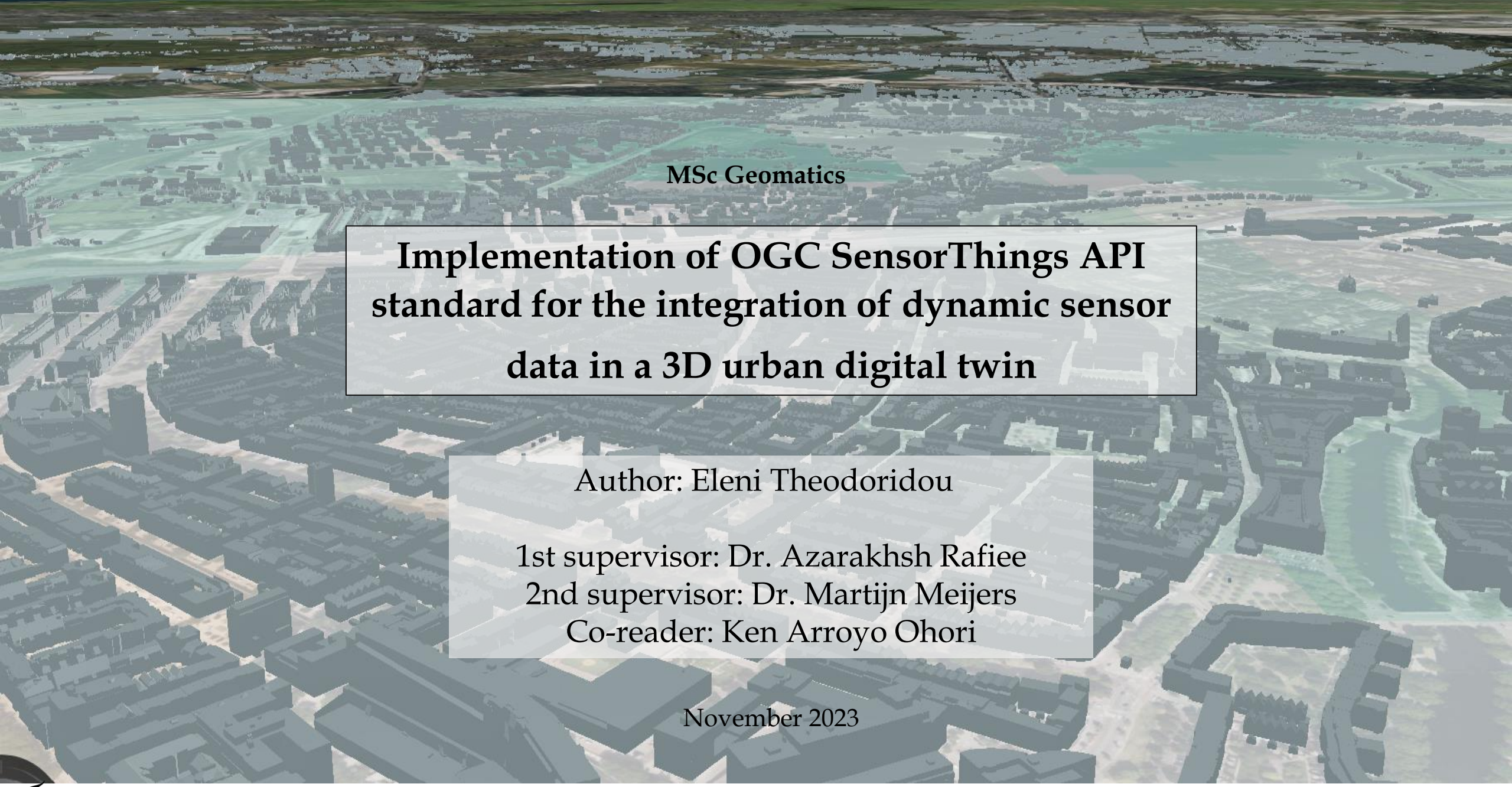


MSc Geomatics

Implementation of OGC SensorThings API standard for the integration of dynamic sensor data in a 3D urban digital twin

Author: Eleni Theodoridou

1st supervisor: Dr. Azarakhsh Rafiee
2nd supervisor: Dr. Martijn Meijers
Co-reader: Ken Arroyo Ohori

November 2023

TU Delft

Urban Areas

INTRODUCTION

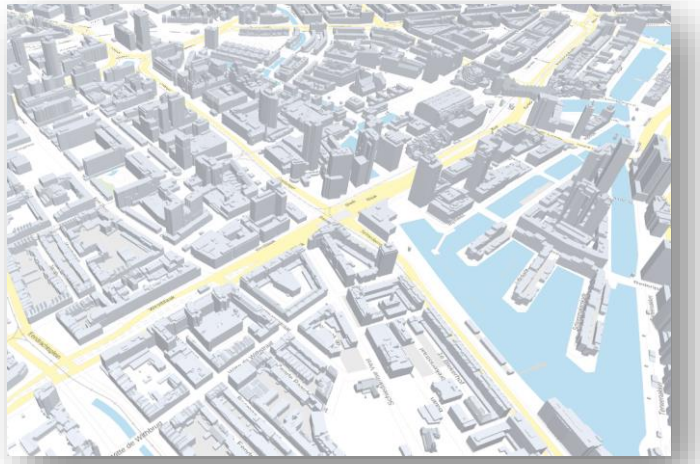
Resilience

- Enables cities to effectively respond to shocks and stresses (natural disasters)
- Generates economic benefits
- Promotes environmental sustainability

Urban Digital Twins

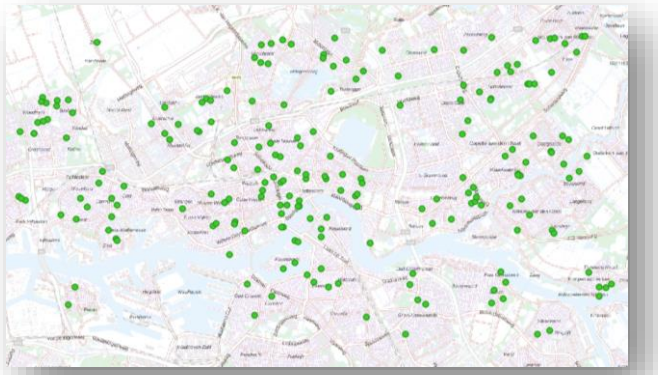
Static Elements

- Represent the physical aspects of the city.
- Include buildings, roads, infrastructure, and topography.
- 3D city models



Dynamic Elements

- Comprise variables like traffic flow, air quality, and weather sensor data.
- Enable cities to monitor, analyze, and respond to changing conditions.
- Crowdsourced sensor data enriches dynamic elements



- ❑ Urban Digital Twins are virtual replicas of real-world cities
- ❑ Provide a holistic view for urban planning, management, and decision-making
- ❑ Contribute to urban resilience and sustainability

Motivation, objective and research questions

Motivation

Lack of interoperability, the ability to exchange data between different systems

Lack of standardization among urban digital twins approaches

Current representations of dynamic data are limited in scope and effectiveness

Pressing need for tools to efficiently integrate and visualize dynamic data

Data acquisition is closely connected to sparse sensor network distribution and heterogeneous sensor data

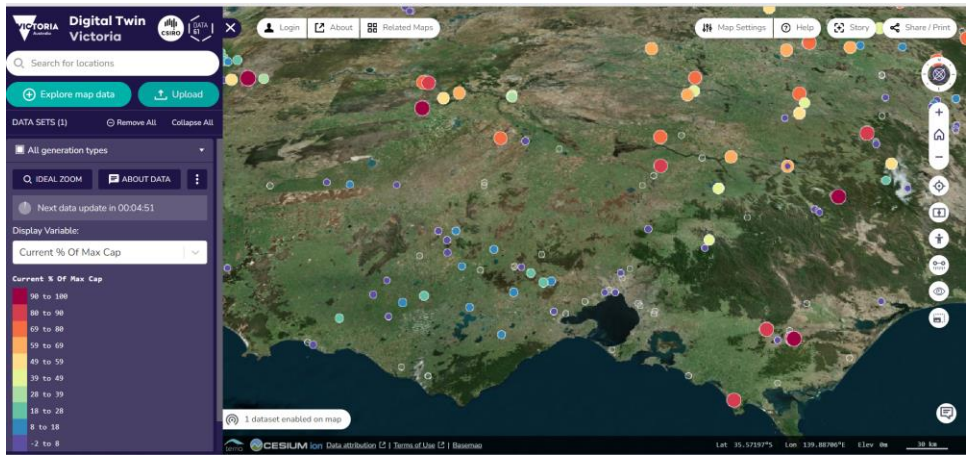
Objective: *How can sensor data integration in a 3D city model facilitate comprehensive visualization of the city's dynamic elements, and what are the technical approaches to achieve this in a web-based environment?*

Research Questions

- How can international standards be employed to acquire, store, and manipulate real-time and historical sensor data, ensuring data consistency and interoperability?
- How can environmental sensor data be effectively processed to provide detailed spatio- temporal information for further analysis?
- How can environmental sensor data be made available and accessed in a standardized manner to enable effective utilization in geospatial applications?

Urban Digital Twins Projects

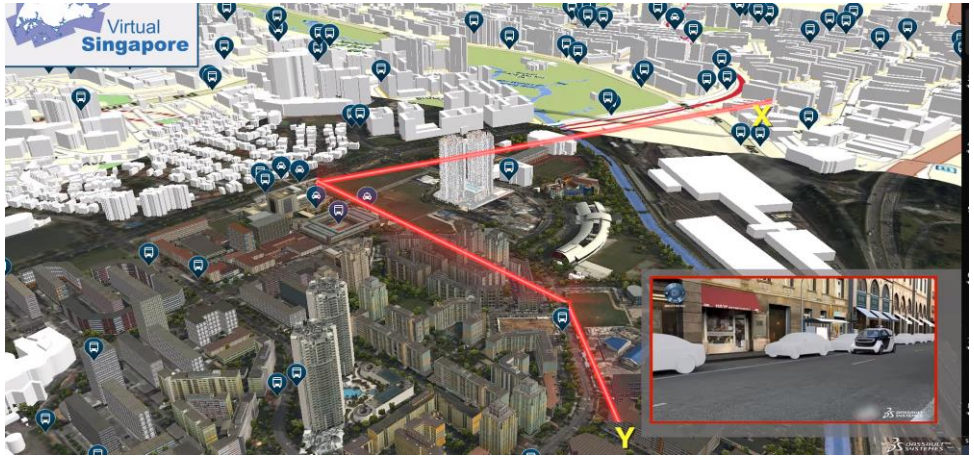
Digital Twin Victoria



Live data state-wide feed for energy production including renewable energy [1]

- *Australia-wide, urban digital twin project*
- *Disaster and asset management, scenario analysis, and planning*
- *Open, real-time data*
- *2D/3D visualization*

Virtual Singapore



Sustainable transportation / autonomous vehicles used for driverless navigation. Residents can check the availability of AV's in an area

- *Singapore urban digital twin*
- *what-if scenarios, decision-making, water supply and real-time information for citizens*
- *Real-time data*
- *2D/3D visualization*

International standards – Open Geospatial Consortium

Open Geospatial Consortium

- Leading organization in the geospatial IT domain
- Developing data technology standards for over two decades
- More than 60 standards and documents

OGC Web Services	OGC API	Functionality
Web Map Service (WMS)	OGC API Maps	Delivering geospatial data as web maps with spatial references in a dynamic manner
Web Map Tile Service (WMTS)	OGC API Tiles	Delivering and accessing geospatial data as tiles
Web Feature Service (WFS)	OGC API Features	Delivering and accessing geospatial data as vector data
Web Coverage Service (WCS)	OGC API Coverages	Delivering and accessing geospatial data as raster data
Web Processing Service (WPS)	OGC API Processes	Enables the processing of geospatial information on the web

International standards – OGC API Standards Overview

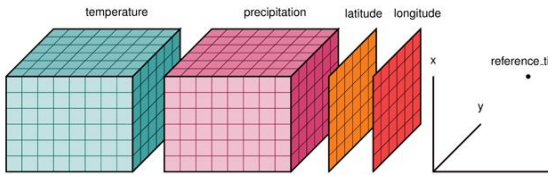
Open Geospatial Consortium

OGC SensorThings API

OGC API Tiles

OGC API Features

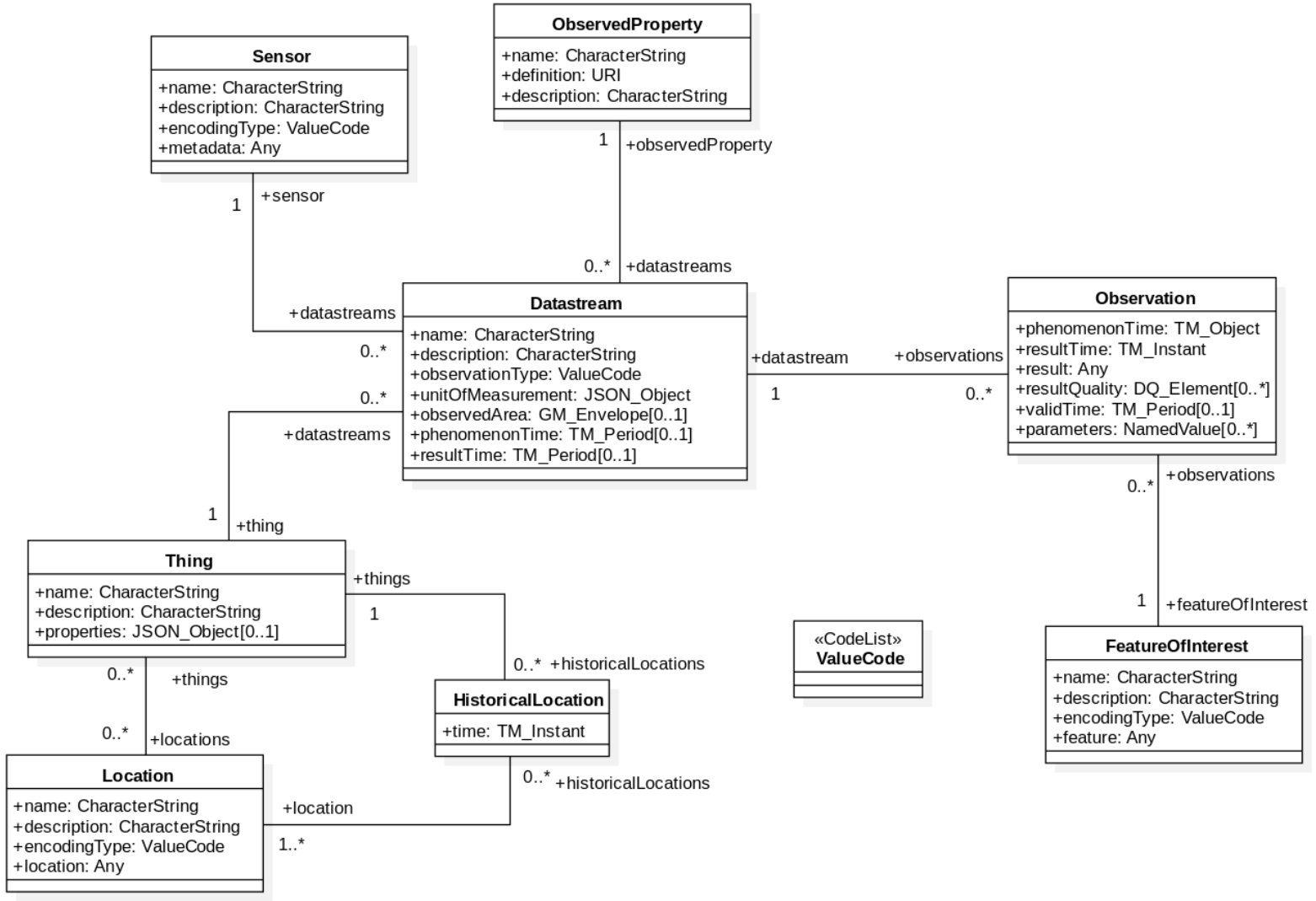
OGC API Coverages



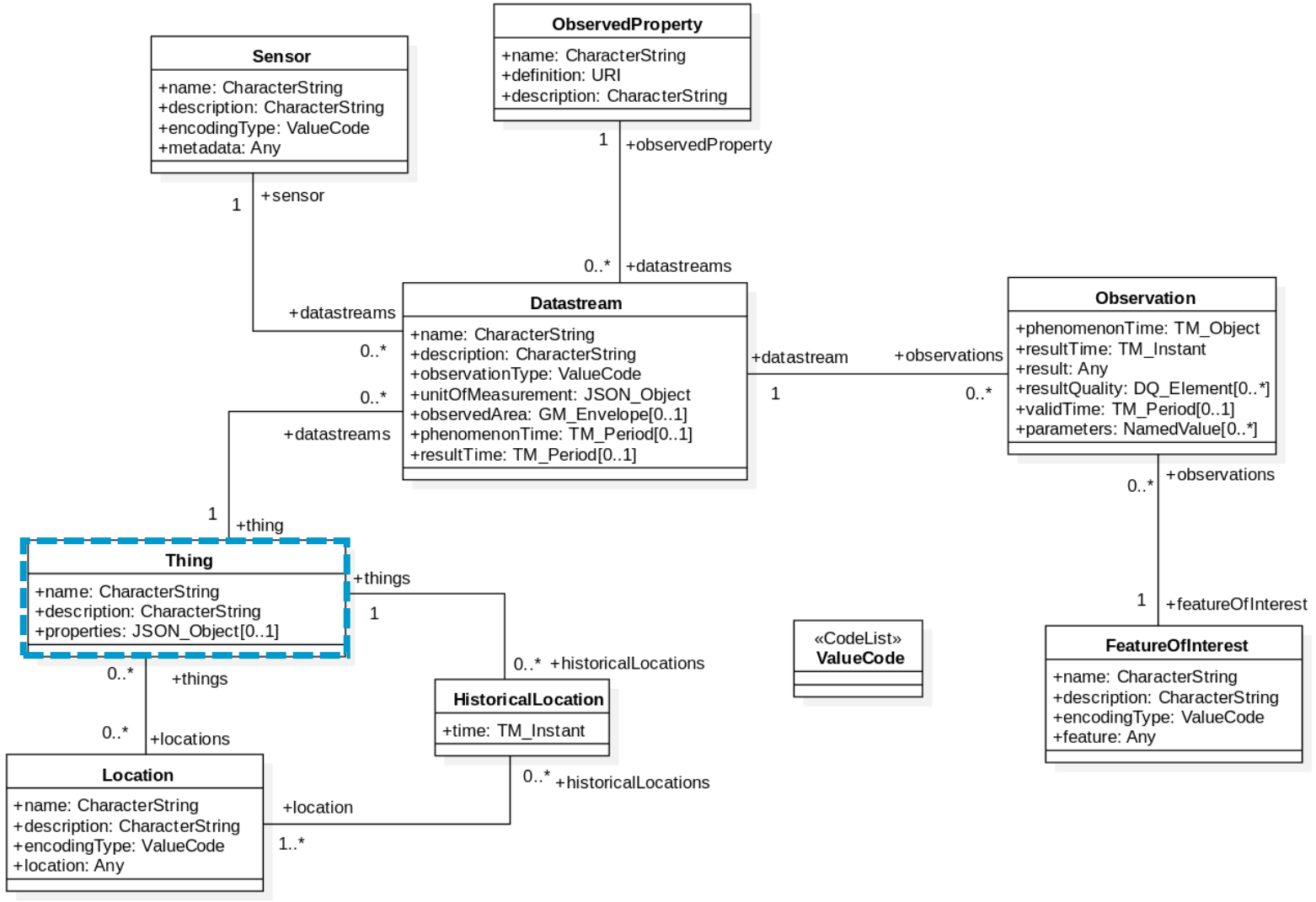
OGC API Processes

OGC API Maps

International standards – Sensor Things API



International standards – Sensor Things API



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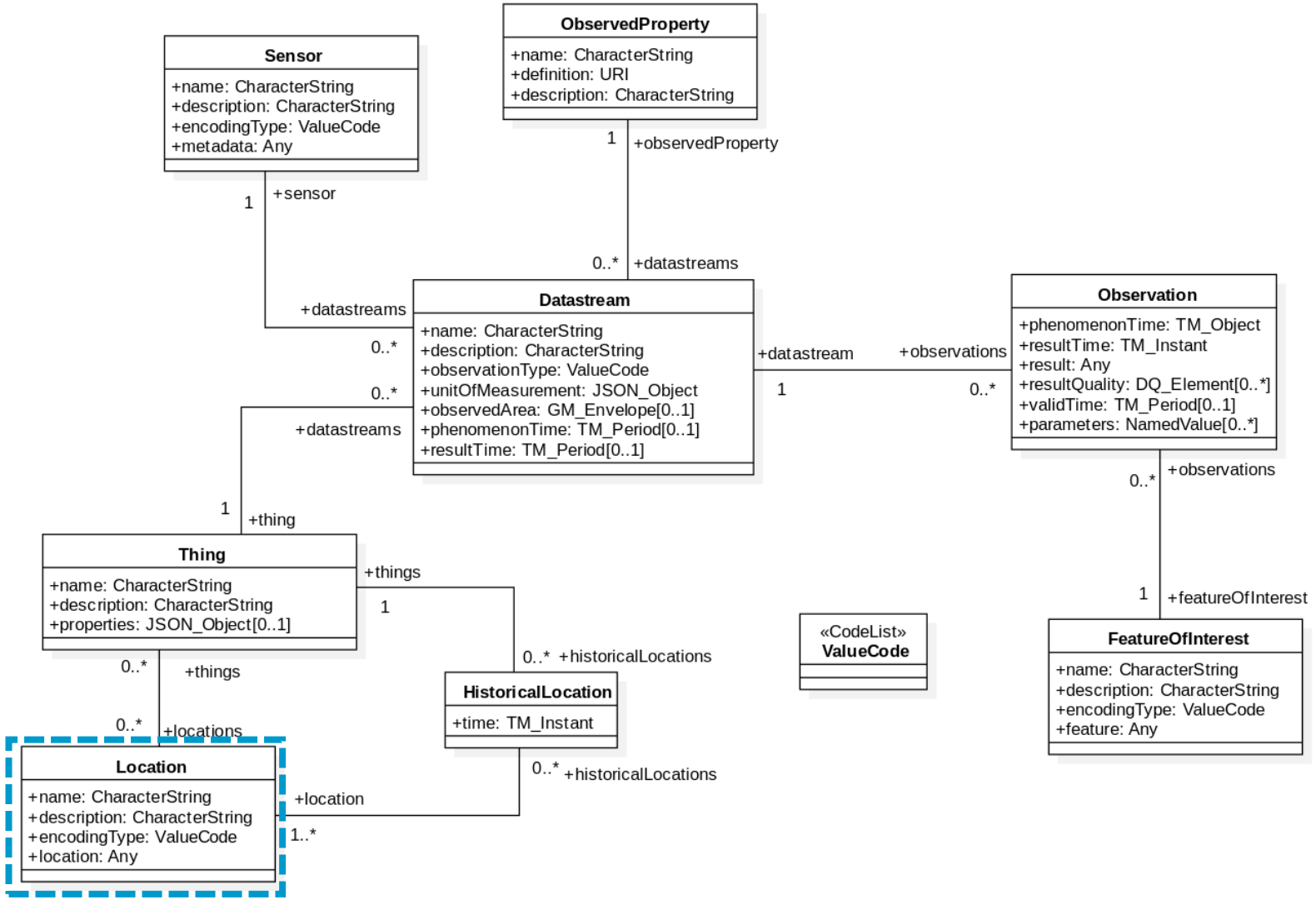
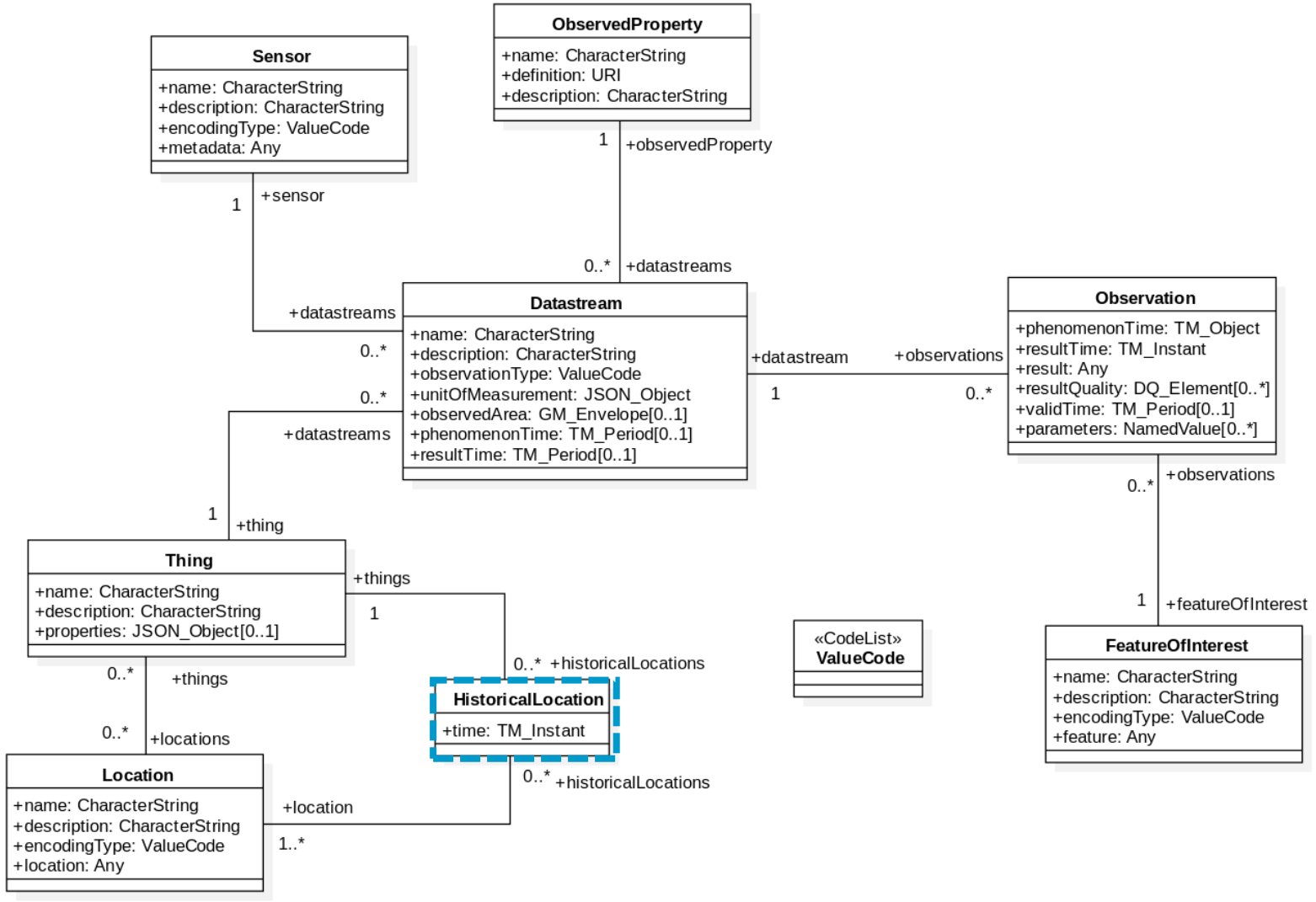
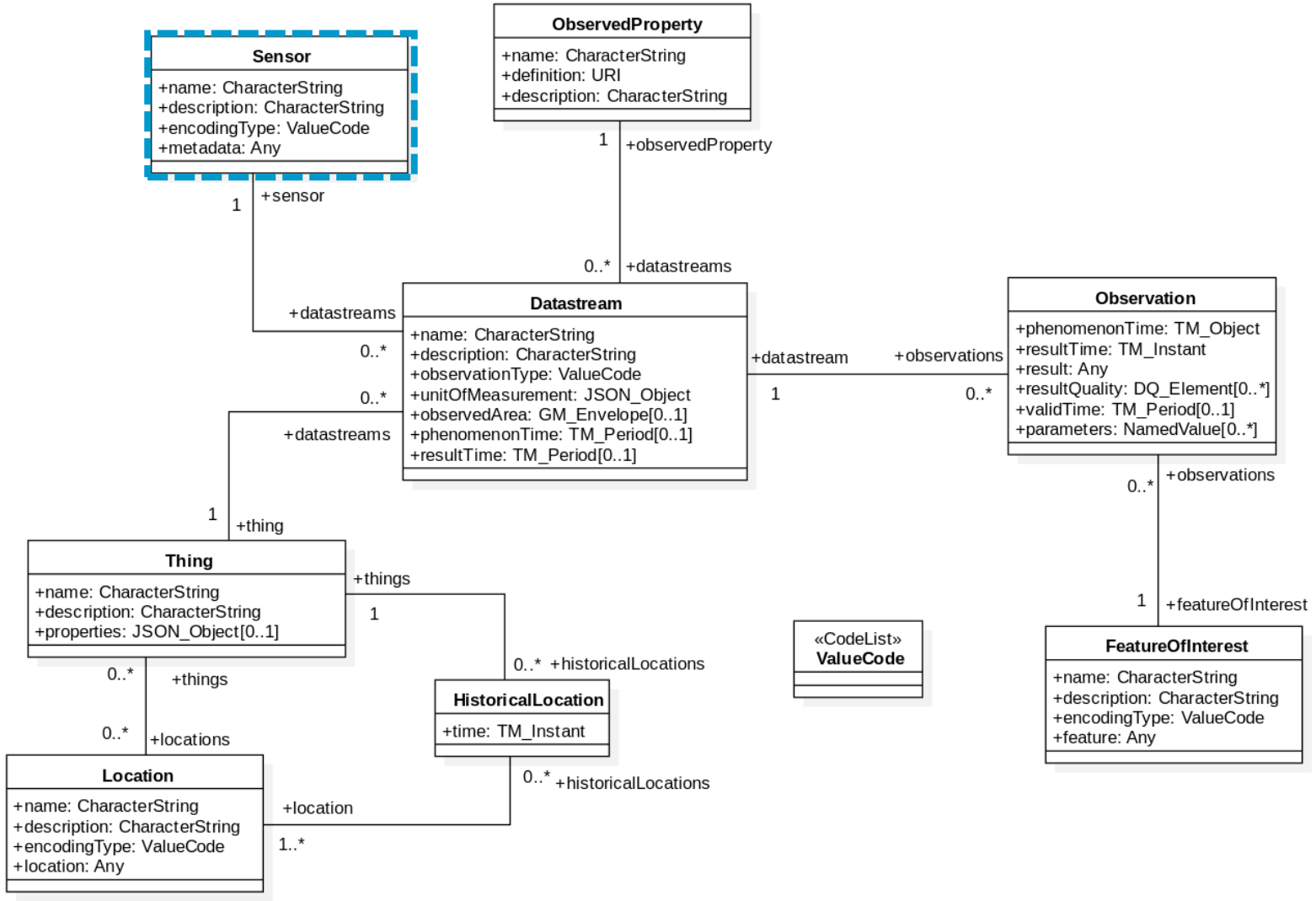


International standards – Sensor Things API



International standards – Sensor Things API



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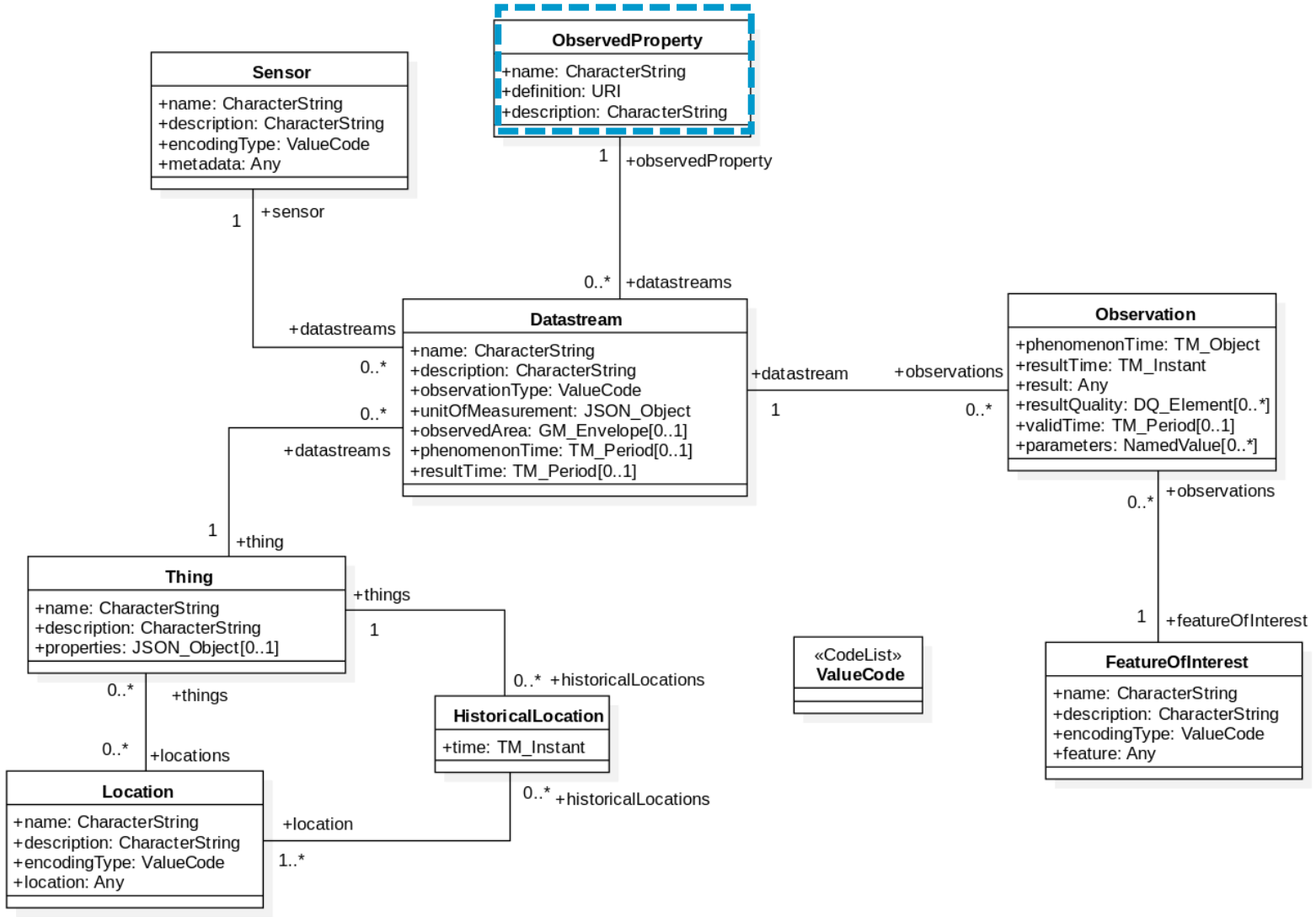
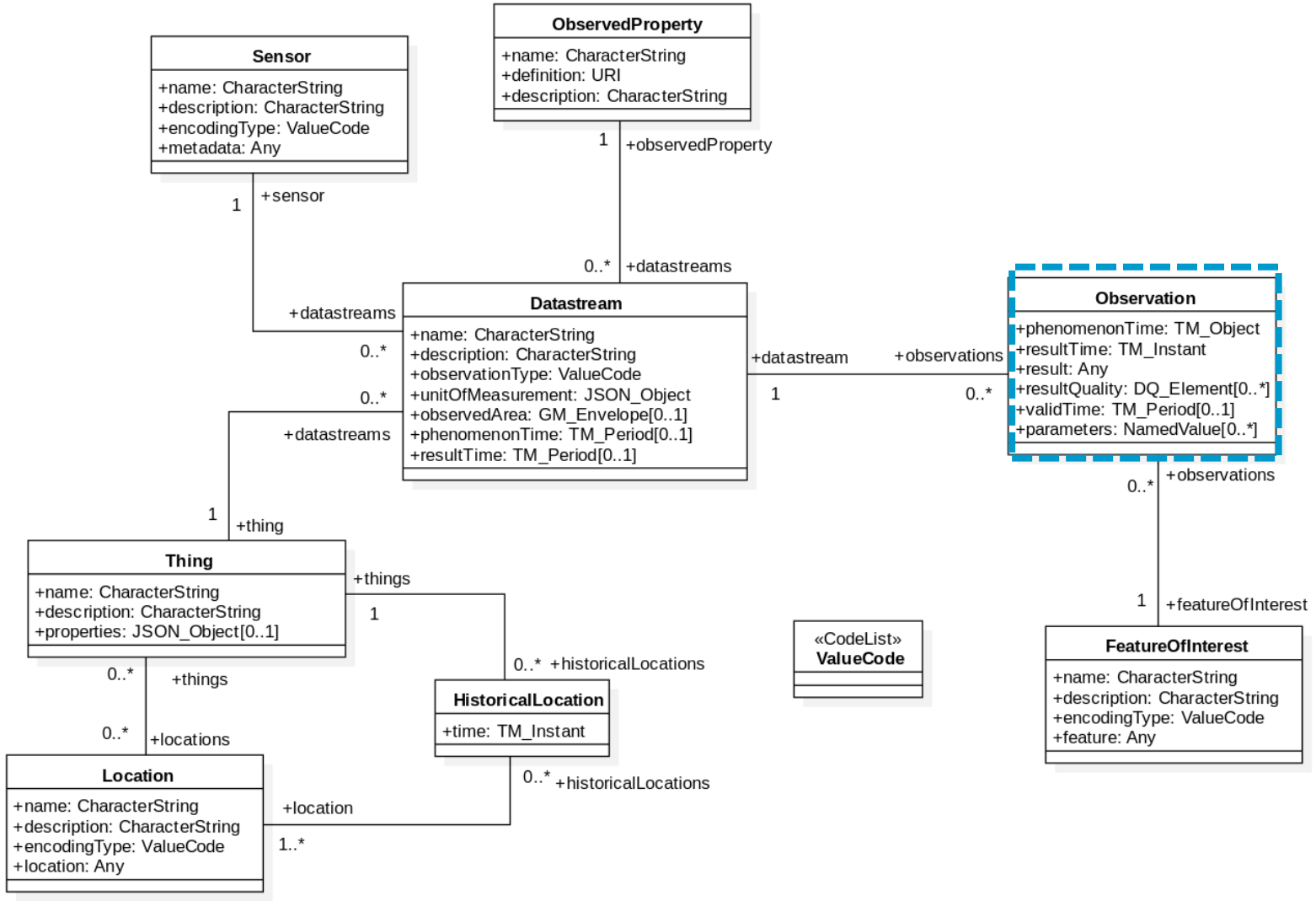
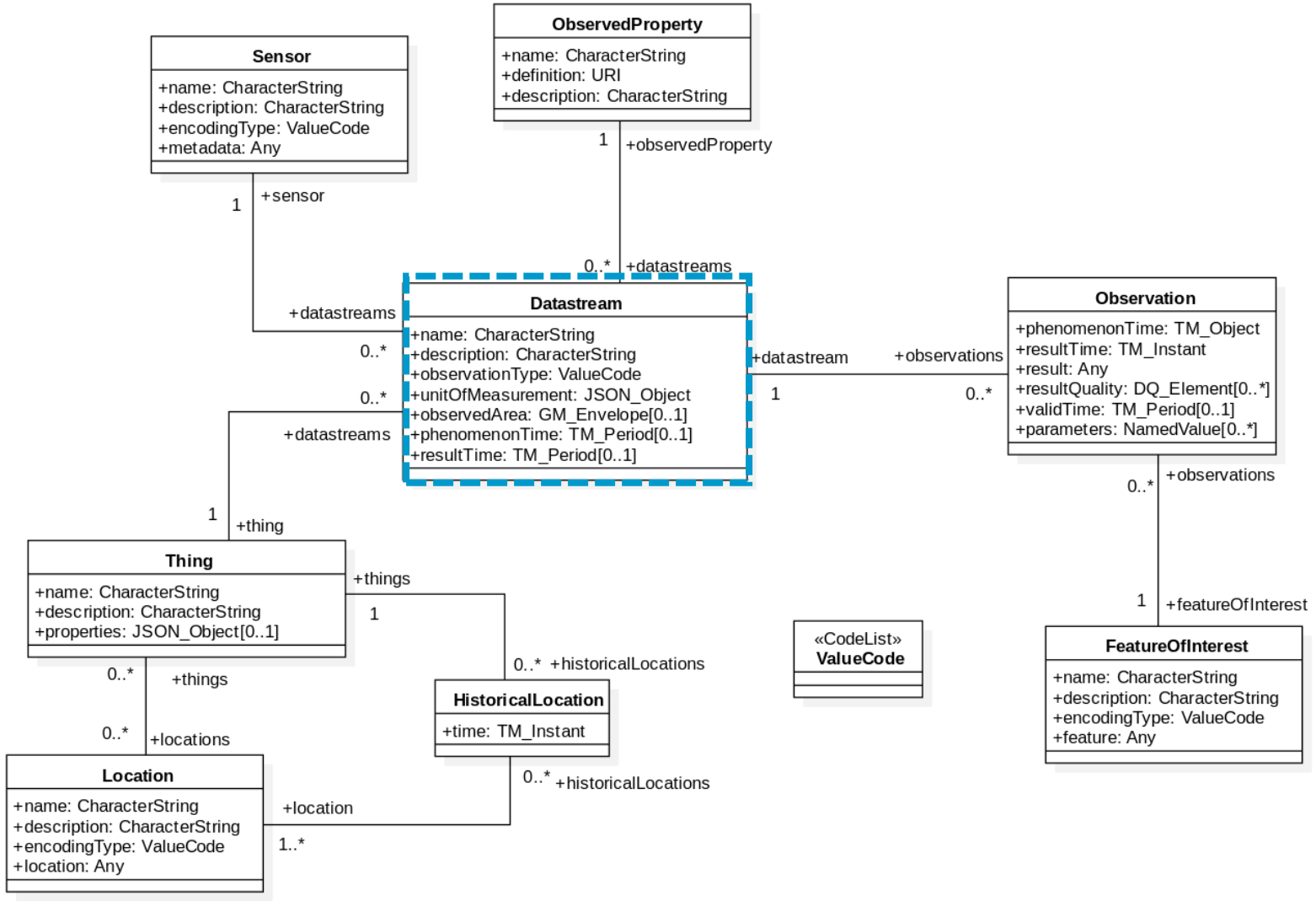


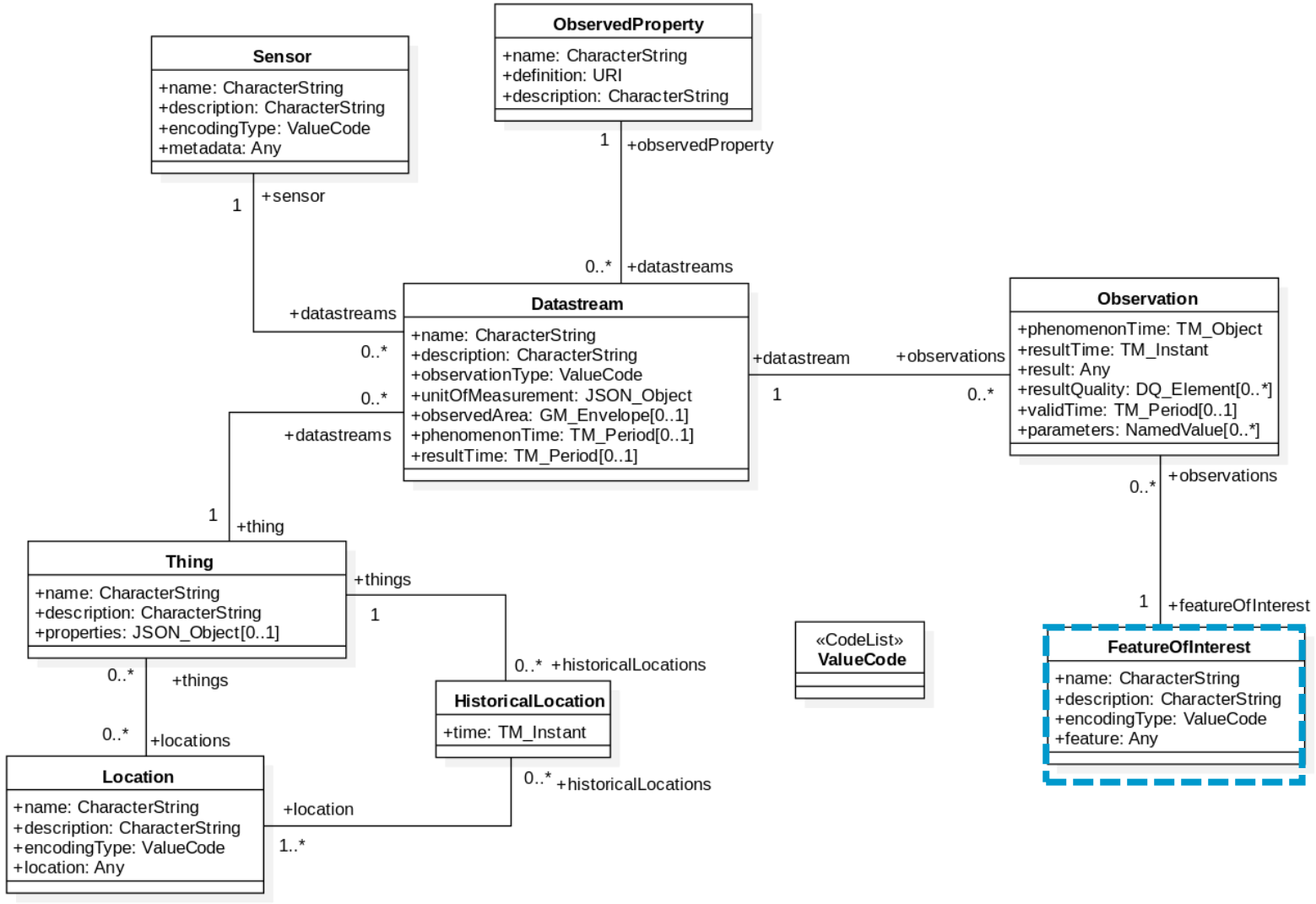
International standards – Sensor Things API



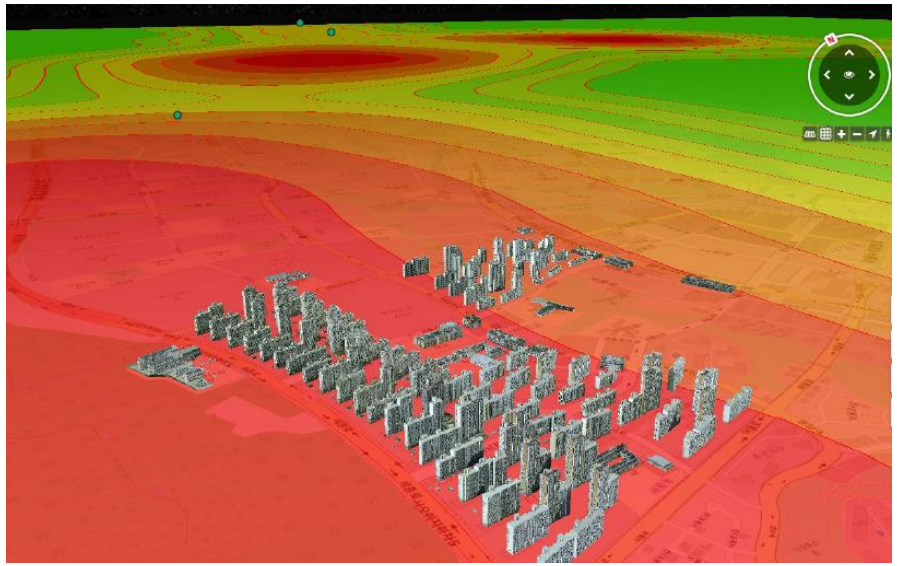
International standards – Sensor Things API



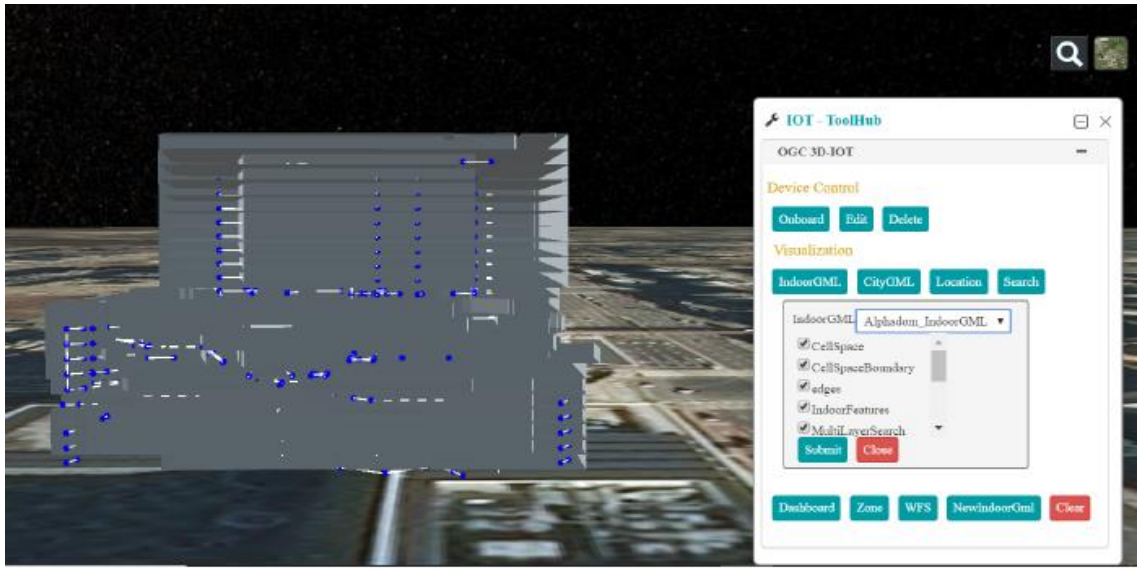
International standards – Sensor Things API



International standards – OGC 3D-IoT Platform for Smart Cities



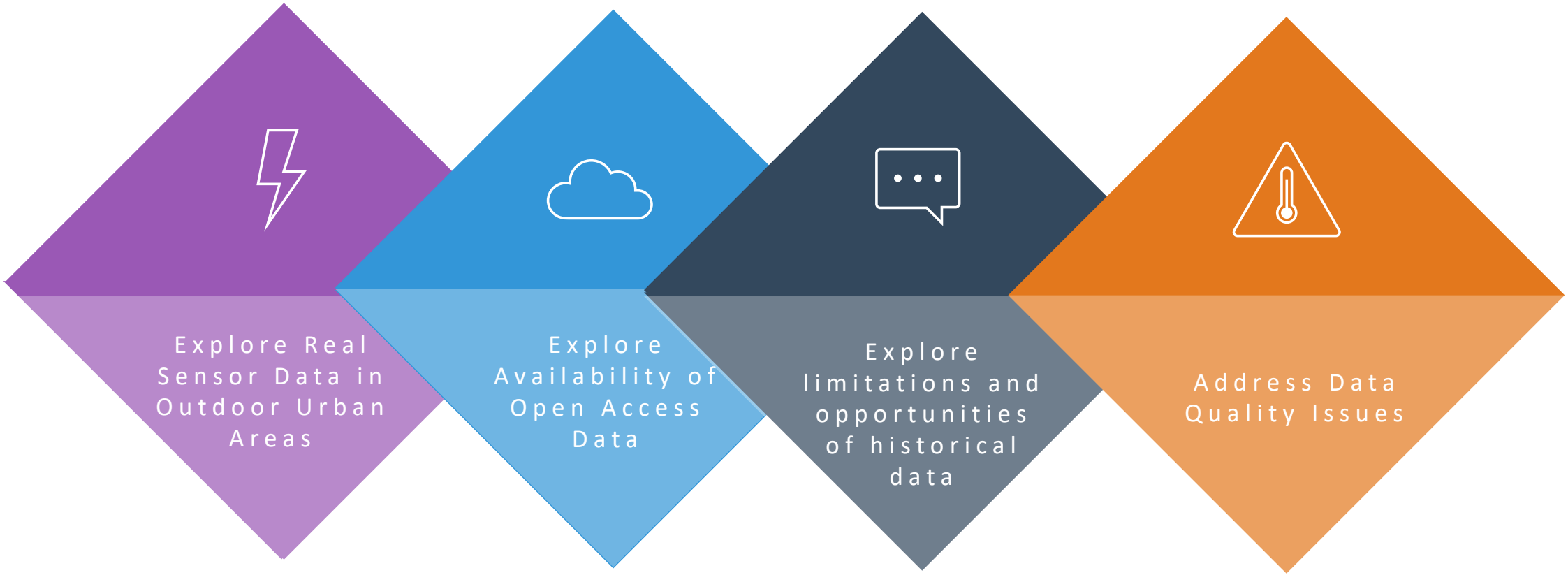
STT GeoPortal with processed sensor data from WPS services [3]



IndoorGML 3D[3]

- Integration of indoor and outdoor city models with sensor data
- Practical architecture based on standards for connecting real-time sensor data with modeled city features
- Measuring: Particulate Matter (PM2.5) air quality and room occupancy
- OGC SensorThings API standard
- OGC IndoorGML building model and 3D-Tiles/glTF city model features

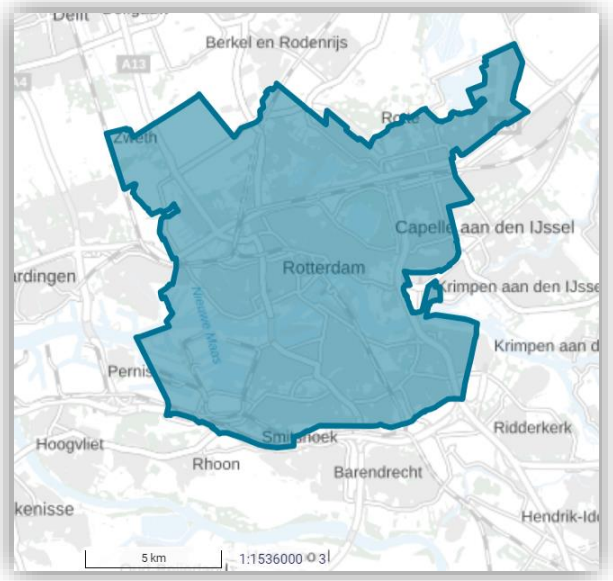
OGC 3D-IoT Platform for Smart Cities – Further Opportunities

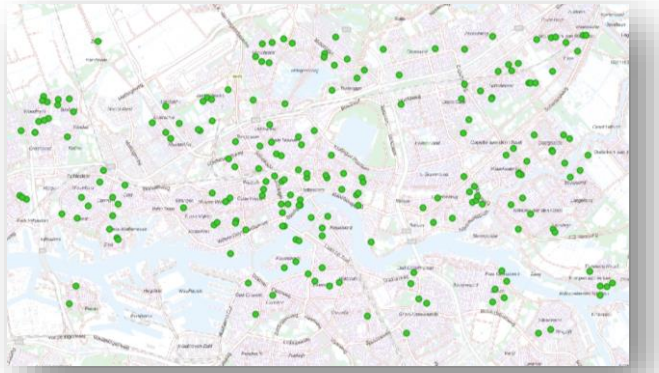


Research area: Rotterdam and environmental sensor data

Research focus

- Providing temperature data for Rotterdam, Netherlands
- Emphasis on resilience and sustainability in urban planning
  - Definition: The ability to survive, adapt, and grow amidst stress and shocks.
  - Rotterdam's inclusion in the 100 Resilient Cities Programme
  - Climate adaptation planning, including temperature, is crucial.

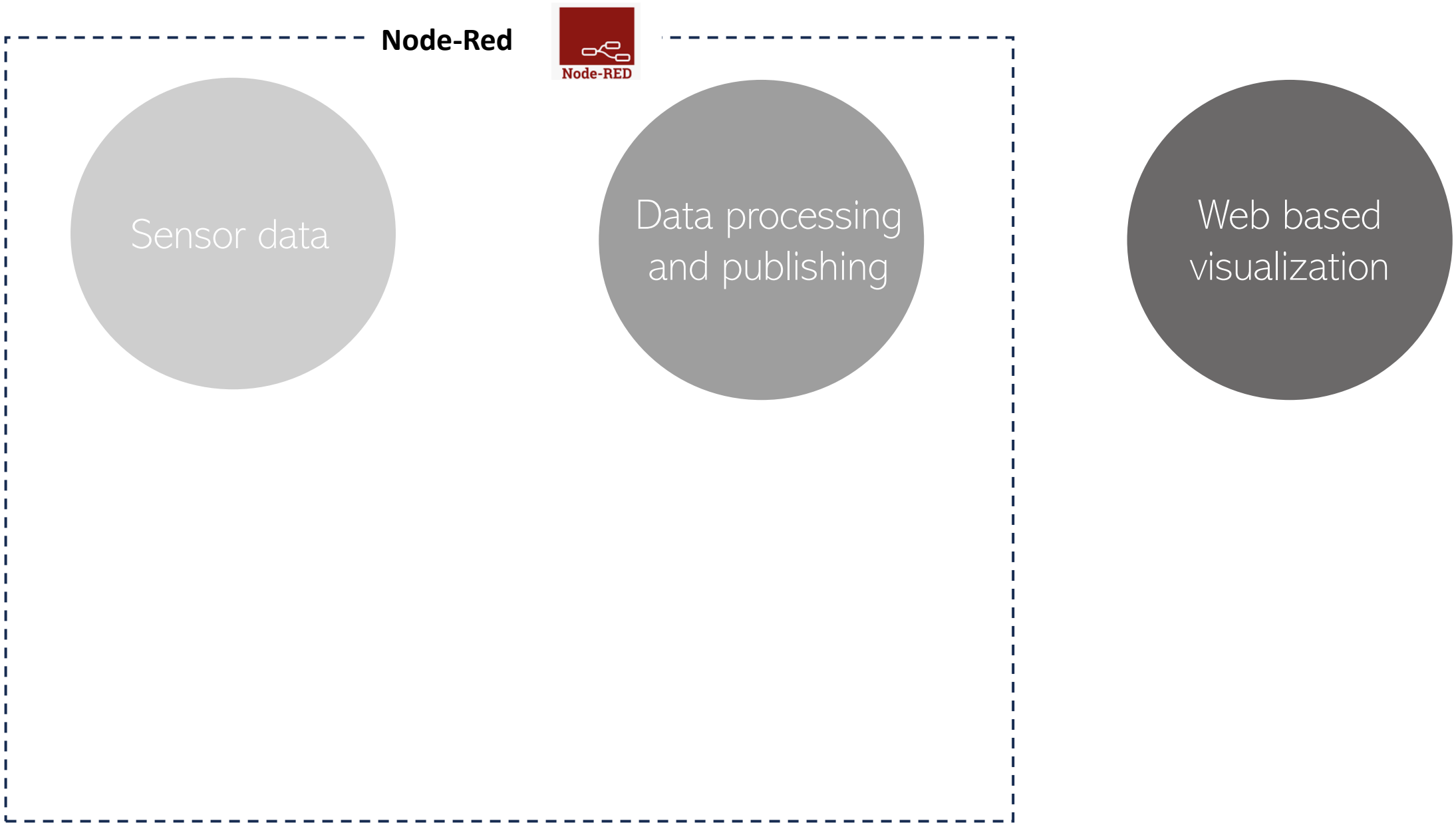




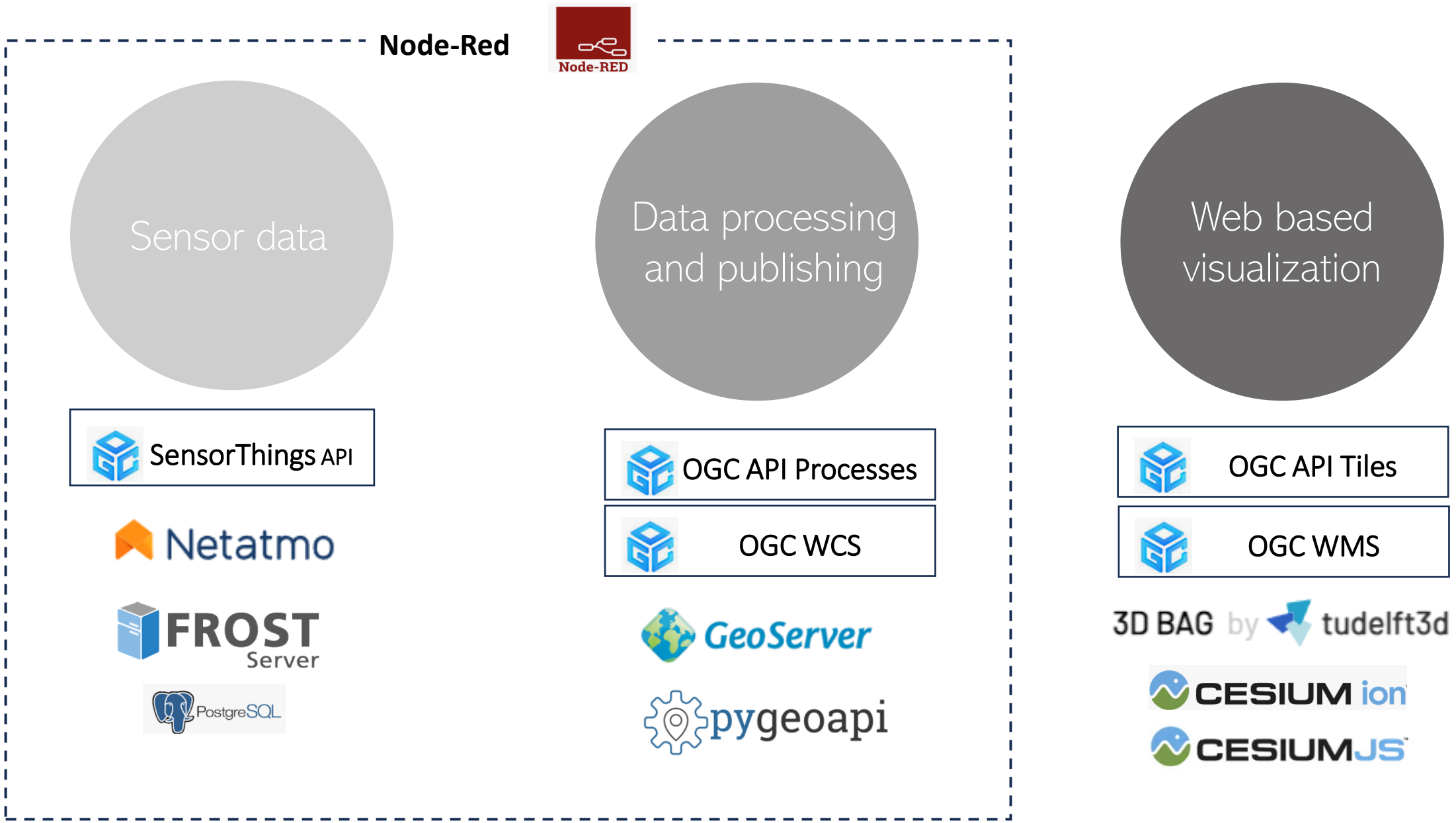
Sensor data

- Netatmo stations
- Outdoor temperature
- Crowd-sourced, open access
- Real – time and historical data
- Dense network of stations

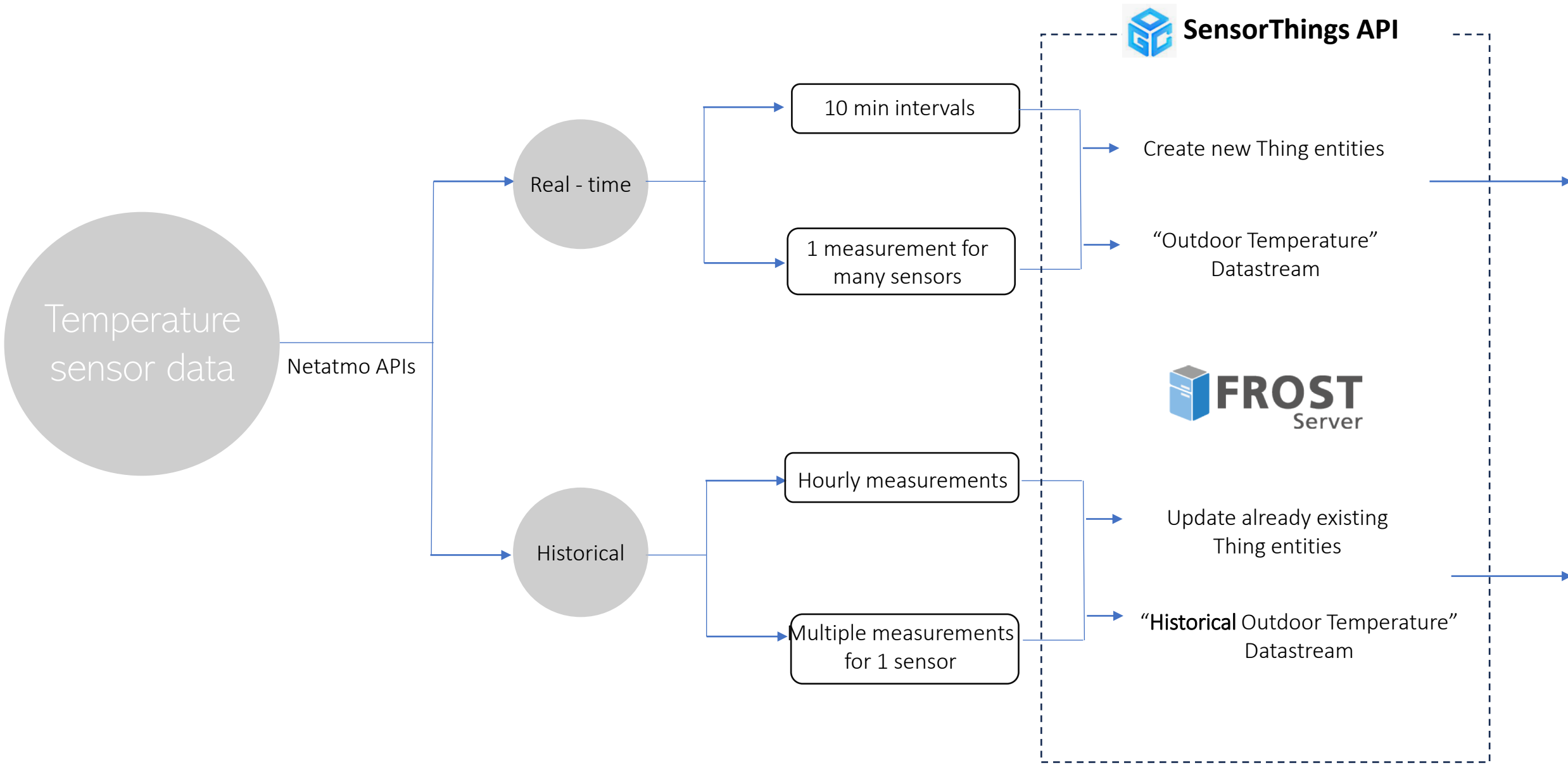
Basic Components



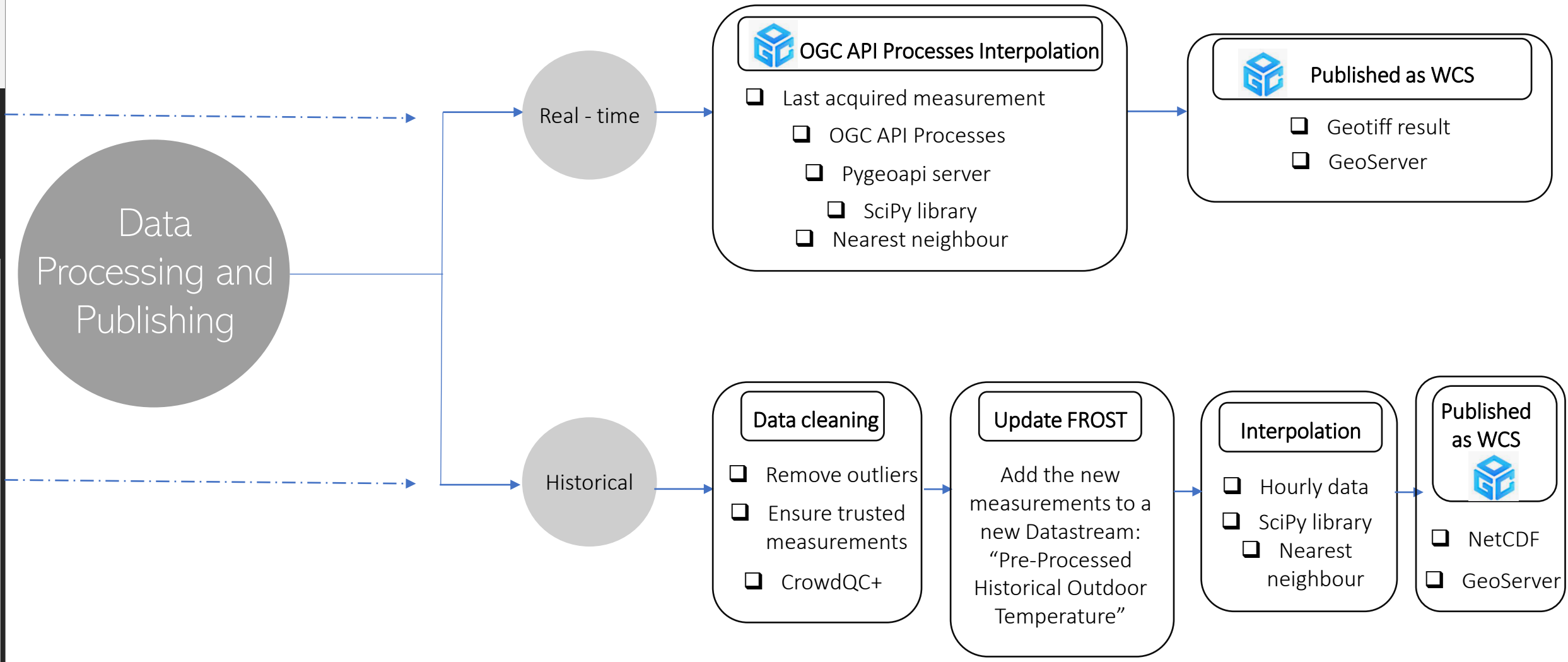
Basic Components



Sensor data and SensorThings API standard



Data processing and publishing



Web Based Visualization

Web based visualization

3D BAG tiles

Format Converting

- ❑ CityJSON to CityGML
- ❑ Citygml-tools

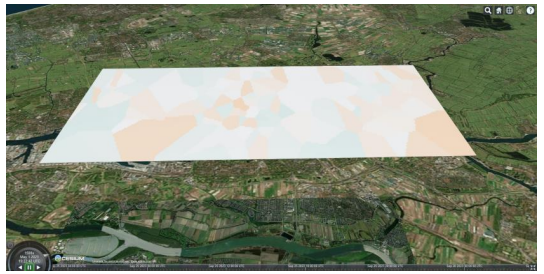
3D Tiles

- ❑ CityGML import to Cesium ion
- ❑ 3D Tiles through Cesium ion

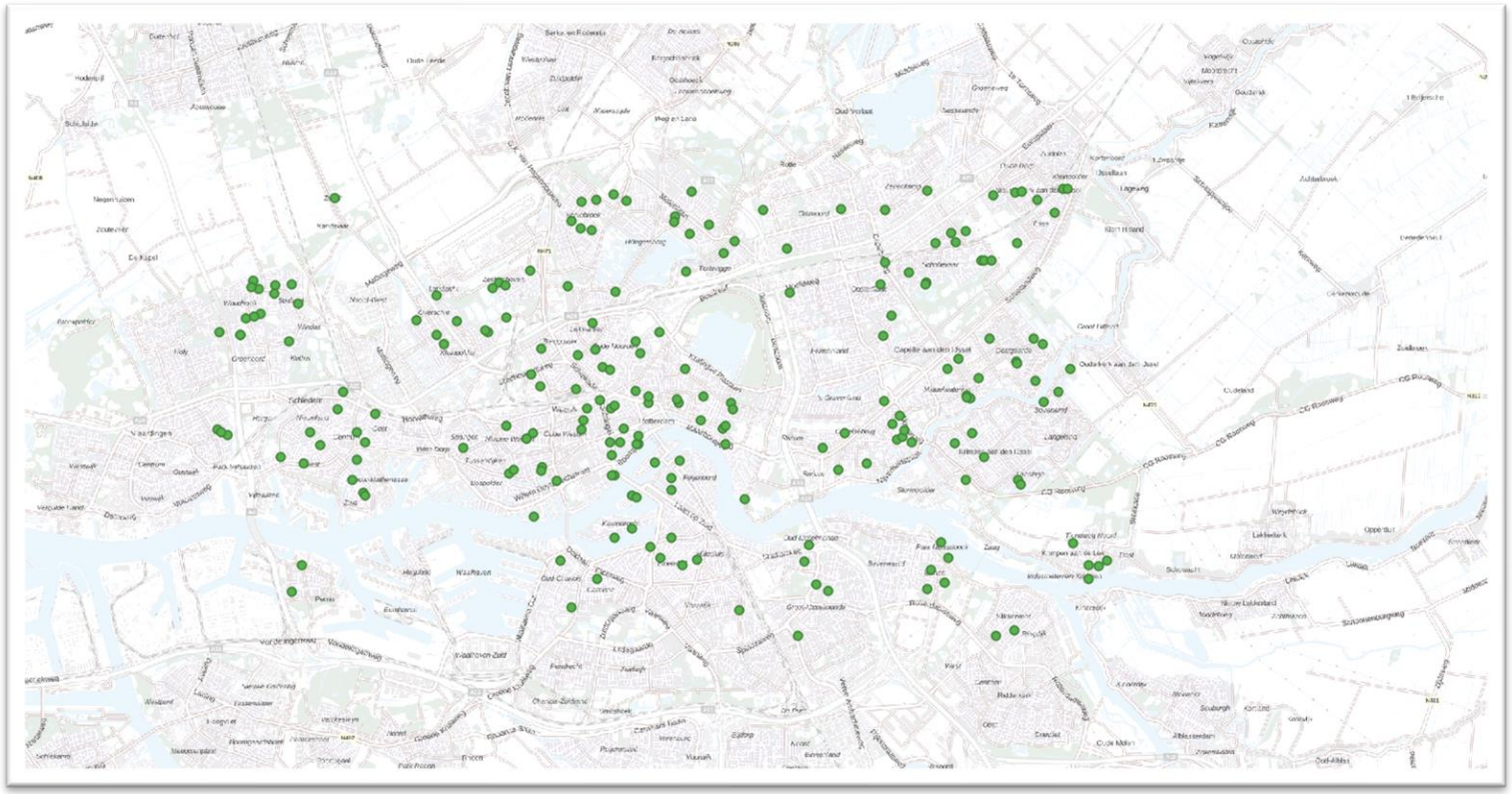
WMS Real-time data

WMS Historical data

CESIUMJS

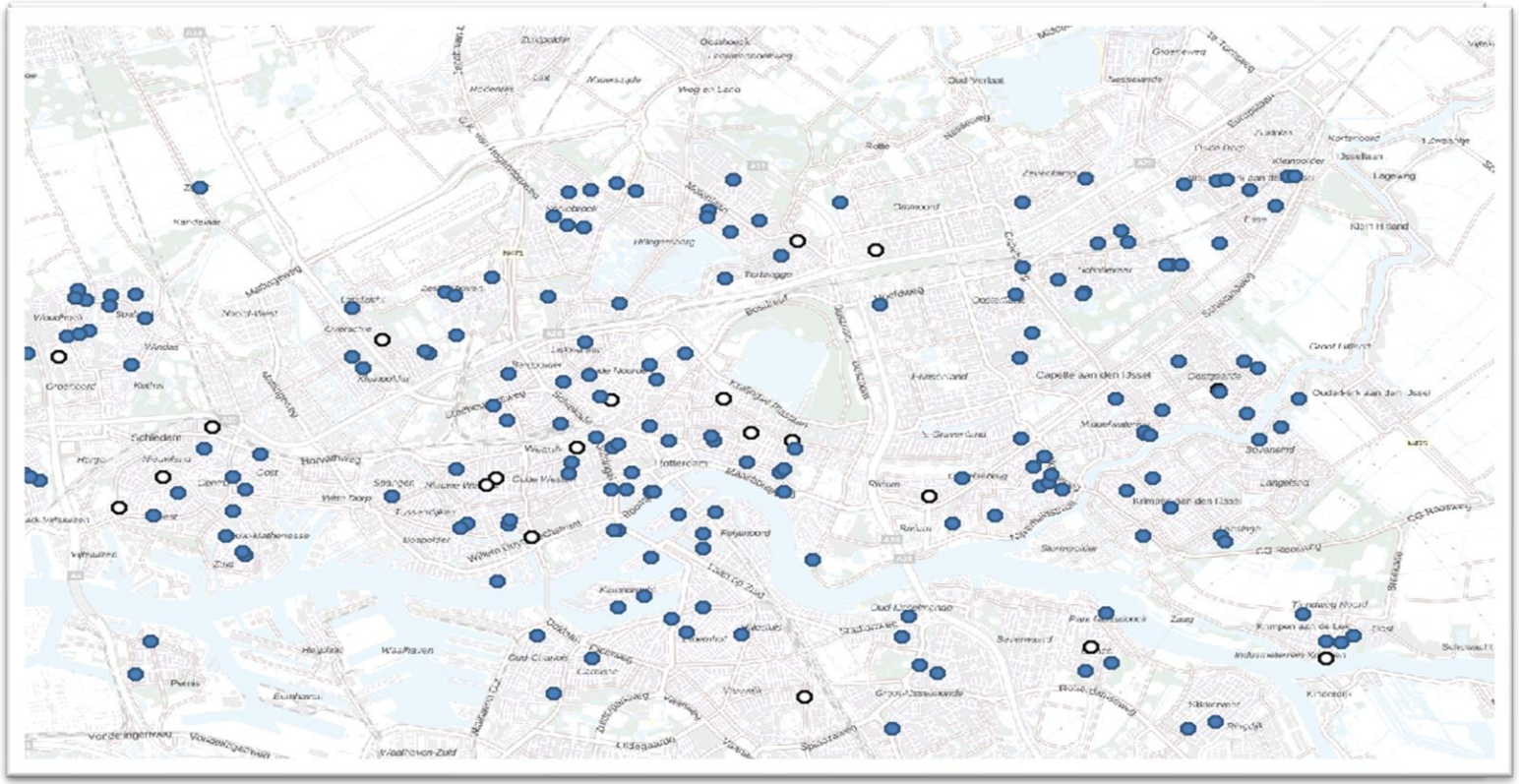


Real-time sensors locations (18:20 | September 15, 2023)



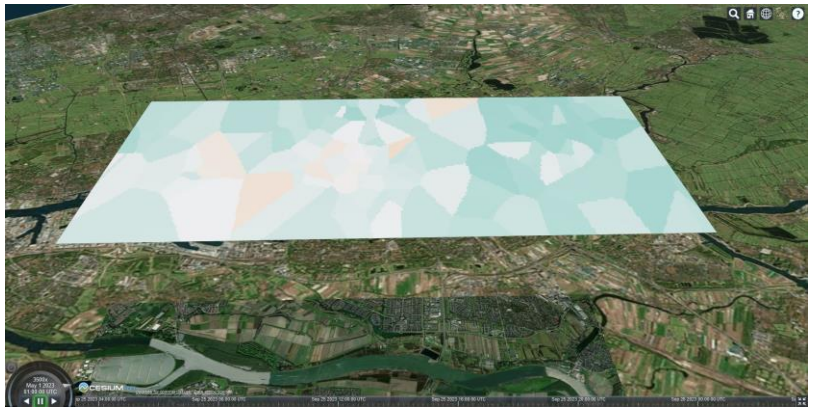
- Green: active sensors

Historical sensors locations and status (May, 2023)

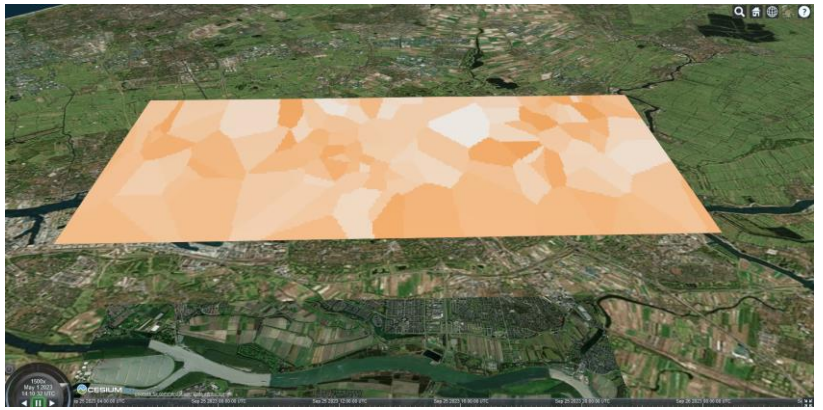


- White: eliminated sensors
- Blue: Accepted sensors

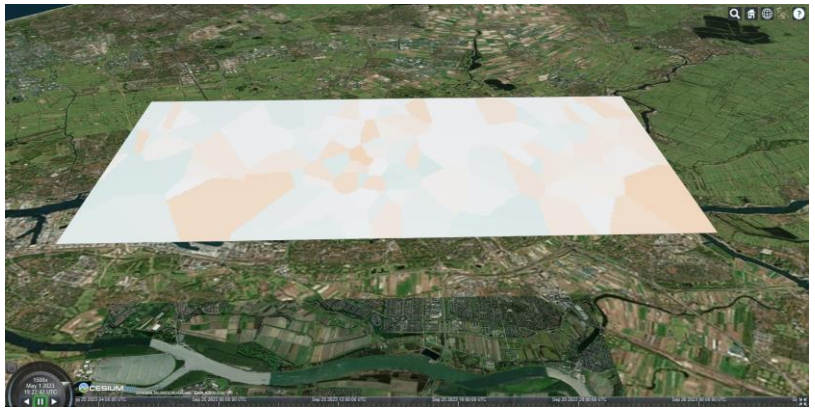
Historical sensors – Interpolation result



Time: 01:00



Time: 14:00

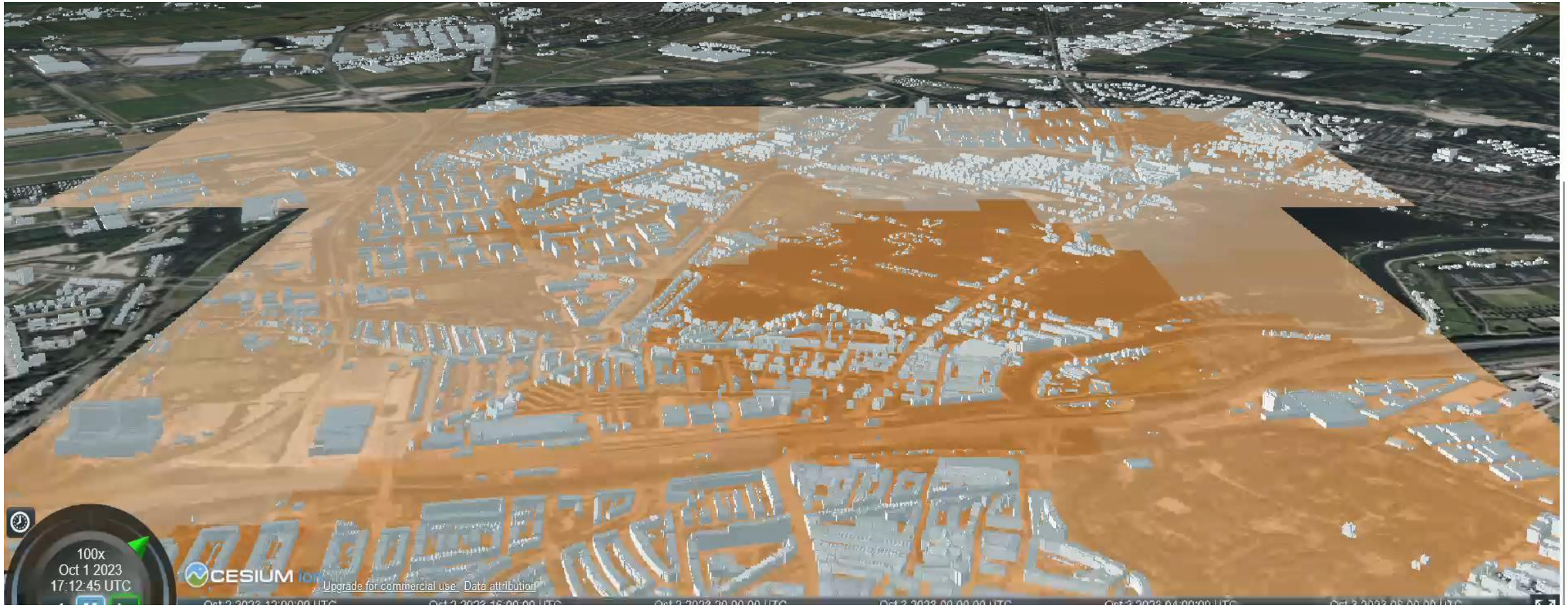


Time: 19:00

Results


1600x
May 2 2023
04:39:55 UTC
CESIUM
Upgrade for commercial use. Data attribution
Oct 2 2023 12:00:00 UTC
Oct 2 2023 16:00:00 UTC
Oct 2 2023 20:00:00 UTC
Oct 3 2023 00:00:00 UTC
Oct 3 2023 04:00:00 UTC
Oct 3 2023 08:00:00 UT

Results


100x
Oct 1 2023
17:12:45 UTC
CESIUM ion
Upgrade for commercial use. Data attribution

How can international standards be employed to acquire, store, and manipulate real-time and historical sensor data, ensuring data consistency and interoperability?

- Fully Developed and Mature Standard
- Complete and Highly Adjustable Framework
- Handles Real-Time and Historical Data
- Organizing Datastreams for Easy Accessibility
- Separately Storing Real-Time Raw Data, Historical Raw Data, and Clean, Pre-Processed Historical Data
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- Crowd-Sourced Data Challenges
  - Abundant Observations but Prone to Errors
  - Fluctuating Availability of Sensors Affects Real-Time Data Quality
  - Real-Time Data May Not Suit All Needs
- Spatio- Temporal information
  - Adequate Accuracy of a Relatively Simple to apply Interpolation algorithm (NN)
  - Utilizing the CrowdQC+ Tool allows complete cleaning of the data without having to rely on external validation sources

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How can environmental sensor data be made available and accessed in a standardized manner to enable effective utilization in geospatial applications?

- Challenges in incorporating the latest OGC API Standards
  - Limitations of publishing directly to OGC API standards due to challenges in OGC API Process chaining standards
  - Limitations on data publishing using OGC API Standards in applications (GeoServer)
  - Limitations on data integration using OGC API Standards in applications (Cesium)
- Second Generation OGC Standards not mature enough for seamless integration with established geospatial applications

Future Work

Broaden research to include various sensor types

Investigate algorithms for real-time data quality assessment and outlier detection, especially for crowd-sourced data

Advance research in spatio-temporal data analysis with more sophisticated interpolation techniques

Bridge the gap between emerging OGC API standards and established standards to make data exchange more seamless

Establish and run the pipeline and required dependencies on a server to ensure reliable real-time data reception

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Thank you
for your
attention!

References

[1] Digital Twin Victoria: https://vic.digitaltwin.terria.io/#share=s-tdQzW8sRvmBeNOOe81ussqDDZkt

[2] Virtual Singapore: National Research Foundation Singapore https://www.youtube.com/channel/UC9ShCzU_PIhd-58M1kwudag

[3] 3D IoT platform for smart Cities Pilot-Open Geospatial Consortium, 2023

Basic Components