal – crime, access to police, social cohesion and social exclusion.

Point/facilities datasets
  - health_facilities – hospitals, health centres, clinics (point features).
  - transport_nodes – bus stops, metro/rail stations and other transport nodes (point features).

- **Use in the scenario**: Enables quality-of-life profiling and neighbourhood comparisons by combining environmental and social dimensions. It supports (1) identification of priority areas (e.g., places with lower green access and higher exposure/pressure), (2) trend analysis across years, (3) equity-sensitive interpretation (who is affected, where, and how), and (4) contextual explanations linking public space conditions to access to services, demographics and vulnerability patterns.

City of Cartagena Weather Data

- **Type**: Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content**: Weather observations from 5 sensors in Cartagena.
- **Use in the scenario**: Provides environmental context (e.g., temperature, humidity, wind) to interpret outdoor comfort and the variability of air-quality/noise conditions. It can also support time-based narratives (e.g., seasonal differences) and contextual warnings during extreme conditions (e.g., hot periods affecting public space use).

City of Cartagena Noise Levels Data

- **Type**: Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content**: Noise level observations from 20 sensors in Cartagena.
- **Use in the scenario**: Supports the identification of noise hotspots and time patterns (day/night), and helps assess the quality of public spaces and corridors. Combined with traffic/crowd indicators, it supports explanations of nuisance drivers and prioritisation of mitigation measures (e.g., traffic calming, reallocation of space, improved buffers).

City of Cartagena Air Quality Data

- **Type:** Data service (FIWARE Orion Context Broker API, NGSIv2, FIWARE Smart Data Models).
- **Content:** Air quality observations from 26 sensors in Cartagena.
- **Use in the scenario:** Enables the visualisation and communication of local air quality conditions and longer-term patterns. It supports exposure-aware interpretation of neighbourhood quality of life, helps relate environmental conditions to mobility/public space dynamics, and provides evidence for explaining interventions (e.g., greening, traffic reduction, LEZ-related effects).

3.7.3 Underlying models

In this section we list the main models that can be considered in the development of the *Public Space, Environment and Quality of Life* scenario. As an extension of the *Smart Urban Mobility* scenario, it reuses part of the same foundational models (3D representation and environmental context), but shifts the analytical focus from routing and compliance towards (1) place-based assessment, (2) environmental quality and exposure, and (3) quality-of-life and equity-oriented hotspot detection.

- **Cartagena 3D City Model**. A high-resolution 3D representation of Cartagena, comprising mainly photorealistic 3D Tiles (3D mesh textured with high-resolution imagery) and supporting layers. It provides the visual/spatial foundation for the scenario and supports interactive exploration of neighbourhoods, public spaces, corridors, POIs and thematic layers in the 3D twin.
- **Public space and green infrastructure model**. A spatial model representing public spaces and their attributes (e.g., parks, plazas, waterfront areas, pedestrian streets and urban green elements). Where available in the underlying GIS layers, the model can encode attributes relevant to use and comfort (e.g., area/extent, connectivity, proximity to key facilities, vegetation cover proxies). It supports place-based inspection ("what is here?") and enables the computation of availability/access indicators (e.g., green access or public-space provision per neighbourhood).
- **Environmental conditions and exposure model**. A set of models translating environmental observations into area- and place-level indicators, combining sensor data (air quality, noise, weather) with spatial aggregation and, where appropriate, interpolation. Typical outputs include: (1) local air-quality context and exceedance patterns, (2) noise context by corridor/area, and (3) comfort-related contextualisation (e.g., meteorology supporting interpretation of outdoor conditions). This model underpins both professional interpretation and citizen-facing explanations.
- **Urban pressure and dynamics model**. A model layer that converts operational mobility signals (e.g., crowd flow and traffic flow) into pressure indicators for public space management. It supports detection of temporal peaks, identification of crowded hotspots, and contextual explanation of why specific areas experience recurring pressure (e.g., commuting peaks, event-driven dynamics, tourist concentrations).
- **Neighbourhood profiling and quality-of-life indicator model.** A modelling layer that integrates zonal socio-economic datasets with environmental and public-space indicators to create neighbourhood profiles (e.g., demographics, access to services, mobility accessibility, environmental stressors). This model supports comparisons across areas and across time, enabling "dashboard-style" summaries and transparent, explainable indicator definitions.
- **Composite index and hotspot detection model.** A multi-criteria analysis model that derives rankings and hotspot maps from multiple indicators (e.g., low green access + high noise + high crowding + vulnerable population). Methods may include normalisation, weighted aggregation, quantile classification, clustering, and spatial hotspot detection. The key requirement is interpretability: the model should expose drivers of the hotspot (which variables contribute most) to support decision-making and communication.

4. Kiel - Hidden World

4.1 Scenario Overview

The *Hidden World* scenario in Kiel will use SENSE to create an immersive cultural and heritage experience that reveals stories, places and perspectives that are not immediately visible in the everyday cityscape. Through an interactive 3D model of Kiel, users can explore how the city has evolved over time, discover the traces of past events in today's urban fabric, and understand how maritime history, war destruction and post-war reconstruction have shaped the city's identity.

The scenario is built around a digital cultural tour concept. In a free-exploration mode, users can navigate the three-dimensional representation of Kiel, zooming in on emblematic buildings, squares, waterfront areas and neighbourhoods. Points of interest (POIs) attached to these locations provide contextual information such as historical descriptions, archival photographs, architectural reconstructions of earlier states and narrative explanations of each site's role in Kiel's development.

Beyond open exploration, the system can offer thematic guided tours focused on topics such as:

- Kiel as a maritime city (port development, shipyards, ferry links, Kieler Woche).
- War damage and post-war reconstruction.
- Everyday life in different historical periods.
- Religious, industrial or social heritage (e.g. former synagogue, fish market, workers' housing).

Figure 12. Kiel – Hidden world

These tours can be experienced remotely or on site, with the 3D twin acting as a digital companion that complements the physical visit. Users can also create personalised tours by choosing a starting point, preferred walking duration and topics of interest; the application then composes a route and presents narrative stops along the way.

The scenario is multilingual and self-guided, allowing domestic and international visitors, day tourists and residents to engage with Kiel's history at any time of day and any season. The overarching aim is to strengthen residents' sense of belonging and to deepen visitors' understanding of the city, using SENSE as a bridge between digital storytelling and the lived urban environment.

4.2 Urban and cultural context in Kiel

Kiel is the capital of the German state of Schleswig-Holstein and a major Baltic Sea port. The city combines ferry and cruise terminals, shipyards and maritime industries with residential neighbourhoods, university campuses, cultural venues and recreational waterfront areas. Its location on the Kiel Fjord gives it a strong maritime character and makes it an attractive tourist destination, particularly for short stays.

Kiel records around one million overnight stays per year, with an average length of stay of about 2.1 days. Approximately 18% of visitors are international, driven largely by large events such as Kieler Woche, one of the world's largest sailing events, and by international ferry and cruise traffic.

This creates a significant demand for cultural offerings that are accessible, multilingual and suitable for short visits, while also providing deeper content for repeat visitors and residents.

Historically, Kiel has been a major naval and shipbuilding centre. During the Second World War, around 80% of the city was destroyed, and many historical structures disappeared or were radically transformed. As a result, much of the city's heritage is "hidden" in archives, memories and the underlying urban structure rather than in intact historical districts. The city's history is therefore harder to grasp through conventional sightseeing alone: visitors and even long-term residents may walk past sites of great historical importance without being aware of their stories.

At the same time, Kiel is actively positioning itself as a forward-looking, sustainable port city, investing in new waterfront developments, cultural institutions and climate-related initiatives. This creates an opportunity to present "yesterday's and tomorrow's Kiel" together: connecting the city's maritime and wartime past with current urban development and future sustainability ambitions.

The *Hidden World* scenario responds to this context by:

- Making intangible or invisible heritage accessible through spatialised storytelling.
- Supporting short-stay and cruise tourism with flexible, self-guided cultural experiences.
- Offering residents and schools new ways to (re)discover their city and its neighbourhoods.

4.3 Objectives and expected impact

The *Hidden World* scenario pursues the following overarching objective:

> To reveal the "hidden" cultural and historical layers of Kiel and strengthen citizens' and visitors' sense of belonging by providing an immersive, multilingual and self-guided cultural tour in the SENSE 3D twin.

This objective is articulated into the following specific objectives:

O1. Visibility and accessibility of heritage

- Make historically significant locations visible and understandable within a unified 3D environment, even where physical traces are limited or absent.
- Provide multilingual, self-guided access to cultural content for both international and domestic visitors, as well as residents.
- Integrate archival materials (images, documents, maps) directly into the spatial experience to give depth and authenticity to stories.

O2. Support for informed and meaningful cultural experiences

- Enable users to select themes, durations and difficulty levels (e.g. family-friendly, barrier-free routes) so that the experience fits their interests and constraints.
- Provide interpretive content that links individual sites into coherent narratives (e.g. a "reconstruction tour" or "maritime economy tour").
- Combine historical information with practical data such as current weather, opening hours or public transport connections, supporting on-site exploration.

O3. Community engagement and co-creation

- Involve local guides, shop owners, cultural organisations and citizens in co-creating stories, providing media content and validating narratives.
- Offer channels for users to leave feedback, share their own stories and contribute to a living city archive within SENSE.

The expected impacts of the scenario can be grouped into two broad categories:

Short-term impacts

- Enhanced visitor experience through interactive, memorable and shareable tours that can be accessed at any time.
- Increased visibility of lesser-known sites and neighbourhoods, potentially dispersing visitor flows beyond a few landmark locations.
- Stronger cooperation between the city archive, local guides, shop owners and tourism services around a common digital platform.

Medium- to long-term impacts

- Strengthened sense of belonging among residents, especially younger generations and newcomers who can discover their city's stories in accessible ways.
- Support for sustainable and inclusive tourism by promoting local businesses, reducing the need for resource-intensive printed materials, and offering more flexible, autonomous visits.
- A reusable digital infrastructure that can host additional tours, themes and collaborations, and potentially be replicated in other cities in future phases of SENSE.

4.4 Stakeholders, user groups and roles

The *Hidden World* scenario brings together several stakeholder groups with distinct interests, roles and levels of engagement. Building on the engagement mapping in D6.1, we can distinguish between primary users, enabling stakeholders and institutional partners.

Primary user groups

- **Visitors and tourists**
  - *Profile:* International and domestic tourists, including cruise passengers and day visitors.
  - *Needs:* Easy-to-use, multilingual, self-guided tours that fit short stays and can be started at any time; engaging, visually rich content that is easy to share.
  - *Role:* Core users of the digital tour; their numbers, satisfaction and word-of-mouth strongly influence impact.
- **Residents and local communities**
  - *Profile:* Long-term residents, new residents, families, and individuals with an interest in local history and identity.
  - *Needs:* Recognition of their own neighbourhoods, stories and perspectives; accessible content that does not assume prior historical knowledge; opportunities to contribute stories or feedback.
  - *Role:* Both users and potential co-creators; their engagement is key to ensuring that the tour reflects diverse local voices.

Enabling stakeholders

- **Local guides**
  - *Role:* Provide authentic insights, personal stories and contextual explanations that enrich the digital content.
  - *Interest:* Deliver high-quality visitor experiences; strengthen their professional profile.
  - *Influence:* High impact on narrative quality and tour attractiveness.

- **City of Kiel / City archive**
  - *Role:* Key providers of historical photographs, documents and contextual information that underpin the narratives.
  - *Interest:* Visibility of archival collections; public engagement with historical resources.
  - *Influence:* Shapes the depth, authenticity and reliability of content.
- **Local shop owners and businesses**
  - *Role:* Points of interest along routes, providing present-day “touchpoints” that connect historical narratives to current life; potential providers of stories and imagery.
  - *Interest:* Increased footfall, visibility and economic benefit from tour participants.
  - *Influence:* Can affect the “feel” of the experience and support sustainable, locally anchored tourism.

Institutional partners and internal stakeholders

- The city’s local tourism organisation (strategy, branding, coordination).
- Digital and IT departments (hosting, integration with SENSE platform and data space).
- Research partners (evaluation, user studies, content experimentation).

For each of these groups, the platform can support differentiated access rights, from public users (anonymous or lightly authenticated) to professional users (curators, city staff, teachers) and administrators managing content and roles, following the pattern established for other scenarios.

4.5 Functional description of the use case

4.5.1 Interactive 3D cultural twin of Kiel

The core of the scenario could be conceived as an interactive 3D representation of Kiel that serves as the entry point for cultural exploration, broadly analogous to the mobility twin developed for Cartagena (see Section 2.5.1) but tailored to heritage and storytelling content. Functionally, the 3D twin could include the following capabilities:

- **City coverage and performance:** it could cover the main urban area, waterfront and relevant neighbourhoods with sufficient detail to distinguish buildings, streets, port facilities and landmarks, while remaining usable on standard devices.
- **Intuitive navigation and orientation:** it could provide basic navigation controls (pan, rotate, zoom) and include a minimap or overview to support orientation and quick repositioning.
- **Semantic linking to heritage content:** it could support links between 3D objects (e.g. buildings, squares, waterfront segments) and associated heritage records, narratives and media assets.

- **Time-related views:** where relevant, it could offer basic temporal views, such as overlays of historical maps or simplified 3D reconstructions representing earlier building states.

From a functional perspective, the twin could also support:

- **Layer switching:** users could switch between cultural themes (e.g. "war damage and reconstruction", "maritime economy", "religious heritage") and additional contextual layers (e.g. viewpoints, public transport stops).
- **Contextual information on selection:** clicking or tapping a point of interest could open an information panel with text, images, audio or short video clips; in some cases, this could include reconstructions or artistic renderings of past states.
- **Bookmarks and perspectives:** predefined camera positions (e.g. main squares, harbour viewpoints, former shipyard areas) could be made available for quick access with a single click.

4.5.2 Heritage and storytelling layers

The scenario could build several content layers on top of the 3D base model:

- **Points of interest (POIs)**: georeferenced locations such as sights, restaurants, shops, former industrial sites and characteristic streets. Each POI is associated with metadata (name, category, time period, thematic tags) and one or more narratives.
- **Narratives / storylines**: structured sequences of POIs forming a thematic tour (e.g. "From harbour to shipyard", "Kiel in ruins and rebuilding"). Each narrative includes an introduction, per-stop content and a closing summary; content can be textual, audio-guided, visual or mixed.
- **Media assets**: archival photographs, historical maps, documents and audio recordings provided by the city archive and other partners. Contemporary photos and media contributed by local guides, businesses or citizens, subject to curation.
- **Operational context layers**: optional overlays for current weather, opening hours of museums or shops, public transport stops or walking times between POIs, reused from other SENSE components where possible.

4.5.3 Visitor and citizen functionalities

For public users, the *Hidden World* scenario could behave as a "cultural tour companion" in 3D:

- **Free exploration**: users could move freely around the 3D city, select any POI and access its content. Filters allow restricting the view to certain themes, time periods or difficulty levels (e.g. family-friendly, "in-depth").
- **Predefined guided tours**: a catalogue of tours could be available, each with estimated duration, distance and theme. When a tour is started, the system would guide the user step by step through the city, highlighting the next POI and providing navigation cues in the 3D view.

- **Personalised tours**: users could specify starting point (or current location), desired duration or walking distance, and preferred topics. The backend composes a route that meets these constraints and returns a list of stops with associated stories.
- **Multilingual support and accessibility**: content could be available in multiple languages, reflecting the mix of international and domestic visitors. The interface would support larger fonts, high-contrast modes and simplified views; audio narration could support users with reading difficulties.
- **Feedback and participation**: simple mechanisms (short surveys, ratings, open comments) allow users to evaluate tours and individual POIs. Where appropriate, users can propose new stories or upload material through a controlled submission workflow for curators.

4.5.4 Curatorial and management features

For professional users (city staff, archive curators, tourism organisations), the scenario could include:

- **Content authoring tools** to create and edit POIs, narratives and media bundles, and to define tours and thematic layers.
- **Workflow support** for reviewing and approving new or updated content, especially when submitted by external contributors (guides, businesses, citizens).
- **Analytics dashboards** summarising usage by tour, language, time of day and location, helping to understand which content resonates with which user groups.
- **Configuration of visibility rules** (e.g. experimental tours only visible to pilot groups) and integration with the broader SENSE data space and user management.

4.6 User journeys

The user journeys below illustrate how different actors might interact with the *Hidden World* scenario once fully operational. As in other scenarios, these narratives are aspirational and may include functionalities that go beyond what can be implemented within the SENSE project timeframe.

4.6.1 Visitor discovering the "hidden city behind the waterfront"

A couple visiting Kiel for a weekend disembarks from a cruise ship at the harbour. While checking tourist information, they see a QR code inviting them to "Explore Kiel's *Hidden World* in 3D". They scan it and the SENSE app opens directly in the Kiel cultural twin, centred on the waterfront.

The app proposes a 90-minute themed tour titled "Harbour stories: from shipyards to city life", available in several languages. The couple selects their language, and the app shows the first stops along the quay, including the site of a former shipyard and a square rebuilt after the war. At each stop, they see archival photographs overlaid on the current 3D scene, listen to short audio clips and read concise explanations.

Between stops, the app guides them with simple arrows in the 3D view and an estimated walking time. When the tour passes a cluster of local shops identified as POIs, the app briefly highlights their specialities and invites the couple to discover them.

At the end of the tour, the couple rates the experience and leaves a brief comment about which stories they found most impactful. Their feedback is aggregated in the analytics dashboard for curators and city staff.

4.6.2 Resident reconnecting with their neighbourhood

A resident who has lived in Kiel for years hears about the SENSE tour from a local newspaper. At home, they open the web version of the cultural twin and search for their own neighbourhood.

They discover that nearby there was a former industrial site with an important role in the city's labour history, and that their street was part of a post-war reconstruction plan. The app suggests a short "neighbourhood past and present" tour tailored to their location, with a duration of 30 minutes.

After completing the route, the resident notices that one of the stories mentions an event they remember from their childhood. Through the built-in participation features, they submit a short personal recollection and a family photo; the submission enters a review queue for the city archive, potentially enriching future versions of the tour.

4.6.3 Curator and tourism officer planning new content

A curator at the city archive and a tourism officer meet to review usage statistics from the last quarter. The analytics dashboard shows that a specific tour is popular among international visitors but has low engagement among locals, while another neighbourhood-focused tour is widely used by residents and school groups.

Based on this, they decide to:

- commission local guides and shop owners in an under-represented district to co-create new POIs;
- add an additional language to a high-performing tour; and
- test a pilot tour during Kieler Woche that links regatta locations with historical maritime sites.

They use the authoring tools to configure the new tour and schedule its publication, ensuring that all content is reviewed and approved according to agreed workflows.

As in the Cartagena scenario, these journeys can be decomposed into flows between the SENSE web app, the scenario back-end and the Data Platform / Data Space: the front-end collects user inputs, the back-end composes routes and delivers narratives, and the platform provides harmonised access to 3D, heritage and contextual data.

4.7 Technical foundations

This section highlights the key technical aspects for implementing the scenario, including both common elements across SENSE scenarios and scenario-specific considerations.

4.7.1 Interaction flows

The sequence diagrams below define the interaction flows associated with the user journeys described in the previous section, illustrating the expected end-to-end behaviour of the scenario. The diagrams are based on the core components introduced in Section 2.7.1: (1) the SENSE User Application, (2) the Scenario Service Layer, and (3) the Data & Knowledge Layer.

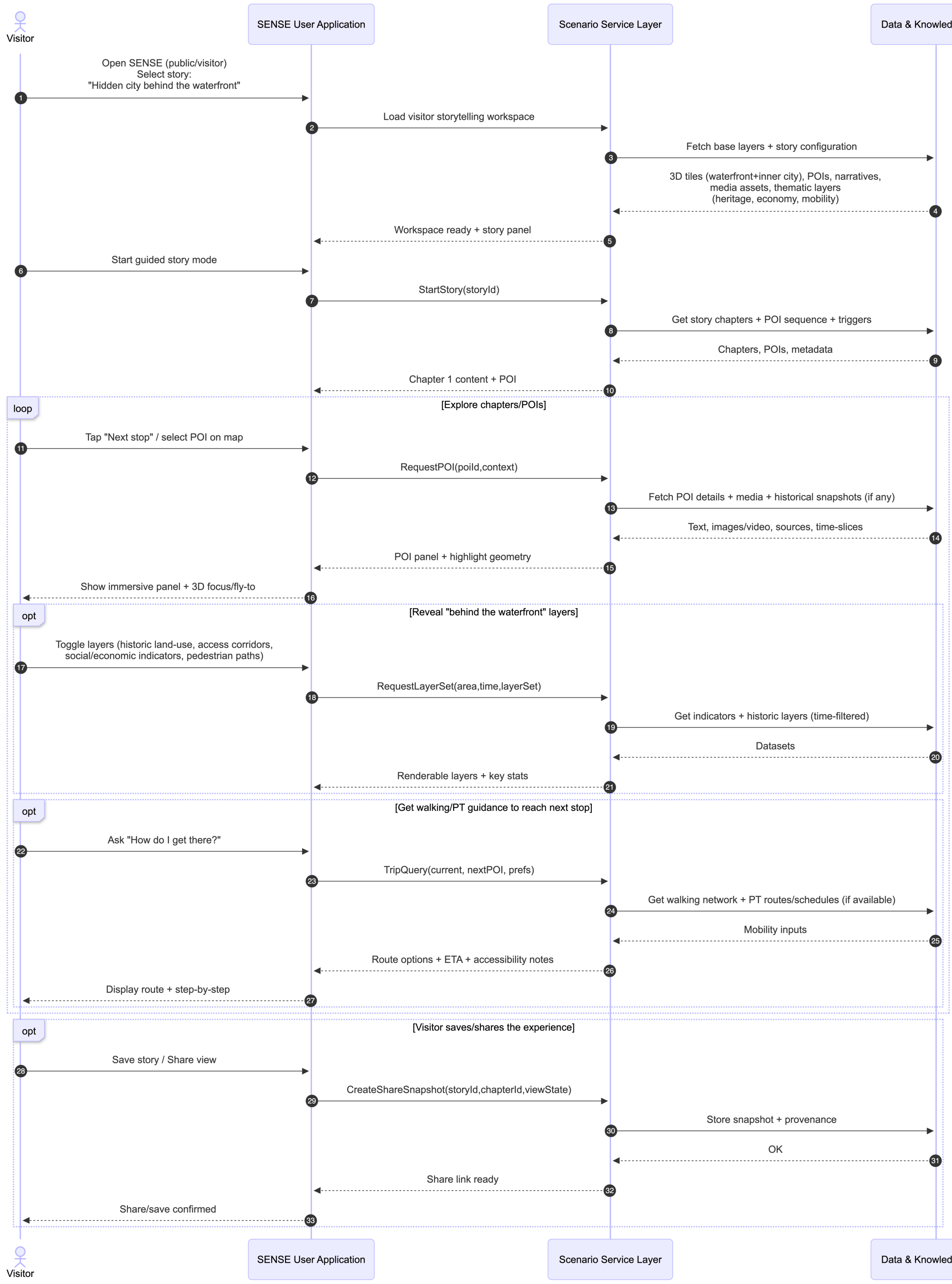

Figure 13. Sequence diagram for 'Visitor discovering the "hidden city behind the waterfront"'

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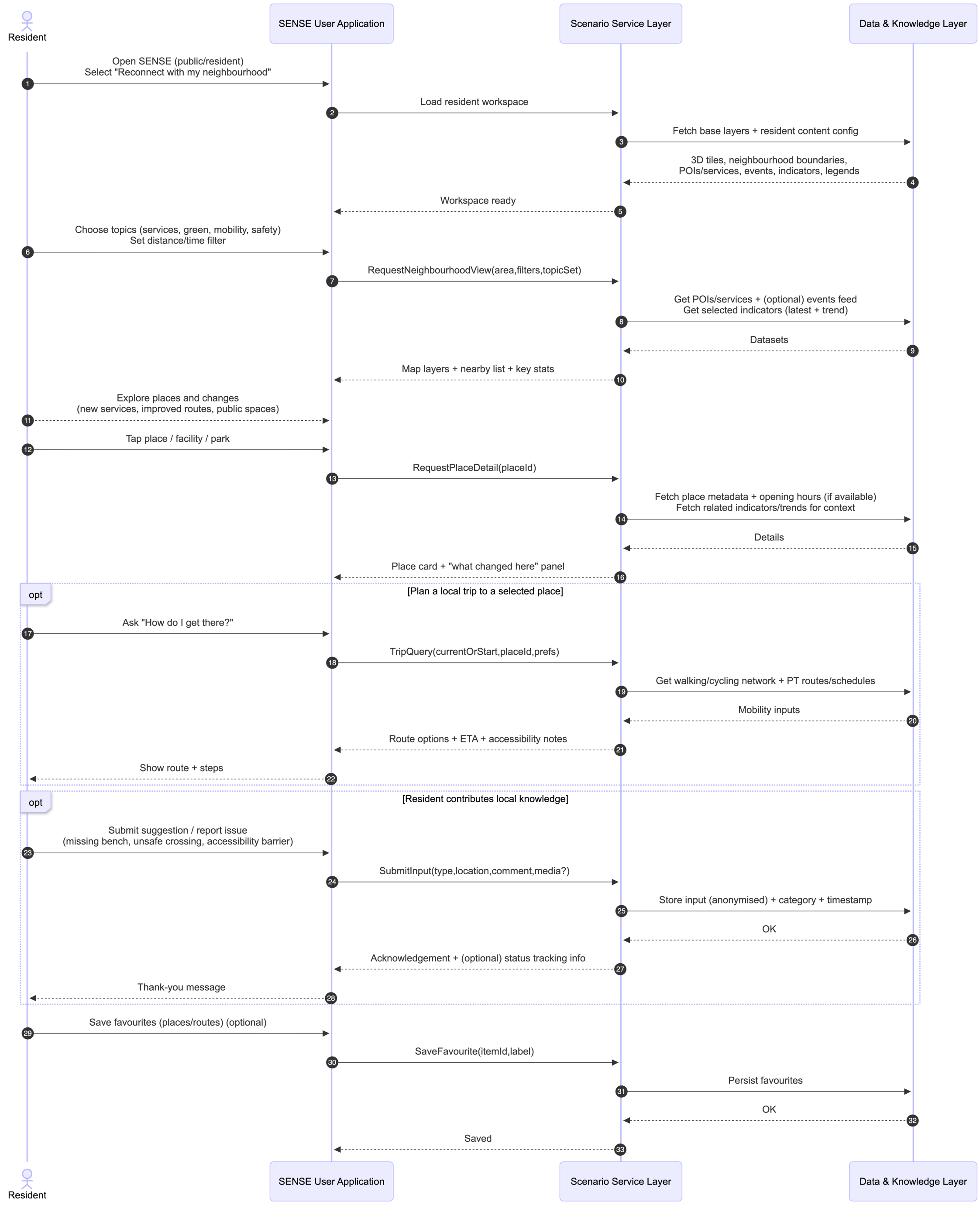

Figure 14. Sequence diagram for “Resident reconnecting with their neighbourhood”

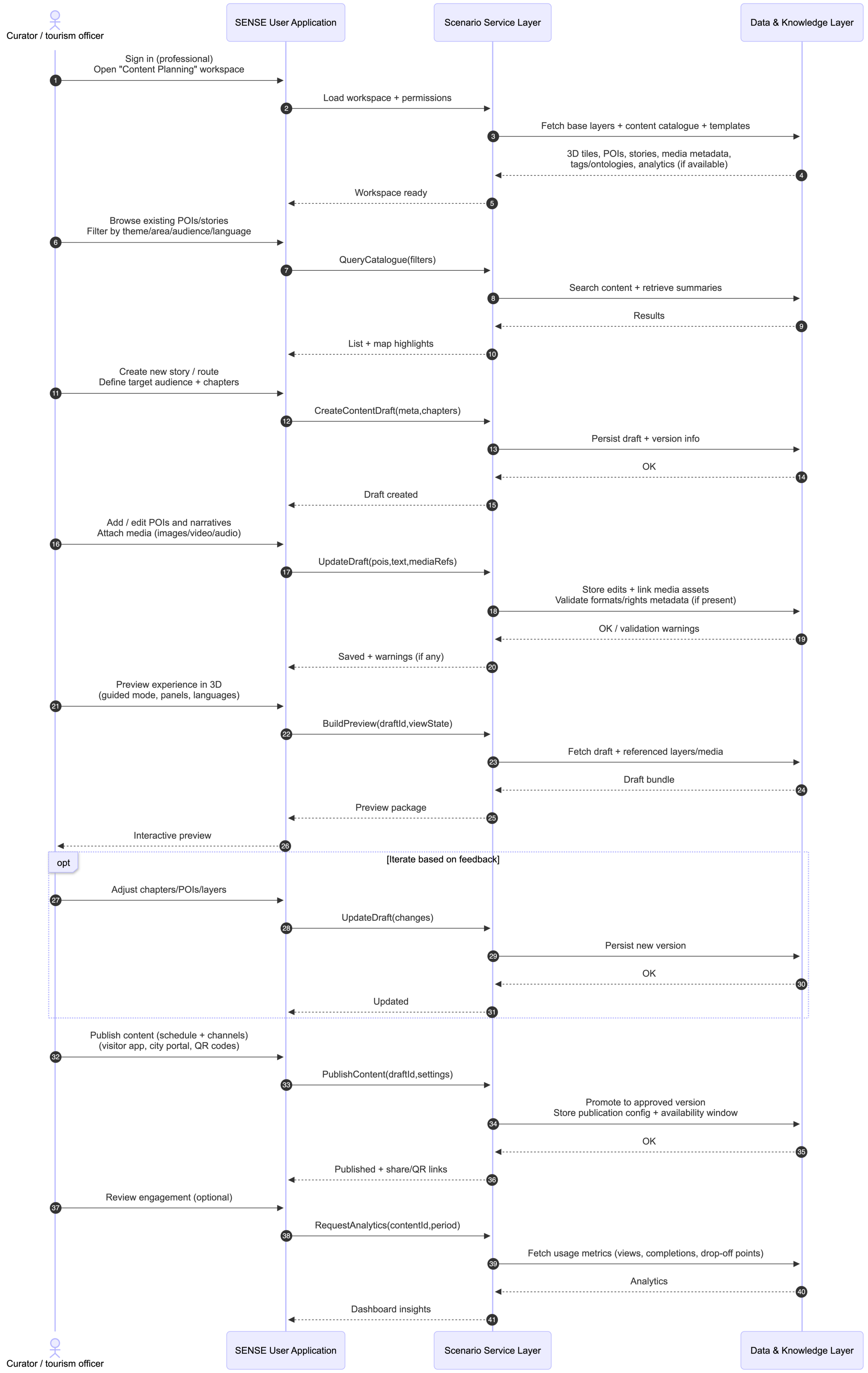

Figure 15. Sequence diagram for "Curator and tourism officer planning new content"

4.7.2 Input datasets

Below, we list the datasets published in the SENSE Data Space catalogue that are considered in the Kiel – *Hidden World* scenario. Collectively, these datasets provide: (1) the geospatial and semantic context (POIs and reference layers) to anchor the experience in the digital twin, (2) curated multimedia assets to enrich the narrative, and (3) structured tour definitions that drive guided storytelling and self-paced exploration in the 3D environment.

City of Kiel Geospatial Data

- **Type**: OGC GeoPackage (static / periodically updated).
- **Content**: Reference and thematic geospatial layers for Kiel, including Points of Interest (aligned with the OGC POI standard) and additional GIS layers used by the scenario (e.g., districts/neighbourhoods, waterfront features, paths or other context layers where available).
- **Use in the scenario**: Provides the spatial backbone for the 3D twin (basemap/overlays), supports POI discovery and filtering (by theme, time period, category), and supplies the stable spatial anchors used by the narrative engine (e.g., “fly-to POI”, highlight geometry, define tour stops, and attach story chapters to locations).

City of Kiel Media Data

- **Type**: Media package (static / curated).
- **Content**: Multimedia assets related to Kiel, including images and 3D models. This package complements the *City of Kiel Geospatial Data* dataset, which may include references (e.g., within POI attributes) linking features to corresponding media resources.
- **Use in the scenario**: Enriches user-facing panels and story-like explanations with contextual content (e.g., landmark imagery, archival illustrations when available, 3D representations of key sites). Media assets improve engagement and comprehension by allowing the user to connect locations in the 3D twin with historically or culturally relevant material.

City of Kiel Tour Narratives

- **Type**: JSON (static / curated).
- **Content**: Structured narrative tour definitions designed to support guided and self-paced experiences in the SENSE platform. Each tour is represented as an ordered sequence of stops linked to specific locations and POIs. For every stop, the dataset typically provides:
    - Geospatial information (latitude/longitude) and/or references to the corresponding POI identifiers in the *Kiel GeoPackage*.
    - Narrative content (titles, descriptive text sections, optional “did you know?” facts, calls to action).

   - Optional media references (e.g., image/3D model identifiers) to be presented in the 3D experience.
   - Tour metadata such as theme(s), interaction mode (e.g., guided vs. free exploration), intended transport mode (e.g., walking), and indicative duration/distance.
- **Use in the scenario**: Acts as the experience "script" for the client application: it orchestrates chapter progression, triggers map actions (fly-to, highlight, focus), and binds story text/media to POIs. It also enables multiple curated experiences (e.g., thematic routes) to reuse the same underlying geospatial and media assets while presenting different narratives for different audiences.

4.7.3 Underlying models

In this section we list the main models that can be considered in the development of the *Kiel – Hidden World* scenario. The models focus on (1) the 3D representation and spatial anchoring of cultural content, (2) the narrative/tour orchestration logic that drives guided experiences, and (3) supporting models for discovery, personalisation and content lifecycle management.

- **Kiel 3D City Model**. A high-quality 3D representation of Kiel (e.g., photorealistic 3D Tiles and supporting layers) forming the spatial foundation of the experience. It enables immersive navigation (pan/zoom/fly-to), viewpoint selection, and the contextual rendering of POIs and thematic overlays along the waterfront and in the "hidden" inner-city areas.

- **Kiel street network model**. A graph-based representation of the mobility system, modelling streets and intersections (as edges and nodes respectivily) and, where applicable, public transport stops/lines/interchanges. The graph is enriched with attributes required by the scenario (e.g., accessibility constraints and connection rules for intermodal transfers), supporting the route planning interactions described for citizens and visitors.

- **Route planner and multi-criteria optimisation**. A routing model operating on the street graph, with dynamic edge weights driven by near real-time context and user intent (e.g., thematic/tourism interest, accessibility needs, walking comfort, time available). The route planner can be implemented as a multi-criteria optimisation process (e.g., using a Dijkstra/A* family algorithm with dynamic costs), combining indicators such as travel time, walking effort, route simplicity (e.g., number of turns), and—where relevant—experience-oriented scores (e.g., scenic value or proximity to selected POIs).

- **POI and semantic place model (OGC POI-aligned)**. A structured model representing Points of Interest with stable identifiers, categories, multilingual labels (where available), and links to geometry and media. This model provides the semantic layer that connects the 3D twin to cultural and tourism content, enabling filtering (theme/era/type), search, and consistent referencing from tours and story chapters.

- **Narrative tour model (chapter/stop orchestration)**. A model describing each tour as an ordered sequence of stops/chapters with associated narrative content, media references and interaction metadata (e.g., guided vs. free exploration, intended transport mode, indicative duration). It orchestrates progression through the story and triggers map actions such as fly-to, highlight and focus at each stop.

- **View-state and interaction model (scene framing)**. A lightweight model that binds narrative steps to the 3D environment through view parameters (camera position, orientation, zoom/tilt) and spatial targets (POI geometry, buffered highlight areas). This ensures each chapter reliably reproduces the intended "scene" and viewpoint, improving storytelling quality and consistency across devices.

- **Content curation and publication model (versioning/provenance)**. A model supporting professional workflows to create, revise and publish tours and POIs with clear versioning (draft/review/published), validity windows, and provenance/attribution fields. This enables safe updates over time (e.g., adding new stops or media) while maintaining stable references for already published experiences.

5. Kiel - SEALEVEL

5.1 Scenario Overview

The SEALEVEL scenario in Kiel uses SENSE to support environmental education and climate awareness, with a strong focus on the marine and coastal environment around the Kiel Fjord. In this scenario, the SENSE 3D representation of the city is extended into its waterfront, harbour areas and coastal surroundings, so that users can explore the land–sea interface as a coherent spatial environment.

Users can navigate this extended 3D twin in a coastal exploration mode, where thematic markers are placed along the shoreline, in harbour basins and in marine zones of the fjord. Each marker provides scientific and educational information about topics such as local marine ecosystems and biodiversity, the geological formation and ecological relevance of the Kiel Fjord, and key oceanographic indicators including water temperature, pollution levels and overall water quality.

When interacting with these markers, users access explanatory content, audiovisual material and comparative views that illustrate how the marine environment is evolving over time and how human activities such as shipping, port operations, recreation and urban runoff affect it.

The SEALEVEL scenario is also conceived as the digital extension of the physical SEALEVEL exhibition in Holstenstraße. Exhibition modules, objects and stories are translated into spatially anchored “digital stations” within the twin. Stations that in the exhibition are experienced as physical installations (e.g. a model, an interactive screen or a video projection) are mirrored in the digital environment as interactive scenes that users can explore on their own devices or on large displays. In this way, the exhibition’s journey “from the coast to the deep sea” becomes accessible anytime and from anywhere, and can be experienced both inside and outside the physical venue.

Figure 16. Kiel – SEALEVEL Scenario

Overall, the scenario serves both as an engaging educational experience for citizens, schools and visitors and as a strategic communication tool for public authorities and port stakeholders, helping them to communicate climate-related risks (such as flooding or long-term sea-level rise) and to make the rationale for adaptation and protection measures more understandable.

5.2 Environmental and policy context in Kiel

Kiel is the first German city to commit to marine conservation at municipal level. Alongside efforts to reduce pollution and implement land-based and coastal protection measures, raising public awareness plays a central role. Understanding the state of the oceans and the pressures they face is intended to encourage behavioural change and individual responsibility, while early education helps to make an appreciation of marine ecosystems almost second nature.

To make this tangible for residents, schools and visitors, Kiel has organised the SEALEVEL temporary exhibition in the city centre (Holstenstraße). The exhibition offers an immersive journey “from the coast to the deep sea”, combining interactive stations, films and physical exhibits to communicate both the beauty of the ocean and the challenges it faces. It has evolved into a communication hub and meeting place, where people can encounter marine research, conservation issues and local initiatives in an accessible way.

A key success factor of SEALEVEL is the close cooperation with three major research institutions: GEOMAR, Kiel University / Kiel Marine Science (CAU/KMS) and Kiel University of Applied Sciences (FH Kiel). These partners contribute exhibits, objects and scientific content and, for the first time, present themselves jointly in a shared public format. Additional achievements include the development of an extracurricular education programme, high visitor numbers, and the strong linkage of marine and environmental education with tourism and city-centre marketing.

Figure 17. SEALEVEL Exhibition

For Kiel, the exhibition is an important element of stakeholder dialogue on marine protection and a further step towards establishing a marine visualisation centre (working title) – an edutainment facility focused on marine research and conservation that is currently in the conceptual phase.

The SENSE SEALEVEL scenario is conceived as a direct continuation of the SEALEVEL exhibition, extending its marine conservation and research content into an interactive digital environment. It preserves the exhibition's structure and partnerships, but opens them to new formats (3D visualisations, interactive maps, simple simulations) and new audiences who may not be able to visit the physical venue.

5.3 Objectives and expected impacts

The SEALEVEL scenario pursues the following overarching objective:

> To transform Kiel's SEALEVEL exhibition into a persistent digital experience embedded in the SENSE 3D twin, thereby strengthening environmental literacy, climate awareness and stakeholder dialogue on marine conservation.

This objective is articulated into the following specific objectives:

O1. Digital extension of the SEALEVEL exhibition

- Mirror the main exhibition modules ("coast", "fjord", "open sea", "deep sea", "human impact", "future oceans", etc.) as thematic stations within the SENSE coastal twin.
- Enable users to access exhibition content before, during and after a physical visit, and even if the temporary exhibition is no longer in place.
- Provide a flexible platform that can be reused later as part of a future marine visualisation centre.

O2. Environmental and climate literacy

- Explain key concepts related to the Kiel Fjord and the wider ocean (formation, circulation, ecosystems, human pressures) using intuitive, spatial visualisations.
- Make indicators such as water quality, sea-level variations, temperature and biodiversity visible and understandable for non-experts.
- Show how the marine environment changes over time and how it responds to different drivers (climate change, pollution, mitigation measures).

O3. Educational support

- Offer schools and universities a set of ready-to-use digital materials aligned with the physical exhibition and with curricular topics (e.g. climate change, ecosystems, sustainability).
- Allow teachers to combine physical visits with preparatory or follow-up digital activities, including homework tasks that use the 3D twin.

- Provide accessible content formats (short texts, simple diagrams, animations, quizzes) suitable for different age groups.

O4. Policy communication and stakeholder dialogue

- Provide the city administration and research institutions with a shared visual reference for explaining sea-level rise, flood risk and adaptation measures.
- Support participatory processes by allowing stakeholders to explore scenarios and leave feedback anchored to specific locations or themes.
- Increase transparency by clearly showing where data and statements come from (e.g. which research institute or monitoring programme).

The expected impacts of the scenario can be grouped into two broad categories:

Short-term impacts

- Stronger and more durable impact of the SEALEVEL exhibition, as its key messages and materials remain available digitally beyond the temporary physical setup.
- Higher reach of marine education content, including remote users and groups who cannot travel to the exhibition.
- More attractive communication materials for events, workshops and public meetings, reusing SENSE visualisations.

Medium- to long-term impacts

- Better informed citizens and school students, with a clearer understanding of marine ecosystems, local environmental pressures and climate risks.
- Enhanced legitimacy and acceptance of climate adaptation and marine protection measures, supported by accessible visual explanations.
- A mature digital platform that can be integrated into the planned marine visualisation centre and replicated or adapted in other coastal cities.

5.4 Stakeholders, user groups and role

The SEALEVEL scenario builds on the stakeholder ecosystem already created around the physical exhibition and extends it into the digital sphere. Based on the engagement mapping in D6.1, we can distinguish the following actors.

Primary user groups

- **Families and individual citizens**

  Families and individual citizens explore the fjord and the exhibition content at home or on mobile devices, often in short sessions. They need intuitive, visually engaging interfaces that do not require any prior knowledge.

- **Visitors and tourists**

  Visitors and tourists may discover the digital exhibition through city marketing or during a stay in Kiel, and use it to gain orientation and contextual information about the fjord and about Kiel's commitment to marine protection.

Scientific and educational partners

- **GEOMAR, CAU/KMS, FH Kiel**

  GEOMAR, CAU/KMS and FH Kiel provide scientific content, data and exhibits, and validate the messages and narratives presented in the scenario. They use the platform for science communication and outreach, for example by showing how their research relates to local conditions.

- **Museums and educational initiatives**

  Museums and educational initiatives integrate SENSE visualisations into workshops, guided activities or exhibitions outside Holstenstraße and contribute their own materials to the digital exhibition catalogue.

Public authorities and port stakeholders

- **City of Kiel**

  The City of Kiel (environment, climate, education, culture, city marketing) uses the scenario to communicate strategies and measures, coordinate events and monitor engagement. City departments have editorial roles for certain content areas and access to analytics.

- **Port authority and maritime businesses**

  The port authority and maritime businesses provide information on measures to reduce emissions and environmental impact and use the platform to demonstrate their contribution to marine protection.

Roles are differentiated by access rights:

- **Public users:** read-only access to exhibition stations, indicators and basic interaction features.
- **Educators / facilitators:** can assemble "collections" of stations for a specific class or event, add annotations and view simple usage statistics.
- **Content curators:** can create, modify and approve exhibition stations and associated media, in coordination with research institutions and the city.
- **Administrators:** manage roles, data sources, technical configuration and links to the SENSE Data Space.

5.5 Functional description of the use case

5.5.1 Coastal and marine 3D twin

The technical backbone of the scenario could be a coastal and marine 3D twin of Kiel, which may include the following features:

- **Seaward extension of the city twin:** the existing SENSE 3D city model could be extended into the fjord, including harbour infrastructure, shoreline areas, beaches and key marine zones.
- **Land–sea navigation:** the interface could support smooth navigation over land and water with standard interactions (pan, rotate, zoom) and a set of predefined viewpoints (e.g. inner harbour, outer fjord, city centre).
- **Base layer management:** users could be able to toggle base layers on and off (e.g. terrain, bathymetry, reference maps), so they can focus on the information most relevant to their needs.
- **Time control:** a simple time slider could allow switching between “typical conditions”, selected historical situations (e.g. notable storms or floods) and projected future states (e.g. sea-level rise scenarios).
- **POI interaction:** users could access contextual information by clicking/tapping on a point of interest, opening an information panel with key attributes such as description, status and multimedia resources.
- **Search and centring:** the system could include search functionality for addresses or POIs and automatically centre the view on the selected location.

Overall, this twin would not necessarily be intended as a high-precision planning tool, but rather as a visually coherent “stage” on which exhibition content, environmental data and explanatory narratives can be placed.

5.5.2 Digital SEALEVEL exhibition layers

The physical SEALEVEL exhibition could be translated into a set of digital exhibition layers anchored in the 3D twin. The following capabilities could be supported:

- **Stations and themes:** each physical station (e.g. “Coastal ecosystems”, “Deep sea”, “Human impacts”) could be represented as a digital station with a clear icon and name, and stations could be grouped into thematic collections reflecting the exhibition’s narrative structure (“from the coast to the deep sea”).
- **Content capsules:** for each station, content could be packaged into small, self-contained capsules such as short explanatory texts, diagrams, photos, animations, infographics or short videos. Some capsules could be linked to specific real-world locations (e.g. a seagrass meadow in the fjord), while others could remain conceptual (e.g. simplified global ocean circulation).
- **Interactive visualisations:** simple interactive components could allow users to change parameters (for example via sliders for sea-level rise, pollution levels or water

temperature) and immediately see the effect on the map or on an illustrative graphic. Where feasible, these visualisations could be based on real data provided by partner institutions.

- **Context and provenance:** each station could indicate which institution provided the content (e.g. GEOMAR, CAU/KMS), include links to further resources, and clarify whether displayed values are measured, modelled or illustrative.
- **Layer toggling and comparison:** digital exhibition layers could be switched on and off, allowing users to focus on a subset of themes or to compare how different aspects (ecosystems, human activities, risks, measures) overlap spatially.

5.5.3 Citizen and visitor functionalities

For non-expert users, the SEALEVEL scenario could behave as a digital exhibition embedded in a map:

- **Browse by theme or location**: users could start from a thematic view (list of exhibition themes) or from the map (clicking on an area of interest). Selecting a theme highlights relevant stations in the map; selecting a station opens a panel with content capsules and interactive elements.
- **Multi-device use**: at home or in school, the digital exhibition could be accessed on laptops, tablets or desktop computers via a web browser. On-site, it could be made available on kiosks or large displays inside or near the exhibition, as well as on visitors' own mobile devices.
- **Lightweight interaction and "micro-tasks"**: users could answer simple questions, compare before/after states, or drag sliders to "see what happens" (for example, raising sea level by 0.5 m, 1 m or 2 m). If implemented, the results of such micro-tasks could be shown in aggregate (e.g. "70% of today's users estimated correctly that…"), helping to reinforce learning.
- **Accessibility and languages**: texts and interface could be available in German and English, with the option to add further languages relevant to visitors. Content could be designed to be accessible for different reading levels; where possible, key messages can be also recorded as short audio clips.

5.5.4 Professional and policy communication tools

For professional users and institutional partners, the SEALEVEL scenario could be complemented with additional features designed to support public communication, coordination and reporting, such as:

- **Scenario views for communication**: preconfigured views combining selected exhibition stations, key indicators and interactive visualisations that could be used in public meetings, workshops or press briefings.
- **Presentation mode**: an optional mode that could hide non-essential controls and allow simple navigation via on-screen buttons or a remote-control setup for large displays.

- **Content authoring and updating**: web-based tools that could enable authorised users to upload new media, edit texts and assemble structured content capsules for each exhibition station.
- **Review and approval workflow**: a workflow that could support proposing changes, scientific/curatorial review (e.g. by GEOMAR or other partners) and publication of approved updates only.
- **Analytics and reporting**: aggregated usage statistics that could show which stations are most viewed, which themes attract the most attention and how users typically interact with the content.
- **Export capabilities**: functions that could allow selected analytics outputs (and potentially screenshots or predefined views) to be reused in project deliverables, communication materials and policy reports.
- **Link to a future marine visualisation centre**: configuration options that could facilitate reuse of the digital scenario in a future physical centre, for example by supporting kiosk deployments, connections between kiosks and personal devices, or interactions between digital content and physical exhibition elements.

5.6 User journeys

The following journeys illustrate how different actors might interact with the SEALEVEL scenario. As in other scenarios, these narratives are aspirational and may include functionalities that go beyond what can be implemented within the SENSE project timeframe.

5.6.1 Family exploring the fjord from home

A family living in Kiel hears about the SEALEVEL exhibition but cannot visit immediately. One evening, they open the digital exhibition on a tablet. From the theme list, they choose “From the coast to the deep sea” and see a sequence of stations spanning from the shoreline to the open Baltic.

They start at the coast, looking at an illustration of the beach ecosystem and a short video about dune protection. Then they jump to the “Deep sea” station, which is not physically located in Kiel but linked to global ocean processes. An animation shows how sinking particles from surface waters feed deep-sea organisms. The children answer a few quiz questions embedded in the station and earn a digital “ocean explorer” badge.

Later, when they visit Holstenstraße in person, the children immediately recognise familiar scenes on the physical exhibits and proudly explain them to their parents.

5.6.2 Climate officer preparing a public information event

A climate officer is planning a neighbourhood meeting about flood risk and adaptation measures along the waterfront. In the SENSE SEALEVEL scenario, they open a preconfigured “Coastal risk and protection” view.

The view shows the city’s coastline with overlays for current sea level, historical high-water events and projected inundation areas for 2050 and 2100. Relevant exhibition stations – such as “Storm surges”, “Dikes and barriers” and “Nature-based solutions” – are visible as icons. The officer clicks on each station to check the explanations and ensure that messages are aligned with the latest municipal strategy.

During the meeting, the SEALEVEL view is projected on a large screen. The officer moves between stations, explains how the projections were derived, and activates a slider to demonstrate how much extra area would be flooded if emissions follow a higher trajectory. Citizens ask about specific locations; the officer zooms in and uses annotations to record concerns and suggestions directly on the map.

5.6.3 Research institution showcasing its work

GEOMAR plans an open day and wants to highlight how its research feeds into public communication. Staff use the content authoring tools to create a new station called “Measuring the fjord”. They upload a short video taken on a research vessel, add a simplified diagram of instruments used, and link the station to a location in the fjord where regular measurements are taken.

On the open day, visitors can explore this station on large touchscreens and then step outside to view the fjord itself. After the event, the station remains in the SENSE SEALEVEL scenario, increasing the visibility of GEOMAR’s work for a wider audience.

From a technical perspective, all these journeys involve interactions between the SENSE web client, the SEALEVEL scenario back-end (managing stations, content capsules and visualisations) and the SENSE Data Space (providing spatial data, environmental indicators and metadata).

5.7 Technical foundations

This section highlights the key technical aspects for implementing the scenario, including both common elements across SENSE scenarios and scenario-specific considerations.

5.7.1 Interaction flows

The sequence diagrams below define the interaction flows associated with the user journeys described in the previous section, illustrating the expected end-to-end behaviour of the scenario. The diagrams are based on the core components introduced in Section 2.7.1: (1) the SENSE User Application, (2) the Scenario Service Layer, and (3) the Data & Knowledge Layer.

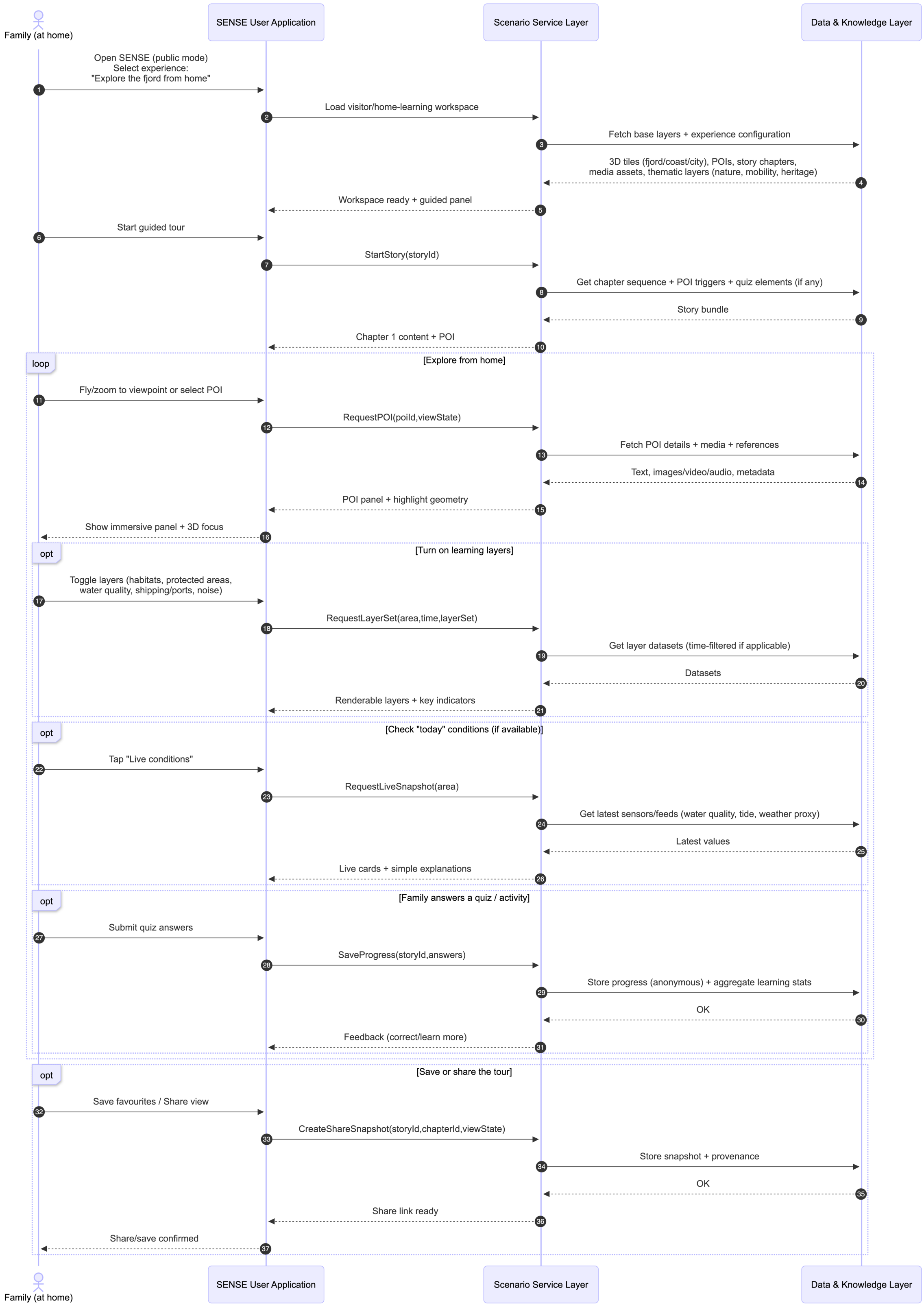

Figure 18. Sequence diagram for “Family exploring the fjord from home”

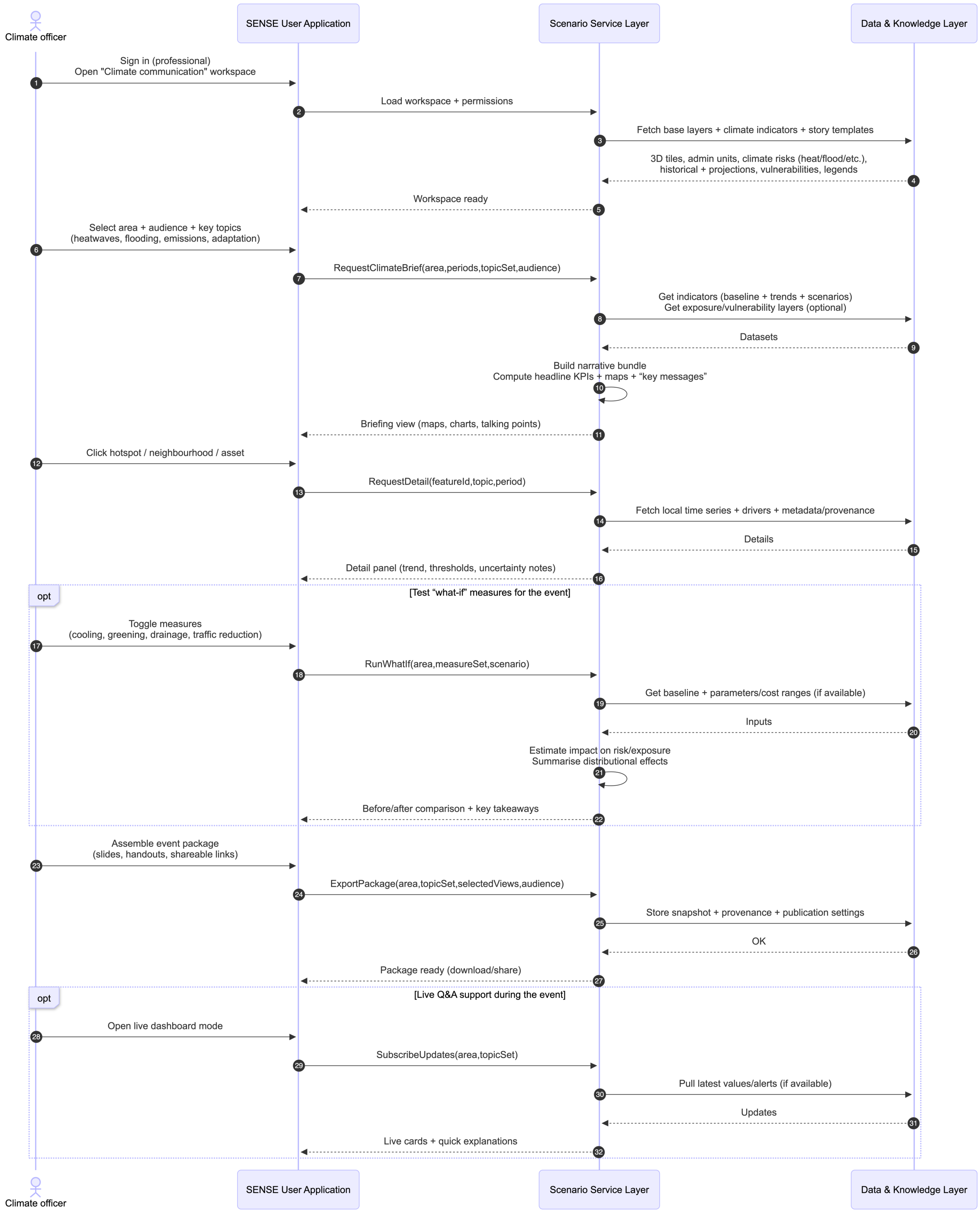

Figure 19. Sequence diagram for "Climate officer preparing a public information event"

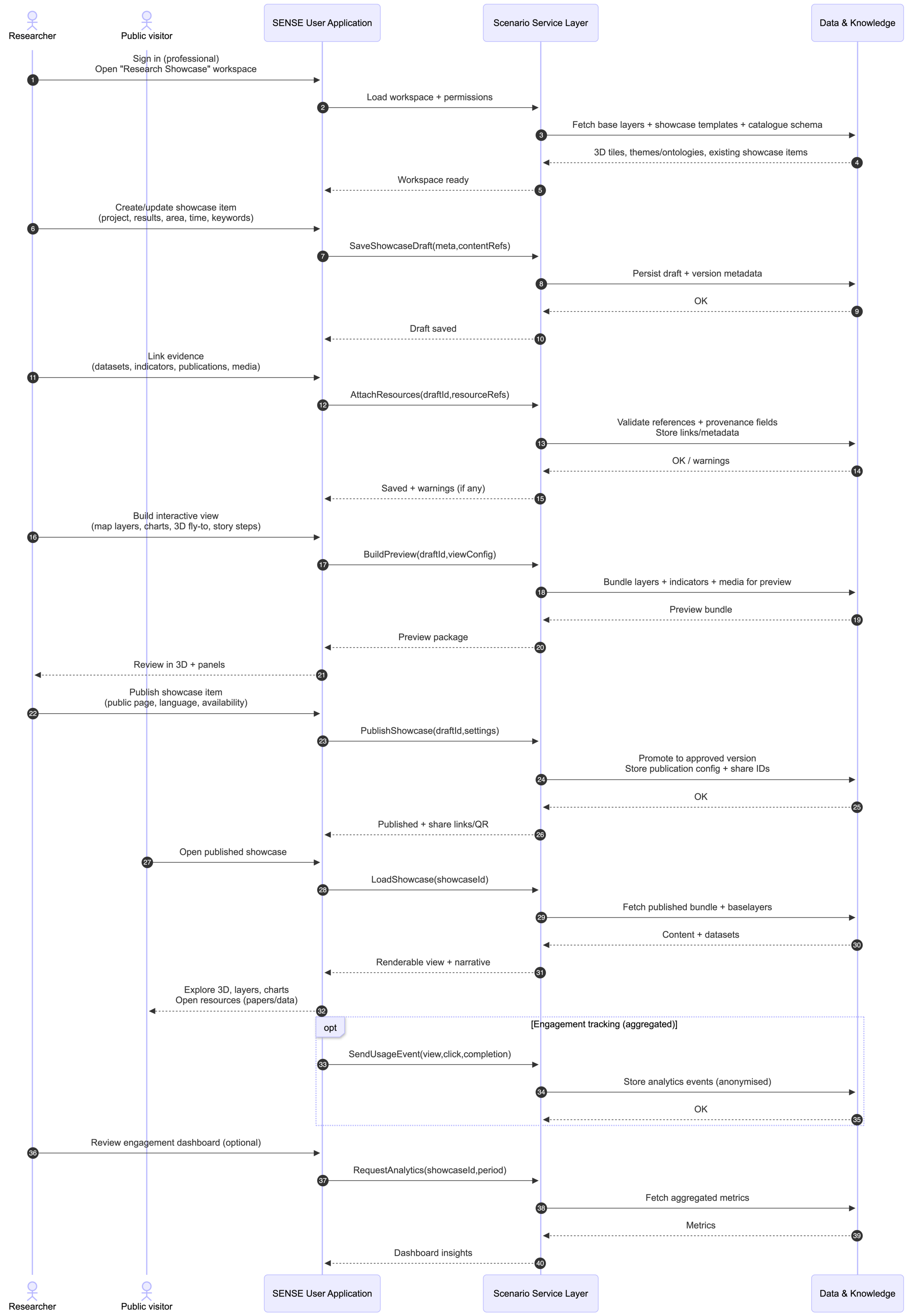

Figure 20. Sequence diagram for “Research institution showcasing its work”

5.7.2 Input datasets

Below, we list the datasets published in the SENSE Data Space catalogue that are considered in the Kiel – SEALEVEL scenario. Together, these datasets provide: (1) the geospatial context needed to anchor content and indicators in the 3D twin (coast, fjord, POIs and reference layers), (2) curated multimedia and exhibition content to support ocean literacy and public communication, and (3) marine and coastal observations used to visualise environmental conditions and explain human impacts and climate-related risks.

City of Kiel Geospatial Data

- **Type**: OGC GeoPackage (static / periodically updated).
- **Content**: Reference and thematic geospatial layers for Kiel, including Points of Interest (aligned with the OGC POI standard) and additional GIS layers relevant to the coastal and fjord context (e.g., districts/neighbourhoods, waterfront features, paths, viewpoints, and other reference layers where available).
- **Use in the scenario**: Provides the spatial backbone for the 3D twin (basemap/overlays) and supports POI discovery and filtering (e.g., nature, marine science, coastal protection, education). It also supplies stable anchors for interactive actions such as "fly-to POI", highlighting coastal areas, and linking explanatory chapters to specific locations along the fjord.

City of Kiel Media Data

- **Type**: Media package (static / curated).
- **Content**: Multimedia assets related to Kiel, including images and 3D models. This package complements the *City of Kiel Geospatial Data* dataset, which may include references (e.g., within POI attributes) linking features to corresponding media resources.
- **Use in the scenario**: Enriches user-facing explanations with contextual visuals (e.g., shoreline views, coastal protection examples, marine habitats, infrastructure). Media assets improve comprehension by connecting mapped information (layers/indicators) with tangible real-world examples and educational material.

City of Kiel Water Data

- **Type**: Data service (dynamic / periodically updated).
- **Content**: Publishes coastal and fjord-related measurements for a range of hydrological and marine environmental parameters, such as water level, water temperature, salinity, and—where available—additional indicators related to water quality and biodiversity.
- **Use in the scenario**: Provides the live or recent environmental state that users can explore in the twin (e.g., "current conditions" panels). It supports educational storytelling (how conditions vary by location/season), helps contextualise risks (e.g., high water levels), and enables the comparison of observed values against reference ranges, thresholds, or historical summaries (where these are available in the catalogue).

City of Kiel SEALEVEL Exhibition

- **Type**: Media package (static / curated).
- **Content**: Digital assets derived from the SEALEVEL exhibition, including narrative modules, descriptive texts, visuals, and other educational resources prepared for public engagement (potentially organised as "stations" or thematic chapters).
- **Use in the scenario**: Acts as the curated educational layer of the experience: it drives guided exploration (e.g., "chapters" on pollution, ecosystems, coastal protection, sea-level rise), provides interpretive text and visuals to accompany map layers and live water data, and supports reuse of exhibition content beyond the physical venue (e.g., schools, home learning, public communication campaigns).

5.7.3 Underlying models

In this section we list the main models that can be considered in the development of the Kiel – SEALEVEL scenario. The models focus on (1) the 3D representation bridging land and sea, (2) the marine/environmental indicator logic used to explain conditions and risks, and (3) the narrative/exhibition orchestration that supports public communication and education.

- **Kiel land-sea 3D twin model.** A 3D representation combining the city context with the fjord/coastal setting (e.g., photorealistic 3D Tiles and supporting layers). It provides the spatial foundation for exploring the waterfront and marine environment, enabling immersive navigation, viewpoint selection, and the visual anchoring of POIs and thematic layers that extend into the fjord.
- **Coastal and marine geospatial reference model.** A set of reference layers describing the shoreline and coastal/fjord features (e.g., coastline, waterfront assets, protected or sensitive areas where available, and monitoring station locations). This model enables consistent georeferencing of marine observations and supports spatial queries such as "conditions at/near this location" or "compare areas along the fjord".
- **Metocean and water-quality indicator model.** A modelling layer translating water-related observations into interpretable indicators and map layers (e.g., water level, temperature, salinity and other available water-quality proxies). It supports aggregation over time windows, comparison against reference ranges/thresholds (when defined), and the generation of simple status summaries for public-facing communication (e.g., "today's conditions" panels).
- **SEALEVEL exhibition 3D model.** A 3D representation of the SEALEVEL exhibition (e.g., exhibition floor layout and/or simplified 3D geometry of the main "stations", panels or interactive elements), used as a digital entry point to the experience. It enables users to navigate the exhibition virtually, select stations in a spatially intuitive way, and launch the corresponding narrative modules. Each station can be linked to specific fjord locations, datasets and indicator views in the land–sea twin (e.g., "water quality", "pollution", "sea-level rise"), ensuring continuity between the physical exhibition, the curated storytelling content and the underlying environmental evidence.

- **SEALEVEL exhibition narrative model.** A structured model (chapters/stations) that orchestrates the educational experience by connecting curated content (texts, images, media modules) with locations and layers in the twin. It controls progression (guided vs. free exploration), triggers "fly-to" viewpoints, and ensures that each story element is paired with the relevant indicators and map context.

6. Development plan

The development of the SENSE pilot scenarios will follow an incremental approach that balances (1) fast prototyping and technical feasibility checks, (2) high-quality “professional” pilot views that can support real operational workflows, and (3) a later adaptation towards public/citizen-facing access with higher scalability requirements. This staged approach reflects the common SENSE scenario structure (User Application ↔ Scenario Service Layer ↔ Data & Knowledge Layer / Data Space) and supports reuse across the Cartagena and Kiel pilots.

The following phases are expressed as indicative project periods rather than fixed dates, and may overlap where technical work and stakeholder validation can run in parallel.

6.1 Phase 1. First demos – tools and architecture design experimentation

The objective of Phase 1 is to put in place a working technical foundation for the SENSE pilots and to de-risk the most critical interactions early. The focus is therefore on feasibility and integration, rather than completeness: we aim to demonstrate that the full chain works (from user interaction to data access and visual output) with representative content for both cities.

At the time of writing this deliverable, Phase 1 is already underway, with initial prototyping activities and integration experiments being executed to validate the architecture and the first end-to-end scenario flows.

During this phase, the expected scope and outcomes are:

- **Baseline system architecture (v1).** Establish the initial separation between the SENSE User Application (frontend), the scenario service layer, and the connected Data & Knowledge Layer / Data Space. This includes practical conventions for scenario configuration (e.g., which layers and viewpoints are available), layer activation/deactivation, and view-state management (e.g., camera position, time slider state, selected POIs). Figure 21 presents a preliminary and simplified architecture illustrating the integration of data providers, the SENSE Data Space, and scenario services (based on Unreal/Cesium components).
- **Development environment and delivery pipeline.** Set up shared repositories and baseline engineering workflows, including CI/CD building blocks, dev/staging deployments, and common asset pipelines for 3D content, basemaps and multimedia resources. The aim is to allow partners to iterate rapidly while keeping the builds reproducible and deployable.
- **3D twin “skeleton” for both cities.** Produce early, navigable 3D representations for Cartagena and Kiel with a minimal set of interactions (pan/zoom/rotate, “fly to” viewpoints, POI selection, and layer toggles). These initial models can include placeholders and simplified geometry: the key validation is performance, navigation usability, and consistency of interaction patterns. Early experiments may leverage Unreal and Cesium to accelerate visual prototyping and test rendering performance. Figure 22 and Figure 23 illustrate an example 3D visualization of Cartagena and Kiel.

- **Early data visualisation and integration spikes.** Connect a small number of representative sources (both static and dynamic) to validate: (1) ingestion and access patterns via the Data Space, (2) the required adapters/format conversions, and (3) how the data should be visualised in the 3D twin (e.g., overlays, markers, heatmaps, time-series panels). This work is aligned with the data integration architecture and Data Space approach defined in WP2 and WP3 deliverables.
- **Walkthrough demos aligned with user journeys.** Deliver end-to-end walkthroughs for at least one user journey per city to confirm that the complete loop works: user action → scenario backend orchestration → data retrieval → visual rendering in the frontend. These walkthroughs are used as early validation with pilot stakeholders and as a baseline for later refinements.

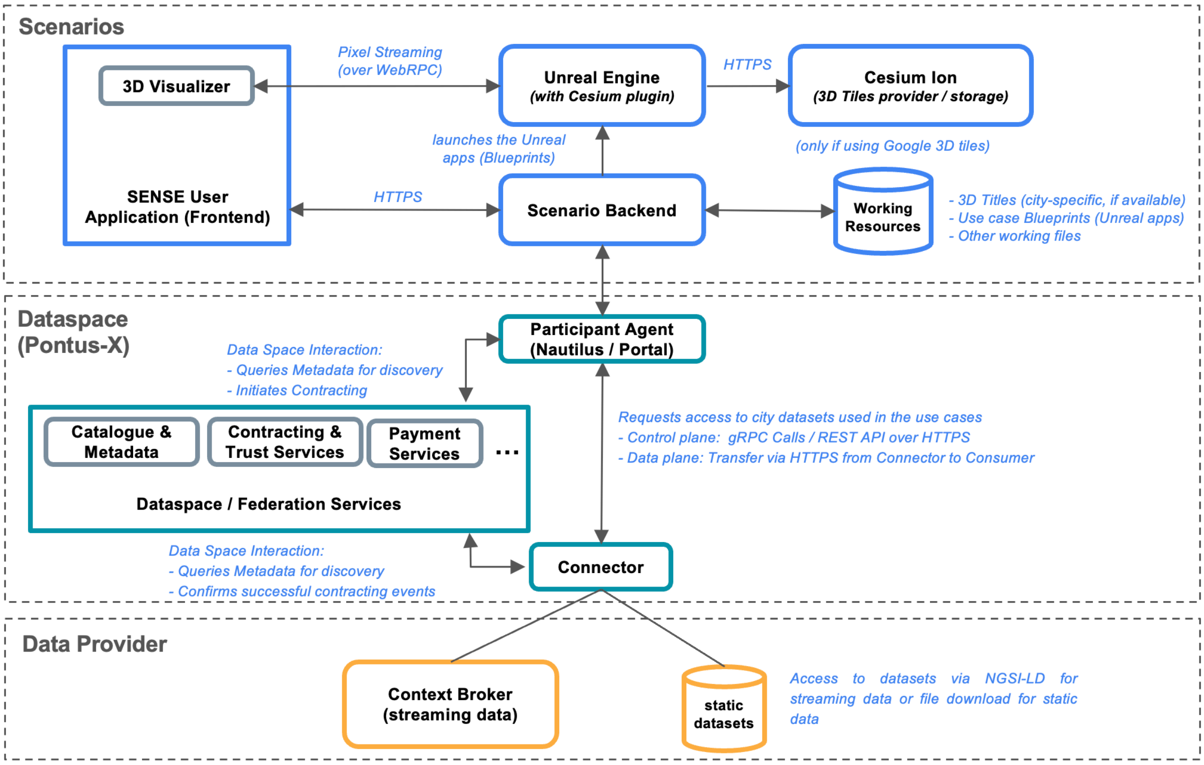

Figure 21. Simplified version of the SENSE architecture

Figure 22. Example of 3D Digital Twin of Cartagena built in Unreal using Cesium

Figure 23. Example of 3D Digital Twin of Kiel build in Unreal using Cesium

6.2 Phase 2. Scenarios for professionals

The objective of Phase 2 is to evolve the initial technical prototype into a first operational pilot that supports professional users (e.g., city staff, operators, curators and technical teams). Building on the validated foundations from Phase 1, the focus shifts to delivering scenario-specific functionality, higher data fidelity, and workflows that can be used in realistic operational contexts.

While Phase 1 focuses on feasibility, Phase 2 focuses on usefulness: providing the capabilities required to complete professional tasks end-to-end (analysis, monitoring, reporting, content management), even if the system is not yet optimised for very large numbers of concurrent users.

During this phase, the expected scope and outcomes are:

- **Professional user workflows and features.** Implement the core features required by professional user journeys, such as advanced navigation and filtering, richer inspection panels, time controls (e.g., replay or comparison), and export or reporting capabilities where relevant.
- **Scenario-specific logic and orchestration.** Extend the scenario service layer so that each pilot can encode its specific business logic (e.g., how layers combine, which indicators are computed, what constitutes an event/alert, how narrative steps progress), while still reusing shared platform components.
- **Role-based access and administrative functions.** Introduce authentication and role-based permissions where needed (e.g., professional vs. admin/editor roles), including functions such as content/layer configuration, controlled publication, and internal-only views.
- **Improved data integration and richer visualisations.** Expand the set of connected data sources and improve the quality of the visual representation (e.g., thematic overlays, time-series charts, interactive POIs, aggregated indicators), including more robust handling of updates and metadata.
- **Performance tuning for professional use.** Optimise the runtime for smooth interaction in professional environments (often fewer but more demanding users), including initial decisions on rendering strategies (client vs. server-side rendering where justified by visual quality requirements).

6.3 Phase 3. Adaptations for citizens, visitors and broader public access

The objective of Phase 3 is to adapt the pilots for public-facing access, ensuring that the experience remains intuitive, performant, and safe when opened to citizens and visitors. This phase prioritises scalability and simplicity: public users typically have shorter sessions, different devices (including mobile), and require clearer guidance and storytelling than professional users.

Compared to Phase 2, the key shift is from “feature richness” to accessible UX, controlled content, and higher concurrency readiness.

During this phase, the expected scope and outcomes are:

- **Public UX and interaction simplification.** Provide a streamlined user experience with clear entry points (e.g., tours, recommended viewpoints, featured layers), simplified controls, and explanatory context for indicators and maps.

- **Scalable delivery modes.** Adapt technical choices to support more concurrent users (e.g., progressive loading, level-of-detail strategies, caching, simplified layer sets, or alternative rendering approaches for public mode if needed).
- **Narratives and curated content.** Strengthen the storytelling and interpretation layer, including curated POIs, guided tours (e.g., for exhibition-style experiences), and consistent "why this matters" explanations.
- **Governance, privacy, and content safeguards.** Apply the necessary protections for public release (e.g., aggregation thresholds, reduced precision, removal of sensitive layers, moderation/approval workflows for publishable content).
- **Feedback and usability iteration.** Incorporate mechanisms to collect feedback and observe usability issues, enabling iterative improvements based on real usage patterns and stakeholder evaluation.

6.4 Phase 4. Operational improvements

The objective of Phase 4 is to harden the pilots into stable, maintainable services and to consolidate the results into assets that support longer-term operation and replication. This phase focuses on reliability, maintainability, and operational readiness, ensuring the solutions can run consistently and be managed efficiently over time.

During this phase, the expected scope and outcomes are:

- **Operational hardening and observability.** Improve monitoring, logging, error handling, and alerting across the full chain (frontend ↔ scenario services ↔ data access), supported by clear operational procedures (e.g., incident response, backup/restore).
- **Data pipeline robustness.** Stabilise connectors and refresh cycles for dynamic sources, improve metadata quality, and formalise ingestion/update processes to reduce manual interventions.
- **Security and resilience.** Strengthen security measures (access control reviews, dependency management, secure deployment practices), and improve resilience (graceful degradation when a data source is unavailable, fallbacks for visual layers).
- **Documentation and replication assets.** Produce reusable artefacts such as deployment guidance, scenario configuration templates, onboarding checklists for new data sources, and lessons learned to support replication beyond the initial pilot cities.
- **Performance and cost optimisation.** Optimise runtime performance and operational footprint (e.g., caching strategies, resource sizing, deployment patterns) to ensure sustainable operation.

Figure 24 and Figure 25 present a conceptual mock-up illustrating how the SENSE interface could look at the end of the project.

Figure 24. Mock-up of the *Smart Urban Mobility* scenario in Cartagena

Figure 25. Mock-up of the *Hidden World* scenario in Kiel

6. Conclusions

This deliverable defines the SENSE pilot scenarios for Cartagena and Kiel and describes the foundational models and enabling technologies that will be used to implement them, providing a shared basis for the subsequent design, integration and validation activities across the pilots.

Across the different use cases, the document consistently frames each scenario through (1) its urban/policy context and expected impacts, (2) stakeholders and user roles, (3) a functional description of the target solution, and (4) concrete user journeys and interaction flows.

On the technical side, the deliverable establishes a common, reusable scenario structure built around three core components: SENSE User Application, Scenario Service Layer, and Data & Knowledge Layer connected to the SENSE Data Space. This separation is central to ensuring that different scenarios can share a consistent frontend and data foundation, while implementing scenario-specific logic and content orchestration in dedicated backend services.

The scenario definitions illustrate how SENSE can support both (1) operational and analytical workflows for municipal professionals (e.g., monitoring and decision-support, indicator exploration, reporting), and (2) public-facing experiences for citizens and visitors (e.g., guided cultural narratives, educational exploration, accessible thematic layers). The Kiel SEALEVEL scenario, for example, explicitly connects the SENSE coastal twin with curated “digital stations” derived from the physical exhibition and with marine indicators that make environmental conditions and climate risks understandable to non-experts.

Finally, the deliverable outlines an incremental development approach with four phases, moving from early feasibility demos to professional-grade pilots, then to public-facing adaptations and operational hardening. At the time of writing, the project is already executing Phase 1, focusing on tool experimentation, first architecture validation and initial end-to-end demonstrations.