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Context Information Management (CIM); Using NGSI-LD in the context of Building Information Management (BIM)

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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) cross-cutting Context Information Management (CIM).

Modal verbs terminology

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1 Scope

The present document encompasses BIM from the city scale down to building components but is mainly focused on the buildings scale and related data. This approach remains inside the domain of application of BIM: Building close environment, Building envelop and indoor components. Infrastructures are not considered here, as they are not covered by actual BIM standards and overlap with geospatial standards at upper scales. The approach is illustrated through a few use cases that cover the main multi-scale aspects of BIM. It also gives some guidelines and recommendations to use NGSI-LD in Buildings context.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AECO	Architecture, Engineering, Construction, and Operations
API	Application Programming Interface
BBS	Building Block System
BIM	Building Information Modelling
BMS	Building Management System
BOT	Building Operation and Technology
CIM	Context Information Management
CRS	Coordinate Reference System
ECM	Energy Concervation Measures
EPA	Environmental Protection Agency
FAIR	Findable, Accessible, Interoperable, and Reusable
FOG	File Ontology for Geometry formats
GLTF	GL Transmission Format (a file format for 3D models and scenes)
GML	Geography Markup Language
GUID	Global Unique Identifier
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information Technology
IFC	Industry Foundation Classes
IoT	Internet of Things
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data
LBD	Linked Building Data
LD	Linked Data
LOD	Level Of Details
NGSI	Next Generation Service Interfaces
NGSI-LD	Next Generation Service Interface - Linked Data
NIBS	National Institute of Building Sciences
OGC	Open Geospatial Consortium
OMG	Object Management Group
OWL	Web Ontology Language
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
SAREF	Smart Applications REFerence ontology
SOSA	Sensor, Observation, Sample, and Actuator (ontology)
SPARQL	SPARQL Protocol and RDF Query Language
SRS	Spatial Reference System
SSN	Semantic Sensor Network
SVG	Scalable Vector Graphics
TIN	Triangulated Irregular Network
UID	Universal Identifier
URI	Uniform Resource Identifier
UUID	Universal Unique Identifier
W3C®	World Wide Web Consortium
WNS	Web Notification Standard

4 Background information

Next Generation Service Interface - Linked Data (**NGSI-LD**) is an open standard for context information management, which defines a common data model and interface for exchanging context information between different systems and applications [i.1]. It is an extension of the NGSI standard, which was developed by the FIWARE Foundation, and is designed to support the integration of Internet of Things (IoT) devices and data sources. NGSI-LD uses Linked Data principles to represent context information as a graph of interconnected entities, where each entity has a unique Uniform Resource Identifier (URI) and can be described using a set of attributes and relationships. This allows for greater flexibility and interoperability in the exchange of context information, as it enables data to be shared and reused across different domains and applications. NGSI-LD is used in a variety of domains, including smart cities, industry 4.0, and transportation. It provides a common framework for managing context information in these domains, enabling the development of new services and applications that can leverage data from multiple sources. By using NGSI-LD, organizations can improve data sharing and collaboration, reduce integration costs, and accelerate the development of innovative solutions.

The NGSI-LD information model (Figure 1) is derived from PGs. Entities, relationships, and properties are the key components of the NGSI-LD information model, as shown in Figure 2. A real-world item, such as a building or a person, is represented by an entity. A relationship connects two or more entities, such as a person who works in a building. A property connects values to elements, such that it can identify that an entity corresponds to a real person. Due to its extensive data structure, it may be utilized for practically any data exchange situation throughout the life cycle of a building.

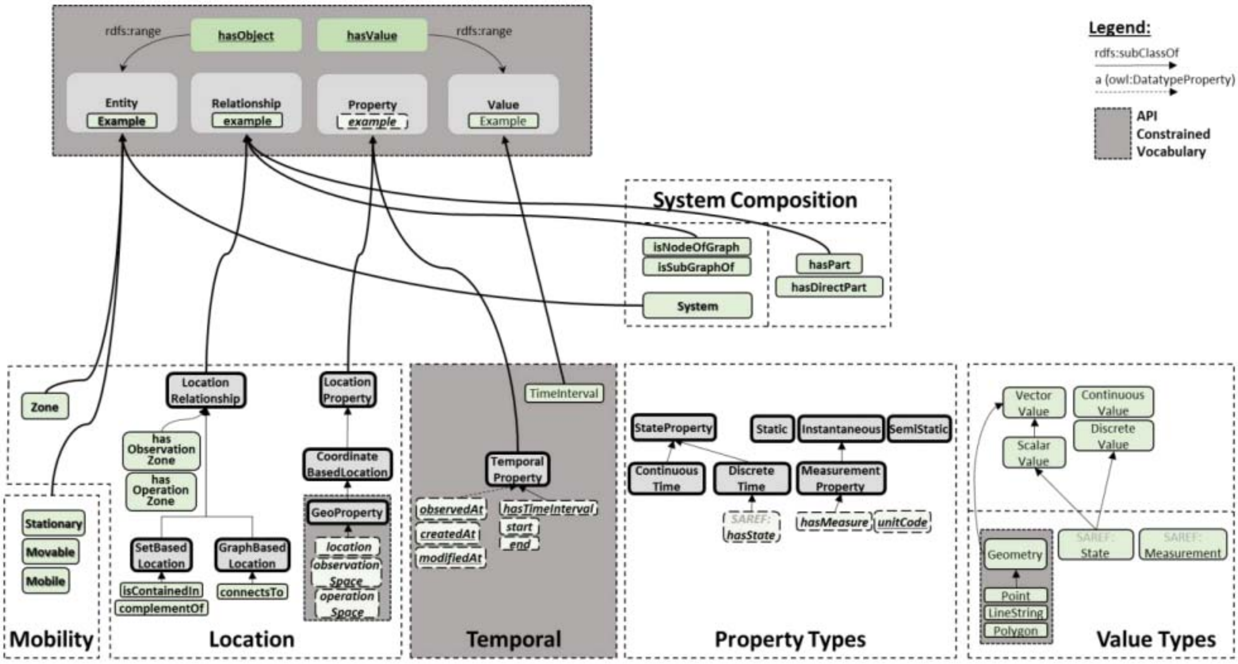

Figure 1: NGSI-LD Information Model

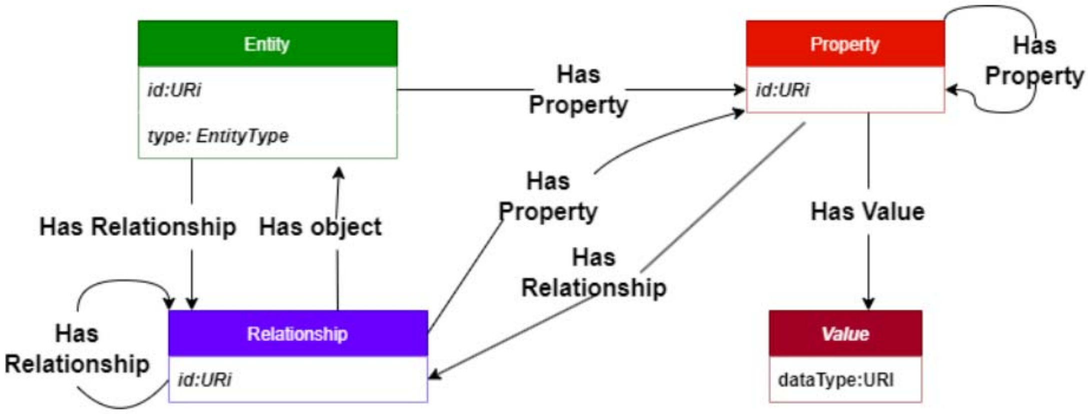

Figure 2: Key components of the NGSI-LD ontology

BIM stands for Building Information Modelling. It is a digital representation of the physical and functional characteristics of a building, including both geometric and non-geometric information. BIM is a process that involves creating and managing digital models of a project, which can be used for planning, design, construction, and management of buildings and infrastructure. The BIM process allows architects, engineers, and construction professionals to collaborate more effectively, as it provides a shared view of the project and enables better communication and coordination. It can also help to improve the accuracy of cost estimates and construction schedules, reduce waste, and enhance the overall quality and sustainability of buildings. BIM is typically used throughout the entire lifecycle of a building, from the initial design phase through to construction, operation, and maintenance. By using BIM, stakeholders can make more informed decisions, improve the efficiency of their workflows, and ultimately deliver better outcomes for their clients and end-users.

Data spaces are a concept used in data management and integration to describe a virtual environment where data from different sources can be stored, managed, and shared in a secure and controlled manner. Data spaces are typically designed to support specific use cases or domains, such as healthcare, finance, or manufacturing. Data spaces provide a common framework for data integration and sharing, enabling organizations to break down data silos and leverage data from multiple sources to gain new insights and create new value. Data spaces typically include a set of tools and services for data discovery, access control, data quality management, and data governance. Data spaces can be implemented using a variety of technologies and architectures, such as data lakes, data warehouses, or federated data platforms. They can also be implemented using decentralized architectures, such as blockchain or peer-to-peer networks, to enable secure and distributed data sharing. Data spaces are becoming increasingly important in the era of big data and digital transformation, as organizations seek to leverage data to gain a competitive advantage and create new business models. By providing a secure and controlled environment for data sharing and collaboration, data spaces can help organizations to unlock the value of their data, while ensuring compliance with privacy and security regulations. By using NGSI-LD, data spaces can provide a common data model and interface for representing and sharing data, enabling greater interoperability and integration between different data sources and applications. For example, in a smart city context, different data spaces may be created for different domains, such as transportation, energy, and building management. NGSI-LD can be used as a common data model and API specification for exchanging data between these different data spaces, enabling greater integration and collaboration between different domains and stakeholders.

Domain models are models that represent the concepts, entities, and relationships within a specific domain or area of interest. A domain model is typically developed by domain experts who have a deep understanding of the business or technical requirements of the domain. The purpose of a domain model is to provide a common language and a shared understanding of the domain among stakeholders, such as business analysts, developers, and users. A domain model typically includes entities, attributes, relationships, and constraints that are relevant to the domain.

A **cross-domain** model refers to a common data model that can be used to represent and exchange context information across different domains or applications. A cross-domain model provides a standardized way to describe entities, attributes, and relationships in a way that is interoperable and reusable across different domains. NGSI-LD is designed to support cross-domain data integration and interoperability, and the development of cross-domain models is an important part of this effort. Cross-domain models can be created by mapping and aligning domain-specific data models to a common data model, using Linked Data principles and vocabularies such as RDF, RDFS, and OWL. For example, in a smart city context, a cross-domain model may be developed to represent and exchange data related to buildings, transportation, energy, and environmental conditions. This cross-domain model would provide a common data model and vocabulary for representing entities such as buildings, vehicles, sensors, and weather conditions, as well as their attributes and relationships. By using a cross-domain model, stakeholders can improve data integration and interoperability, enabling greater collaboration and innovation across different domains and applications. Cross-domain models can also help to reduce data silos and enable the development of new services and applications that leverage data from multiple domains. Developing cross-domain models requires collaboration and consensus-building between different stakeholders, including domain experts, data modelers, and software developers. It also requires the use of common vocabularies and standards, such as those provided by the W3C® and other standards organizations.

An **ontology** is a formal representation of a set of concepts and their relationships within a specific domain of knowledge. An ontology provides a shared vocabulary and a set of rules for describing and reasoning about the concepts and relationships within that domain. Ontologies are used to enable interoperability and knowledge sharing between different systems, applications, and stakeholders. By providing a common understanding of the concepts and relationships within a domain, ontologies can help to overcome semantic heterogeneity, which is the difference in meaning and interpretation of data between different systems and stakeholders. An ontology typically includes a set of classes or concepts, which represent the entities or objects within a domain, and a set of properties or attributes, which describe the characteristics of those entities. Ontologies can also include relationships between classes, such as hierarchical or associative relationships, and constraints or rules that govern the use of the ontology. Ontologies are used in a variety of domains, including healthcare, finance, biology, and engineering. They are often used in the development of semantic web applications, which aim to provide a more meaningful and contextual representation of data on the web. Ontologies can also be used in artificial intelligence and machine learning applications, to provide a structured representation of knowledge and enable more sophisticated reasoning and decision-making.

5 FAIR requirements in BIM context

5.1 Introduction

This clause lists Findable, Accessible, Interoperable, Reusable (FAIR) [i.20] requirements specific to BIM context, and how they are currently addressed by architecture and construction communities [i.14] and [i.15]. W3C® interoperability recommendations and OASC Minimal Interoperability Mechanisms are also listed and taken into account.

5.2 Findable: Locating and Identifying instances

The first step in using data is to be able to find them. Metadata and data should be easy to find for both humans and computers. Machine-readable metadata are essential for automatic discovery of datasets and services.

F1. (Meta)data are assigned a globally unique and persistent identifier

F2. Data are described with rich metadata

F3. Metadata clearly and explicitly include the identifier of the data they describe

F4. (Meta)data are registered or indexed in a searchable resource

Unique identifiers, by means of namespaces and registration identifiers, provided by National Registration authorities (e.g. Nation Building Referential in France) or Building Owners, are to be used.

Identifying properties and geospatial references (as, for instance, described in the user guide for geo-referencing in IFC) is extremely important.

Finding a glue between different scales, for instance using NGSI-LD (see [i.16]), is important.

5.3 Accessible: Publishing Models and Data

This principle encourages long-term preservation and easy access to data such as open standards and protocols. It also covers security aspects for data access (confidentiality, copyright, privacy, cyber security).

A1. (Meta)data are retrievable by their identifier using a standardized communications protocol

A1.1. The protocol is open, free, and universally implementable

A1.2. The protocol allows for an authentication and authorization procedure, where necessary

5.4 Interoperable

Interoperability encourages open, widely shared vocabulary and formats, which enable exchanges between computer systems and increase the capacity of metadata to be combined.

I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation

I2. (Meta)data use vocabularies that follow FAIR principles

I3. (Meta)data include qualified references to other (meta)data

Interoperability has to occur at several levels: Technical (protocols), Syntactic (structures and formats), Semantic (controlled vocabulary, models), Organizational (processes), legal (licences, policies, confidentiality, regulation)

5.5 Reusable

Reusability asserts the need for metadata that provides information about the origins of the data and the conditions for its re-use: general terms of use, distribution licences.

R1. (Meta)data are richly described with a plurality of accurate and relevant attributes

R2. (Meta)data are released with a clear and accessible data usage license

R3. (Meta)data are associated with detailed provenance

R4. (Meta)data meet domain-relevant community standards

6 Open standards in BIM domain

6.1 Introduction

There have been many previous works that explore the modelling of smart building entities and their metadata. The Smart Appliances REFerence (SAREF) [i.22] ontology captures key features of connected and smart appliances. While SAREF does not cover the entire range of devices and sensors found in buildings, it can be mapped to the NGSI-LD Information Model, making use of this Context Information Management API specification for smart home applications. Similarly, the Building Topology Ontology (BOT) and more complex metamodels such as SOSA / SSN ontology, to represent relationships between the low-level IoT device world and semantic concepts [i.3] and [i.38], can also be mapped to NGSI-LD entities. The Industry Foundation Classes (IFCs) is a digital standard for describing the building asset domain. It supports vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases and is an open, international standard. It offers a comprehensive, standardized data format for the vendor neutral interchange of digital building models that are a crucial foundation for the development of Big Open BIM.

The following clauses give a short description of existing standards related to BIM. More detailed information can be found in Annex D.

6.2 BOT - Building Topology Ontology

The Building Topology Ontology (BOT) [i.28] is a minimal OWL Description Logics (DL) ontology for defining relationships between the sub-components of a building. It was suggested as an extensible baseline for use along with more domain specific ontologies following general W3C® principles of encouraging reuse and keeping the schema no more complex than necessary.

6.3 Digital Construction Ontology (DiCon)

The purpose of the Digital Construction Ontology Suite [i.27] is to address the semantic level of this challenge, by providing the essential concepts and properties of construction and renovation projects, thus paving the way to the ultimate integration of information from different decentralized sources over construction lifecycle.

6.4 TNO Interconnect Ontology series

The interconnect ontology is based on the ETSI SAREF or Smart Applications Reference ontology with its distributions for energy and buildings. It extends this ontology family with concepts specific to the cross-domain semantic interoperability: extensions for representing the user information and profiles, device and sensor information and profiles, forecast and flexibility information.

6.5 SSN / SOSA - Semantic Sensor Network

The Semantic Sensor Network (SSN) ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators. SSN follows a horizontal and vertical modularization architecture by including a lightweight but self-contained core ontology called Sensor, Observation, Sample, and Actuator (SOSA) for its elementary classes and properties. With their different scope and different degrees of axiomatization, SSN and SOSA are able to support a wide range of applications and use cases, including satellite imagery, large-scale scientific monitoring, industrial and household infrastructures, social sensing, citizen science, observation-driven ontology engineering, and the Web of Things. Both ontologies are described below, and examples of their usage are given.

6.6 SAREF4BLDG - Smart Applications for Building

SAREF4BLDG is an extension of the SAREF ontology [i.22] that was created based on the Industry Foundation Classes (IFCs) standard for building information. It should be noted that not the whole standard has been transformed since it exceeds the scope of this extension, which is limited to devices and appliances within the building domain. SAREF4BLDG is meant to enable the (currently missing) interoperability among various actors (architects, engineers, consultants, contractors, and product component manufacturers, among others) and applications managing building information involved in the different phases of the building life cycle (Planning and Design, Construction, Commissioning, Operation, Retrofitting/Refurbishment/Reconfiguration, and Demolition/Recycling).

6.7 Smart Model Building

This model [i.47] contains a harmonised description of a Building. It is associated with the vertical segments of smart homes, smart cities, industry and related IoT applications. This data model has been partially developed in cooperation with mobile operators and the GSMA, compared to GSMA data model following changes are introduced the reference to BuildingType is removed, since BuildingType compared to category attribute does not introduce significant information. category attribute is required. openingHours is introduced following schema.org data model to allow fine-grained on building opening times.

6.8 CityGML

The CityGML standard [i.11] defines a conceptual model and exchange format for the representation, storage and exchange of virtual 3D city models. It facilitates the integration of urban geodata for a variety of applications for Smart Cities and Urban Digital Twins, including urban and landscape planning; Building Information Modelling (BIM); mobile telecommunication; disaster management; 3D LAND registry; tourism; vehicle & pedestrian navigation; autonomous driving and driving assistance; facility management, and; energy, traffic and environmental simulations.

6.9 IFC - Industry Foundation Classes

The Industry Foundation Classes (IFCs) are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The IFC standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well.

IFC2x3 TC1 (Industry Foundation Classes, version 2.3.0.1 ISO/PAS 16739:2005 [i.50]) has been widely used for many years and is still in use today. It provides a comprehensive schema for representing building data, including elements such as walls, doors, windows, and various building services.

However, the newer IFC4 ADD2 TC1 (Industry Foundation Classes, version 4.0.2.1 ISO 16739-1:2018 [i.50]) has been introduced to improve upon the previous version. It offers several enhancements, including better support for complex geometries, improved representation of building services, and more. It is gradually becoming the new standard for Building Information Modelling (BIM).

With the introduction of IFC4.3 ADD2 (Industry Foundation Classes, version 4.3.2.0 ISO 16739-1:2024 [i.50]), the standard has been further extended to include infrastructure elements such as bridges, roads, rails, and ports & harbours. This version also includes support for modelling terrain and geological layers, making it more versatile and applicable to a wider range of projects.

The evolution of the IFC standard [i.50] reflects the ongoing efforts to improve interoperability and data exchange within the building and construction industry and with GIS data [i.42] and [i.43]. It is important for professionals in this field to stay updated with these changes to ensure they can effectively work with the latest BIM models and data.

6.10 OGC GeoSPARQL

The OGC GeoSPARQL standard [i.24] supports representing and querying geospatial data on the Semantic Web. GeoSPARQL defines a vocabulary for representing geospatial data in RDF, and it defines an extension to the SPARQL [i.9] query language for processing geospatial data. In addition, GeoSPARQL is designed to accommodate systems based on qualitative spatial reasoning and systems based on quantitative spatial computations.

6.11 GLTF - GL Transmission Format

glTF [i.29] is a royalty-free specification for the efficient transmission and loading of 3D scenes and models by engines and applications. glTF minimizes the size of 3D assets, and the runtime processing needed to unpack and use them. glTF defines an extensible, publishing format that streamlines authoring workflows and interactive services by enabling the interoperable use of 3D content across the industry. glTF 2.0 has been released as ISO/IEC 12113:2022 [i.54].

6.12 The FOG ontology - File Ontology for Geometry formats

The File Ontology for Geometry formats (FOG) [i.30] provides geometry schema specific relations between things (e.g. building objects) and their geometry descriptions [i.13]. These geometry descriptions can be:

1) RDF-based (e.g. using specific ontologies such as GEOM, OntoBREP, etc.);

2) RDF literals containing embedded geometry of existing geometry formats; and

3) RDF literals containing a reference to an external geometry file.

The FOG ontology extends the Ontology for Managing Geometry (OMG) and consists of three taxonomies of properties.

7 Use cases for Buildings

7.1 Introduction

Smart Buildings leverage advanced technologies and data analytics to optimize the use of resources, improve operational efficiency, and enhance occupant comfort and well-being. They are designed to be self-sufficient, adaptive, and responsive to changing conditions, providing a more sustainable and cost-effective approach to building management.

On a larger scale, Smart Cities extend these principles to the entire urban ecosystem. They use digital technologies to collect, analyse, and act on data from various sources, such as sensors, devices, and systems, to improve infrastructure, public services, and quality of life. By integrating Information and Communication Technology (ICT) and various physical devices connected to the network, smart cities optimize the efficiency of city operations and services and connect to citizens.

Here is a list of use cases where NGSI-LD could benefit from BIM context to handle information about buildings as geographic features and systems.

Smart Building Use Cases:

- Water Management: Smart buildings can monitor water usage, detect leaks, and automatically adjust usage to conserve water.
- Air Quality: Advanced systems can monitor and control air quality, ensuring a healthy environment for occupants.
- Energy Efficiency: Smart buildings can optimize energy usage, reducing costs and environmental impact.
- Carbon Footprint: By monitoring and managing energy usage, smart buildings can significantly reduce their carbon footprint.
- Construction Process: Smart technologies can streamline the construction process, improving efficiency and safety.
- Building Maintenance: Predictive maintenance can prevent equipment failures and extend the life of building systems.
- Space Usage: Smart buildings can track how spaces are used, enabling more efficient use of resources.
- Simulation: Buildings can be modelled to predict acoustics, ventilation, thermics, and lighting, improving design and performance.
- Cost/Performance Evaluation: Smart systems can provide real-time data on building performance, aiding in cost management.
- Building Code Compliance and Quality Control: Digital tools can ensure compliance with building codes and maintain quality control.
- Life Cycle Assessment: Smart buildings can track and manage the environmental impact of materials throughout their life cycle.
- Construction Process Monitoring: Real-time monitoring can improve construction efficiency and safety.
- Digital Permits: Digital permitting can streamline the construction process.
- Digital LogBook: A digital record of building operations can aid in maintenance and management.

Smart City Use Cases:

- Water Management: Smart cities can monitor and manage water usage city-wide, reducing waste and improving efficiency.
- Air Quality (Indoor/Outdoor): Smart cities can monitor air quality in real-time, alerting citizens to potential health risks.
- Energy Efficiency (Building Surrounding): Smart cities can optimize energy usage in public spaces and buildings, reducing costs and environmental impact.
- Urban Heat Island: Smart technologies can help mitigate the urban heat island effect, improving city livability.
- City Planning: Data from smart systems can aid in city planning, improving efficiency and quality of life.
- Mobility: Smart cities can improve transportation systems, reducing congestion and improving mobility.
- Green Cities: Smart technologies can aid in the creation of green cities, improving environmental sustainability.
- Water Management: Smart cities can manage water resources more effectively, reducing waste and improving water quality.

In the following clause, with focus into three specific use cases are examined at both city and building scales: Air quality, Energy management and Water management.

7.2 Air Quality

7.2.1 Scenarios and assumptions

Air pollution is one of the greatest environmental health threats. 9 out of 10 people globally are living in **areas** with **levels of pollution** over officially established **health limits**. People spend almost 80 % of their time in buildings and indoor air quality is often poorer than outdoor air quality [i.32]. The UN reports that almost 80 % of deaths caused by air pollution could be avoided if current air pollution levels were reduced to Air Quality recommendations. Identifying pollution source and understanding **exposure** factors is the key to reduce human and economics damage.

Air quality forecasts could give up-to-date advice to citizens for sports **activities** or urban mobility to reduce **pollutants** emission and exposure. Finally people suffering from respiratory illnesses can take benefit from personal applications to prevent exposition to a pollutant concentration higher than those required by physicians.

Clear indicators can also help decision makers in conducting necessary interventions to sustainably improve indoor and outdoor air quality or reduce pollutants exposure. Exposure is the correlation between duration of human-pollutant interaction and pollutants concentration. It is one of the main threat indicators [i.31].

Measuring Air Quality can be achieved by analysing satellite data or by deploying networks of sensors in cities (outdoor) and buildings (indoor). The Environmental Protection Agency (EPA) identified six main pollutants (Carbon Monoxide, Lead, Nitrogen Oxides, Ozone, Particulate Matter and Sulphur Dioxide) for outdoor air quality. For indoor air quality more than 250 pollutants are considered by the Air Quality Observatory [i.32] and [i.33]. In addition to **concentrations**, temperature and humidity ratio also need to be captured as they can represent aggravating factors. The frequency of measurement depends on the pollutant characteristics and goes from 10 seconds (for Carbon Monoxide) to 1 week (for mites). Collecting measurement context is essential to guarantee analysis interpretation and traceability.

People location is a key entry for exposure calculation. Furthermore human activities but can produce pollutants. For those reasons people activity and people location should be collected in order to collate concentration measurements with sources and impact on people.

7.2.2 Stakeholders

- Building Owners and Property Managers: They are responsible for ensuring the overall health and safety of occupants within the building. Monitoring indoor air quality data helps them identify potential issues and take corrective actions.

- Facility Management Teams: Facility managers play a crucial role in implementing strategies to maintain optimal indoor air quality. They rely on data to assess performance, identify trends, and make informed decisions regarding maintenance and upgrades.
- Occupants and Tenants: People who live or work in the building have a vested interest in indoor air quality. Access to data about air quality can empower them to take personal precautions and advocate for improvements if necessary.
- Health and Safety Professionals: Health and safety professionals, including occupational health specialists, may use indoor air quality data to assess potential health risks associated with the building environment. This information can inform recommendations for mitigating risks and promoting a healthier indoor environment.
- Environmental Agencies and Regulatory Bodies: Government agencies may set standards and regulations related to indoor air quality to protect public health. These entities rely on data to assess compliance, enforce regulations, and develop policies aimed at improving indoor air quality in buildings.
- Heating, Ventilation, and Air Conditioning (HVAC) Contractors and Engineers: Professionals responsible for designing, installing, and maintaining HVAC systems need access to indoor air quality data to assess system performance, diagnose issues, and optimize ventilation strategies.
- Building Automation and Internet of Things (IoT) Solution Providers: Companies that provide building automation systems and IoT devices for monitoring indoor air quality rely on data to develop and enhance their products. They may offer data analytics services to help building owners and managers optimize indoor environments [i.44].
- Insurance Companies: Insurers may have an interest in indoor air quality data as it relates to risk assessment and liability. They may offer incentives or discounts for buildings with superior indoor air quality practices or provide guidance on risk mitigation strategies based on data analysis.
- Real Estate Developers and Investors: Developers and investors may consider indoor air quality data as part of their due diligence process when assessing the value and desirability of a property. Positive indoor air quality can enhance the attractiveness and marketability of a building.
- Academic Researchers and Consultants: Researchers and consultants specializing in indoor air quality may utilize data from various buildings to conduct studies, develop models, and provide expertise on best practices for maintaining healthy indoor environments.

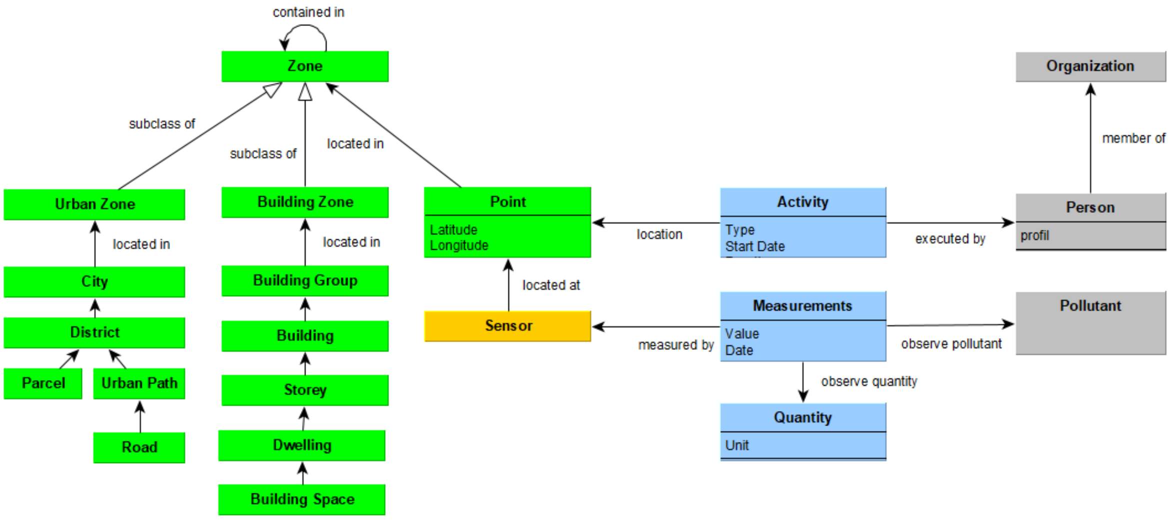

Figure 3: Conceptual model of air quality

7.2.3 Data types and data sources

Geospatial things:

- Space: Unique identifier (String or Integer), Type (String), Surface (Float), location (building storey), geometry (floorplan, height, 3D model). Data sources could be floor plan, building model, digital twin models, or facility management systems.

- Building: Unique identifier (String or Integer), Type (String), Surface (Float), Height (Float), Location (Latitude, Longitude), Address (String), geometry (footprint, bounding box, 3D model). Data sources could be building databases, building model, floorplan, GIS systems, or real estate databases.

- Parcels, Zones, Roads, Paths, Services, Points of Interest, City, Administrative Areas: Geometric data (Polygons, Lines, Points), Names, Types (Strings). Data sources could be GIS systems, urban planning databases, or open data portals.

Features of interest:

- People: Profile (String or Object), Building Role (String). Data sources could be HR systems, building management systems, surveys or user databases.

- Pollutants: Type (String), Concentration (Float). Data sources could be environmental sensors, air quality databases, or pollution monitoring systems.

- Equipment that interacts with Indoor air quality: ventilation, openings, heater.

Time Series:

- Activity: People Concerned (String or Object), Type of Activity (String), Time Stamps (DateTime), Product Used (String), Geolocation Tracking (Latitude, Longitude), Presence in a Space (Boolean). Data sources could be surveys, activity tracking systems, sensors, or user inputs.

- Measurements: Date of Measurement (DateTime), Pollutants Measured (String), Physical Quantity Measured (Float), Unit (String), Sensor Used (String). Data sources could be environmental sensors, air quality databases, or pollution monitoring systems.

Sensors:

- Sensor Description: Geolocation (Latitude, Longitude), Type (String), Maintenance (DateTime or String), Accuracy (Float). Data sources could be sensor databases, maintenance records, or sensor manufacturers' specifications.

7.3 Energy efficiency

7.3.1 Foreword

Building Information Modelling (BIM) and the Internet of Things (IoT) are powerful technologies that, when combined, offer numerous opportunities to enhance energy efficiency in buildings [i.18] and [i.19]. Some typical use cases demonstrating their potential include:

- Smart Building Automation: IoT sensors can be integrated with BIM models to collect real-time data on various building parameters such as temperature, occupancy, lighting levels, and energy consumption. This data can then be analysed to identify inefficiencies and optimize building systems for energy conservation.

- Predictive Maintenance: By monitoring equipment performance and health in real-time through IoT sensors connected to BIM models, facility managers can predict maintenance needs before equipment failures occur. This proactive approach helps prevent energy waste caused by inefficient or malfunctioning systems.

- Energy Monitoring and Management: IoT devices can track energy usage patterns throughout a building, providing insights into where energy is being consumed most and where improvements can be made. BIM models enhance this by providing a digital representation of the building, allowing for better visualization and analysis of energy data.

- Dynamic Building Simulation: BIM models can be coupled with IoT data to create dynamic building simulations that model how changes in building design or operation impact energy efficiency. This allows architects and engineers to test different scenarios virtually before implementing them in the physical building, optimizing energy performance from the design phase onwards.

- Occupant Comfort and Behaviour Analysis: IoT sensors can collect data on occupant behaviour, such as room occupancy patterns and temperature preferences. By integrating this data with BIM models, building operators can adjust heating, cooling, and lighting systems to optimize comfort levels while minimizing energy consumption.

- Renewable Energy Integration: BIM models can be used to design and plan the integration of renewable energy sources such as solar panels or wind turbines into buildings. IoT sensors can then monitor the performance of these systems in real-time, optimizing their operation to maximize energy generation and usage.

- Demand Response and Peak Load Management: IoT-enabled BIM systems can participate in demand response programs by automatically adjusting building systems in response to grid signals or peak demand periods. This helps reduce energy costs and alleviate strain on the electrical grid during peak times.

The **Energy Monitoring and Management** use case leveraging BIM and IoT involves the continuous monitoring and analysis of energy consumption within buildings to identify inefficiencies and optimize energy usage. Here is a more detailed breakdown of how this use case works:

- IoT Sensors Installation: IoT sensors are deployed throughout the building to collect real-time data on various parameters that affect energy consumption. These sensors can measure electricity, water, and gas usage, as well as environmental factors such as temperature, humidity, and occupancy. The sensors are typically connected to a central monitoring system via wireless or wired networks.

- Integration with BIM Models: The data collected by IoT sensors is integrated with the building's BIM model. This integration provides a digital representation of the building's physical and operational characteristics, allowing for more accurate analysis and visualization of energy usage patterns. BIM models capture detailed information about building components, systems, and their interactions, enabling more sophisticated energy simulations and analysis.

- Real-Time Monitoring and Analysis: With IoT sensors feeding data into the BIM model in real-time, building operators can monitor energy consumption patterns continuously. This allows them to identify areas of high energy usage, detect anomalies or inefficiencies, and track energy-saving initiatives' effectiveness. Real-time monitoring also enables quick response to deviations from expected energy usage, helping to prevent waste and optimize energy performance.

- Performance Benchmarking: By comparing current energy usage data against historical data or industry benchmarks, building operators can assess the building's energy performance and identify areas for improvement. BIM models facilitate this benchmarking process by providing a standardized framework for comparing energy usage across different buildings or building components.

- Energy Conservation Measures (ECMs) Identification: Through analysis of the integrated IoT data and BIM model, building operators can identify specific ECMs to reduce energy consumption and improve efficiency. These measures may include upgrading building systems, optimizing HVAC schedules, retrofitting lighting fixtures, or implementing renewable energy technologies. BIM models help evaluate the feasibility and potential impact of these ECMs before implementation.

- Optimization and Automation: Building management systems can leverage the integrated BIM and IoT data to automate energy optimization strategies. For example, automated controls can adjust HVAC setpoints based on occupancy patterns, dim lighting in unoccupied areas, or prioritize the use of renewable energy sources when available. These optimization strategies help maximize energy savings while maintaining occupant comfort and operational efficiency.

- Performance Reporting and Visualization: BIM models provide powerful visualization tools that enable building operators to communicate energy performance data effectively. Dashboards, reports, and 3D visualizations generated from the integrated IoT and BIM data help stakeholders understand energy usage trends, track progress towards energy goals, and make data-driven decisions to further improve energy efficiency.

7.3.2 Stakeholders

Several stakeholders are involved in this use case, who play different roles in the implementation, operation, and management of the system. These stakeholders include:

- Building Owners: Building owners have a vested interest in optimizing energy efficiency to reduce operating costs, enhance asset value, and meet sustainability goals. They are responsible for making decisions related to investments in energy monitoring and management systems, setting energy performance targets, and ensuring compliance with regulatory requirements.

- Facility Managers: Facility managers are responsible for day-to-day operations and maintenance of the building's systems and infrastructure. They play a critical role in implementing energy monitoring and management strategies, coordinating sensor deployments, analysing data, and implementing energy conservation measures to optimize building performance.

- Architects and Engineers: Architects and engineers are involved in the design and construction phases of the building project, where they use BIM technologies to create digital models of the building's physical and operational characteristics. They provide expertise in building design, energy modelling, and systems integration to optimize energy performance from the outset.

- Energy Consultants: Energy consultants provide specialized expertise in energy efficiency, renewable energy, and sustainability. They assist building owners and operators in developing energy management strategies, conducting energy audits, analysing data, and recommending energy-saving measures tailored to the building's specific requirements.

- IoT Solution Providers: IoT solution providers supply the hardware, software, and networking infrastructure necessary to deploy IoT sensors and collect real-time data on building parameters. They offer expertise in sensor technology, data analytics, and integration with building management systems to enable effective energy monitoring and management solutions.

- Software Developers: Software developers create the software applications and platforms used to collect, store, analyse, and visualize data from IoT sensors and BIM models. They develop custom software solutions or integrate off-the-shelf software products to meet the unique needs of energy monitoring and management projects.

- Regulatory Agencies: Regulatory agencies establish energy efficiency standards, codes, and regulations that govern building design, construction, and operation. They may provide incentives, certifications, or compliance requirements related to energy monitoring and management initiatives aimed at reducing energy consumption and greenhouse gas emissions.

- Occupants and Tenants: Occupants and tenants of the building play a role in energy conservation by adopting energy-efficient behaviours, such as turning off lights and equipment when not in use, adjusting thermostat settings, and participating in energy awareness programs implemented by building management.

7.3.3 Data sources

To effectively run the Energy Monitoring and Management use case leveraging BIM and IoT [i.45], a variety of data sources are necessary to collect comprehensive information about the building's energy usage and operational parameters. These data sources include:

- IoT Sensors: IoT sensors are crucial for collecting real-time data on various building parameters such as electricity, water, and gas usage, as well as environmental factors like temperature, humidity, and occupancy. These sensors can be installed throughout the building's infrastructure, including electrical panels, HVAC systems, lighting fixtures, water meters, and occupancy sensors.

- Building Management Systems (BMS): BMSs provide control and monitoring capabilities for building systems such as HVAC, lighting, and security. Data from these systems, including equipment status, setpoints, and energy consumption metrics, are essential for understanding the building's operational performance and identifying opportunities for energy optimization.

- Utility Meters: Utility meters measure the consumption of electricity, gas, water, and other utilities at the building level. Integrating data from utility meters into the energy monitoring system provides accurate measurements of overall energy usage and enables benchmarking against historical data or industry standards.

- Weather Data: Weather data, including temperature, humidity, solar radiation, and wind speed, are important for understanding how external conditions impact the building's energy performance. Access to reliable weather data allows for more accurate energy modelling and helps identify opportunities for optimizing HVAC and lighting systems based on weather conditions.
- Building Information Models (BIM): BIM models serve as the central repository for digital representations of the building's physical and operational characteristics. BIM data includes detailed information about building components, systems, spatial relationships, and performance attributes. Integrating BIM data with IoT and sensor data enables more comprehensive analysis and visualization of energy usage patterns within the building.
- Occupancy and Usage Data: Data on building occupancy, usage patterns, and operational schedules provide insights into how the building is being utilized and when energy-consuming systems are most active. Integrating occupancy data from sensors or access control systems helps optimize energy usage by adjusting HVAC and lighting settings based on occupancy levels.
- Renewable Energy Generation Data: If the building incorporates renewable energy sources such as solar panels or wind turbines, data on energy generation and performance are essential for evaluating the effectiveness of these systems and optimizing their integration with the building's energy infrastructure.

7.3.4 Conceptual Model

Figure 4 illustrate the main concepts and their relation for building energy applications [i.2].

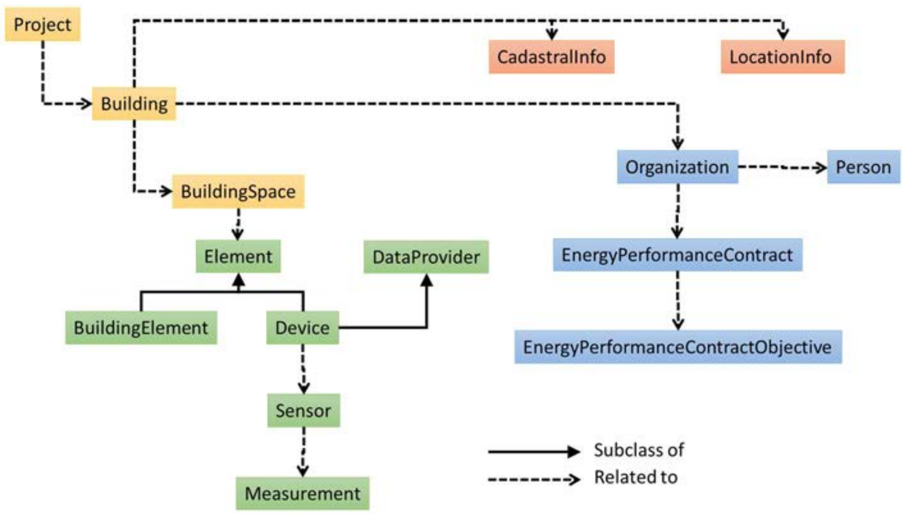

Figure 4: Conceptual model for Energy Monitoring and Management

7.4 Water management

7.4.1 Foreword

From a smart city perspective, the impact of climate change on water management presents both challenges and opportunities for innovation. Digital technology, data analytics, and the Internet of Things (IoT) are used to optimize water management [i.39] and [i.41].

Two different scopes of water management are identified:

1) the utilities viewpoint which includes water sources and collection, treatment plants, distribution systems, wastewater collection and treatment, and stormwater management;

2) the building viewpoint which includes connection of the building to the utilities water and waste systems and the water management inside the building.

7.4.2 Scenario description

As water management becomes increasingly integrated with smart cities initiatives, it is essential to explore how emerging technologies and standards can support buildings, networks and infrastructures. One main aspect of this integration is the use of the Industry Foundation Classes (IFCs) and NGSI-LD for improving interoperability in urban water management systems.

To illustrate the potential, the following hypothetic use cases related to Water Management using the IFC as data models for a Smart Building application in relation to other Smart City application are identified, which will need to relate IFC data with other context data using NGSI-LD as an interoperability format.

- Flooding alerts from water management system or from meteorological agency which sends a message to a smart building application in order to prevent flooding of basements and lower level stories.
- Pollution alert from water management system send to smart building water station to stop incoming flows and prevent contamination.
- Leak detection from water management system to minimize water damage and reduce water wastage.
- Publication of water retention basins volume, location and shapes modifications from a property to the stormwater management system.
- Publication of water devices room locations in a building and other properties like altitude, classification of water drinkable, waste, grey, etc.
- Publication of the full water fire hydrant network inside a building to the fire department of the city, including modifications or repairs during the life of the building [i.46].

NGSI-LD and SAREF [i.10] are already identified as a key enabler of the European Union's policy on Water Management Digitalisation which aims to leverage digital technologies to enhance the efficiency, sustainability, and resilience of water management practices across member states. This policy aligns with the EU's broader goals of sustainable water management, water scarcity, climate change, and environmental degradation. For more details, see EU policy on Water Management Digitalisation.

Most of the Water management use cases using NGSI-LD are IoT-related for the water utilities companies and do not have references to the IFC. Some do mention BIM standards but as the BIM data handover process level, not related to the IFC data representing the assets in the network. See more details on Fiware4Water demos cases in Greece [i.41], France, Netherlands and UK.

On the other hand, there are water management use cases related to IFC and /or CityGML or other GIS models, but one cannot yet found evidence of any usage of NGSI-LD in these contexts. For example, the maintenance of underground piping networks requires extensive integration of both horizontal and vertical dimensions. The underground networks need to consider not only their specific attributes, such as materials, depth, size, and connection, but also the interaction with other objects, as road or surface building. A global underground network contains multiple specific domain network (water, gas, sewage, communication) layered at different depths. For more details, see this study on challenges of underground network maintenance [i.42].

The challenges in visualizing and managing these networks derive from:

- A complexity in visualization because of the composition of numerous nodes, lines, and connections which can be missing a 3D coordinates.
- Interactions between underground and surface structures (roads, buildings, etc.) that require a high level of details of piping network.
- The tools that do not accurately depict overlapping pipes (water, waste, electrical, gas), causing confusion for maintenance teams and increasing complexity of cross-domain cooperation.

Technical difficulties still remain due to the differences between how BIM (focused on architecture with limited domain) and geoinformation (focused on geography with wider extension) represent the world and the objects. These challenges include scale of representation and the coordinate systems, the levels of detail and geometric representation, the exchange file formats, methods for accessing and for the storage of information as well as semantic mismatches and topological issues [i.43]. However, water management including the buildings characteristics has the potential to improve efficiency, sustainability and performance.

7.4.3 Stakeholders

Government & Regulatory Agencies

- Local, state, and federal governments: These entities are responsible for setting policies, regulations, and standards related to water quality, allocation, and conservation. They also play a key role in financing and overseeing water infrastructure projects.
- Environmental Protection Agencies: Specialized government agencies at various levels responsible for protecting water quality and ecosystem health.

Utilities & Water Utilities

- Water Supply Companies: These entities manage the supply of drinking water to residential, commercial, and industrial users. They are responsible for water collection, treatment, distribution, and sometimes wastewater treatment.
- Wastewater treatment entities: Organizations that manage the collection, treatment, disposal, or reuse of wastewater.

Commercial & Industrial Users

- Businesses and industries: Heavy consumers of water for manufacturing, processing, cooling, and other operational needs. They have a vested interest in the reliability, quality, and cost of water services.

Environment & Conservation Groups

- NGOs and environmentalists: organizations and groups dedicated to protecting natural water bodies, preserving biodiversity, and promoting sustainable water management practices to ensure healthy ecosystems.

Research, academic and scientific communities

- Scientists and researchers: Experts who study water systems, climate change impacts, water quality, and conservation techniques, providing essential data and information for informed decision-making.
- Academic institutions: Universities and colleges involved in researching and training the next generation of water professionals.

Local communities and civil society

- Residents: Individuals and communities who are end users of drinking, sanitation, and recreational water. They are directly affected by water management policies and practices.
- Indigenous communities: Indigenous groups may have historical or cultural claims to water resources and may be particularly influenced by water management decisions.
- Community organizations: Local groups and nonprofit organizations that work on issues related to community water access, quality, and conservation.

International organizations

- Multilateral Development Banks and Humanitarian Organizations: These include the World Bank, the Asian Development Bank, and various United Nations agencies that provide financing, expertise, and policy guidance for water management projects, particularly in developing countries.
- International Water Management Networks: Organizations that facilitate knowledge exchange and cross-border collaboration to effectively manage transboundary water resources.

Private Sector & Technology Providers

- Technology and service providers: Companies that develop and provide water technologies, such as treatment systems, irrigation equipment, and water efficiency devices, to improve water management practices.
- Consultants and Engineers: Professionals who design, advise, and implement water management solutions and infrastructure projects.

7.4.4 Data sources

Spatial data

- Satellite imagery: Provides complete and up-to-date images of the Earth's surface, useful for monitoring land use, vegetation cover, and the extent of water bodies.
- Aerial Photography: Offers high-resolution images for detailed analysis of specific areas, often used for urban planning and environmental monitoring.
- Topographic maps: contain information about the elevation, slopes, and landforms of the terrain, which is crucial for watershed analysis and water flow modelling.

Environmental data

- Hydrologic data: Includes measurements of stream flows, precipitation records, and water levels in lakes and reservoirs, which are essential for understanding water availability and designing flood management systems.
- Soil data: Soil types, moisture levels, and permeability affect water infiltration and runoff, impacting groundwater recharge and surface water flows.
- Climate data: Temperature, precipitation patterns, and evapotranspiration rates are critical for assessing water demand and supply under changing climatic conditions.

Infrastructure and urban area data

- City, building, Water treatment positions.
- Drainage plans for building permits.
- Water distribution networks: Information on pipelines, pumps, reservoirs, and treatment facilities, used to manage water supply systems.
- Sewer and stormwater systems: Data on sewer lines, drainage systems and stormwater management infrastructure, important for urban water management and flood mitigation.
- Land use and urbanization patterns: Influence water demand and affect runoff and pollution levels, which is necessary for planning and environmental impact assessments.
- Asset Management and Operational Data, Asset registers: Databases containing detailed information about infrastructure assets, their location, status, and maintenance history.
- IoT sensors and devices: Generate real-time data on water quality, flow rates, and system pressures, enabling dynamic monitoring and management of water networks.

Building Information Modelling (BIM) Data

- IFC models: detailed 3D representations of construction and infrastructure projects, including water-related facilities. Three IFC domains are most relevant for water management use cases: the IFC Building Automation, Control, Instrumentation and Alarm domain [i.44], the IFC Heating, Ventilating and Air Conditioning (HVAC) domain [i.45] and the IFC Plumbing and Fire protection domain [i.46].
- IFC entities concerned by IFC Building Automation, Control, Instrumentation and Alarm domain:
    - IfcActuator
    - IfcAlarm
    - IfcController
    - IfcFlowInstrument
    - IfcSensor

- IFC entities concerned by IFC Heating, Ventilating and Air Conditioning (HVAC) domain:
  - IfcBoiler
  - IfcFlowMeter
  - IfcPipeFitting
  - IfcPipeSegment
  - IfcPump
  - IfcTank
  - IfcValve
- IFC entities concerned by IFC Heating, Ventilating and Air Conditioning (HVAC) domain:
  - IfcFireSuppressionTerminal
  - IfcInterceptor
  - IfcSanitaryTerminal
  - IfcStackTerminal
  - IfcWasteTerminal
- And common entities:
  - IfcPlumbingFixture
  - IfcOutlet
  - IfcFilter
  - IfcWaterHeater, etc.

7.4.5 Conceptual model

As mentioned earlier, water meters, leak sensors, and quality sensors can provide data in NGSI-LD format, allowing the building's central system to monitor and manage water resources effectively. By mapping SAREF requirement for the water domain [i.47], [i.48] (SAREF4WATR) concepts to NGSI-LD, the building management system can leverage standardized, interoperable data models, enhancing integration with other smart city systems and IoT platforms, thereby achieving more efficient and effective water management. The mapping from Smart Applications REFerence ontology (SAREF) and its extensions, such as SAREF4WATR [i.47] to NGSI-LD is on-going.

For further details on the models, see the SAREF extension for the water domain shown in Figure 5 and Figure 6 and the NGSI-LD data model for Water Network Management detailed in the FIWARE smart data models repository [i.49].

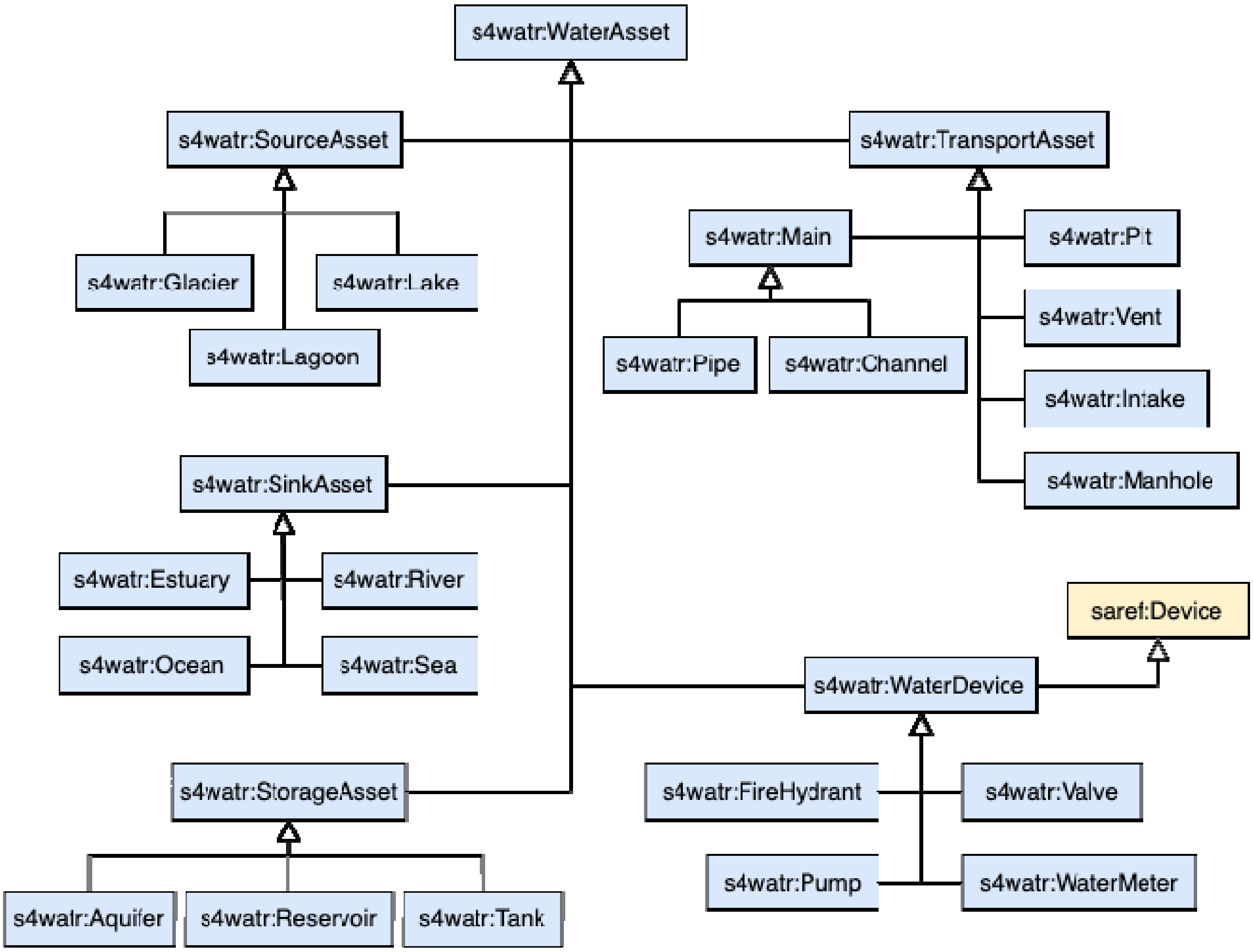

Figure 5: SAREF4WATR asset model

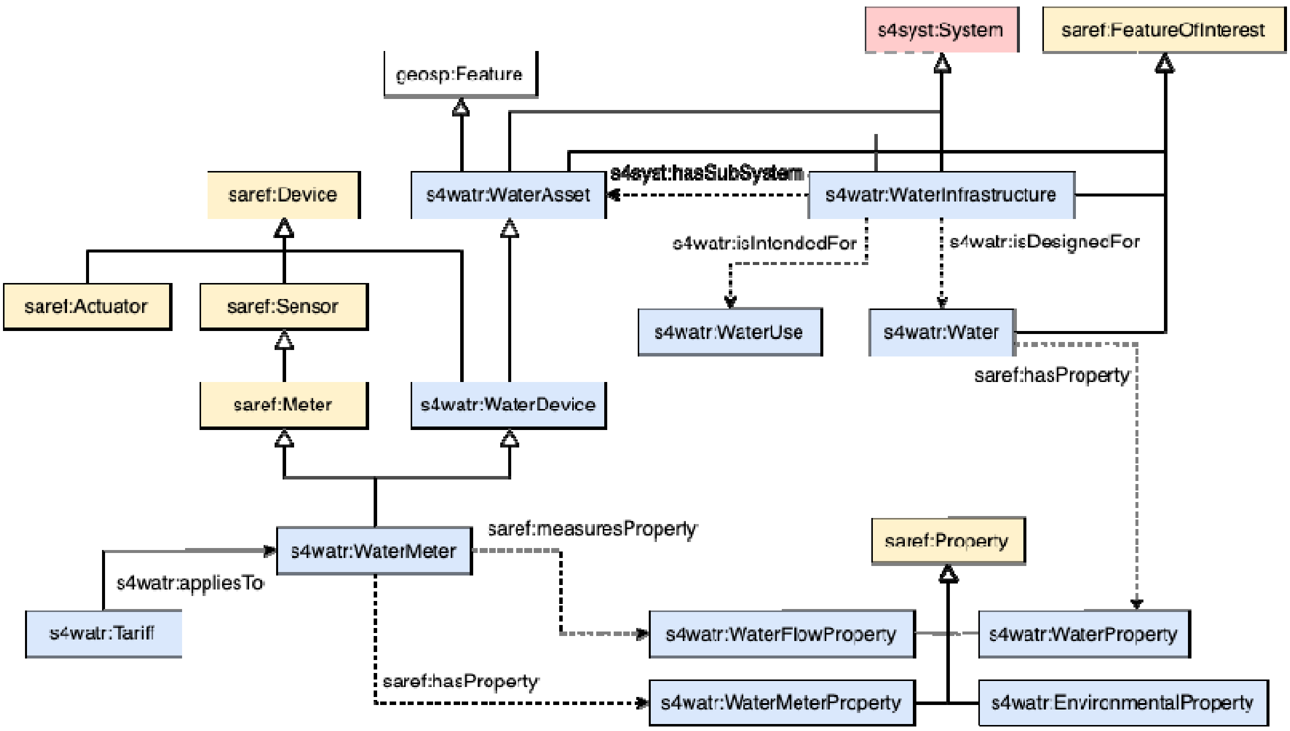

Figure 6: Water-related terms of SAREF4WATR

A mapping between SAREF4WATR and IFC does not currently exist. The present document will show the three cases on how to generate a mapping:

- The concept exists in IFC and SAREF.
- The concept exists in SAREF and not in IFC.
- The concept exists in IFC and not in SAREF.

For each case, Table 1 below illustrates how to define such a mapping.

Table 1: Example of IFC, NGSI-LD mapping for water

<table>
<tr><th>SAREF4WATR (V1.1.1)</th><th>IFC (4.3.2.0)</th><th>NGSI-LD (V1.8)</th></tr>
<tr><td>s4watr:Tank</td><td>IfcTank</td><td>Entity of type [Tank]</td></tr>
<tr><td rowspan="2">s4watr:GaugingStation</td><td>IfcBuilding with PropertySet Pset_BuildingCommon with label:

<Properties>
<IfcPropertySingleValue>
<Name>BuildingType</Name>
<Value> <IfcLabel>Gauging Station</IfcLabel> </Value>
</IfcPropertySingleValue>
</Properties></td><td rowspan="2">Entity of type [GaugingStation]</td></tr>
<tr><td>Association between IfcBuilding and the classification s4watr:GaugingStation:

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<HasAssociations>RelClass_1</HasAssociations>
</IfcBuilding>

<IfcClassificationReference id="MainClassRef">
<Identification>Water System Classification</Identification>
<Description>Main classification for water-related infrastructure</Description>
</IfcClassificationReference>

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<Description>Classification for Gauging Station in SAREF4WATER</Description>

<Location>https://saref.etsi.org/saref4watr/v1.1.1/#s4watr:GaugingStation</Location>
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</IfcClassificationReference>

<IfcRelAssociatesClassification id="RelClass_1">
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<RelatingClassification>ClassRef_1</RelatingClassification>
</IfcRelAssociatesClassification></td></tr>
<tr><td>Does not exist in SAREF</td><td>IfcDuctFitting</td><td>Entity of type [DuctFitting]</td></tr>
</table>

8 Building Model Requirements

8.1 Introduction

This clause discusses on the different data subdomains of BIM context. It presents the main data required by use cases and compares their implementation in existing standards.

8.2 Identification

Building persistent and unique Uniform Resource Identifiers (URIs) for Industry Foundation Classes (IFC) models in a linked data context involves several steps. Here is a simplified process:

- Each IFC model should have a unique identifier. This could be a simple incremental ID, a UUID (Universally Unique Identifier), or any other unique string. This identifier will be used as part of the URI.
- A base URI is needed to represent the location of the linked data. This could be a URL prefix like 'http://linkedbuildingdata.net/ifc/'.
- Combine the base URI with the unique identifier of the IFC model to create a URI. For example, if the base URI is http://linkedbuildingdata.net/ifc/ and the IFC model has an ID of '28edc58bc25f22227a552a019fc682b9', the URI would be 'http://linkedbuildingdata.net/ifc/28edc58bc25f22227a552a019fc682b9/'.
- Then building elements URIs can be built be from the model identifier. For example if the local ID of a Space if 'IfcSpace_249', its URI should be 'http://linkedbuildingdata.net/ifc/28edc58bc25f22227a552a019fc682b9/IfcSpace_249'.

To ensure persistence, one needs to make sure that once a URI is assigned to an IFC model, it never changes. This means that even if the IFC model is moved or changed, its URI should remain the same.

A content negotiation mechanism should be implemented on a web server so that clients can request the IFC model in different formats. For example, a client could request the IFC model in its native format by sending an 'Accept: application/ifc' header, or it could request an RDF description of the model by sending an 'Accept: application/rdf+xml' header.

The URIs should be dereferenceable, meaning that if a client follows the URI, they should be able to retrieve information about the IFC model. This is a key principle of Linked Data.

8.3 Spatial data

8.3.1 Location

The ability to accurately represent and communicate the location of building elements and other spatial entities is a critical requirement for many applications in the built environment [i.21].

The absolute location of a building or element can use geographic coordinates (e.g. latitude, longitude) and/or a postal address. Additional details like building number, room number, floor, staircase, or elevator can be useful for indoor positioning. The BOT ontology establishes the primary location of a building using the "hasZeroPoint" property. Typically, all indoor locations are specified relative to this zero point, which serves as the origin [0,0,0] within the building's local coordinate system.

NGSI-LD use the GeoJSON format which in its current version, IETF RFC 7946 [i.51] from 2016, specifies a unique WGS84 Coordinate Reference System (CRS), with no option to use another CRS. NGSI-LD specifies the geometry properties to be GeoJSON objects, therefore based on a WGS84 CRS.

There are many different Coordinate Systems in use by the geospatial or BIM applications depending on the systems defaults, the region of the world, local regulations and export parameters. The OGC standards and the BIM / IFC standards specify how to define the reference system in which the dataset geolocalized 2D or 3D point coordinates where generated and which will be used when reading these coordinates. The OGC standards also provides the conversion rules and models to transform data from one CRS to another one. Repositories exists to define the CRS unambiguously.

Nevertheless interviews with various parties and some random sample selection on the data.gouv.fr data set has shown that in real world implementations the CRS are not always defined or some datasets are using a different CRS than the one specified in the data catalog. This leads to errors and human intervention to redefine the CRS when importing or aggregating data.

Recommendations:

- The inclusion of a CRS property in the GeoProperty values.
- To emphasize in the NGSI-LD specification the fact that the unique and default CRS is WGS84 for the GeoJSON geometries in NGSI-LD.
- To request a mandatory CRS property in the linked dataset from other domain models.
- The definition of a new 3DShape for indoor locations or CAD data based on the IFC mechanism of local coordinates with a geolocalized Zero-point with a CRS.

8.3.2 Containment

A Building Breakdown Structure (BBS) is a hierarchical decomposition of a building into its constituent parts or elements, organized in a way that reflects the physical and functional relationships among them. The BBS provides a systematic framework for organizing and managing information about a building, and can be used to support a wide range of activities, such as design, construction, operation, maintenance, and renovation.

The specific elements of a BBS will vary depending on the type and complexity of the building, but some common elements that may be included are:

- Site: The external environment and context of the building, including the site, climate, and adjacent buildings and infrastructure.
- Envelope: The exterior walls, roof, and foundation of the building, which provide protection from the elements and help to maintain a comfortable indoor environment.
- Storeys: The vertical division of the building into levels or floors, which may be used for different purposes and may have different structural and mechanical systems.
- Spaces: The interior volumes of the building, which may be subdivided into rooms or areas with specific functions, such as living, working, or storage.
- Equipment: The movable or fixed items within the building that are used for specific purposes, such as appliances, furniture, or machinery.
- Systems and components: The mechanical, electrical, and plumbing systems that provide services such as heating, ventilation, air conditioning, lighting, and water supply, as well as the components that make up these systems, such as pipes, ducts, and wiring.
- Structure and components: The load-bearing elements of the building, such as columns, beams, and walls, as well as the materials and connections that make up these elements.
- Covering: The exterior finishes and cladding of the building, which may be made of materials such as brick, stone, metal, or glass, and which serve both functional and aesthetic purposes.

The BBS can be used to represent a building at different levels of detail, depending on the needs of the user. For example, a designer may use a high-level BBS to organize and coordinate the overall design of the building, while a contractor may use a more detailed BBS to plan and manage the construction process. Similarly, a facility manager may use a BBS to track and maintain the various systems and components of the building over its lifecycle.

The Set-Based Location describes location in terms of relationships between entities**.** It uses "IsContainedIn" like relationships to assert containment, e.g. "TableA IsContainedIn RoomA IsContainedIn BuildingA". Those relations are appropriate for indoor locations like rooms, floors, buildings. For instance, BOT ontology defines a set of relationships for containment description:

<Site>	hasBuilding	<Building>
<Building>	hasStorey	<Storey>
<Zone>	hasSpace	<Space>
<Zone>	hasElement	<Element>

<Element> hasSubElement <Element>

Topology at city scale (SAREF4CITY)

The city environment is composed by City Objects (s4city:CityObject), Administrative Areas (s4city:ADministrativeArea) and Facilities (s4cityFacility). Those concepts are all subclasses of the Feature (saref4city:Feature) and Spatial Object (geosp:SpatialObject). That means that those classes are connected to geometry (geosp:Geometry) and location (geo:location). Note that the saref4city ontology depicted in Figure 7 is based on the geoSPARQL ontology [i.40] hat implements basic location properties and topology relations such as functional containers (geosp:sfContains), geometrical containers (geosp:sfWithin).

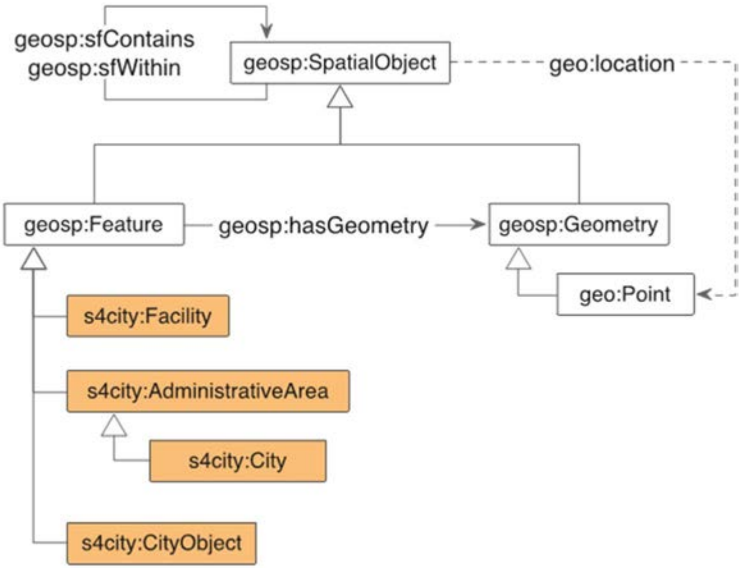

Figure 7: SAREF4CITY ontology with City Objects

Topology between Building and city (SAREF4BLDG)

The Saref4Bldg (SAREF for Buildings) ontology presented in Figure 8 is not explicitly aligned to Saref4city but generally the Building class (saref4bldg:Building) can be considered as a subclass of the city object class (s4city:CityObject). The building is decomposed in spaces (saref4bldg:BuildingSpace) and physical objects (saref4bldg:PhysicalObject) by using topological relations (saref4bldg:hasSpace and saref4bldg:contains). The physical object concept generalizes building components and equipment (saref4bldg:BuildingObject and saref:Device).

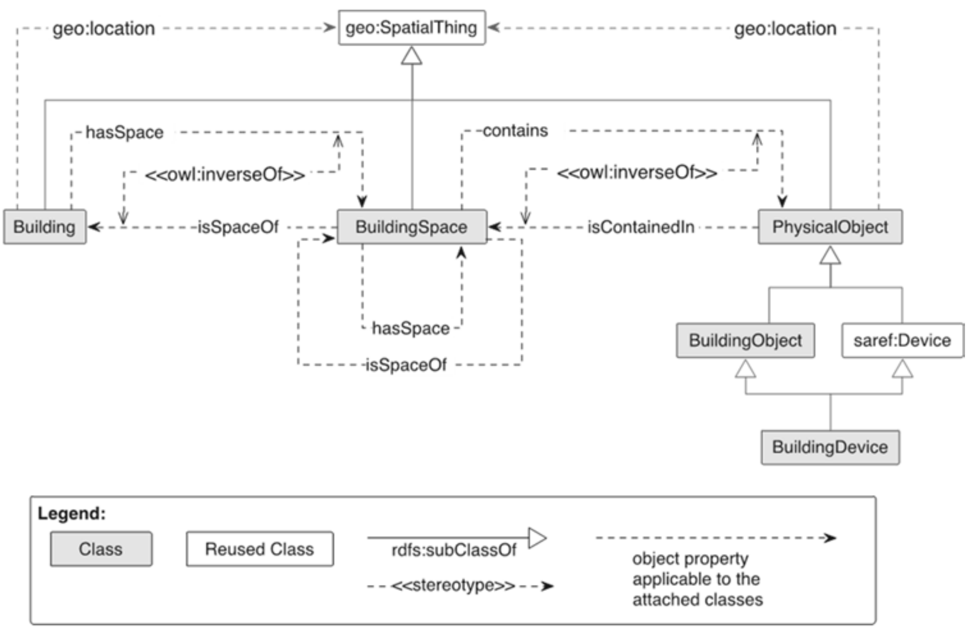

Figure 8: Overview of SAREF4BLDG ontology

Topology at building scale (BOT)

BOT stands for Building Topology Ontology. It is aligned with saref4bldg ontology and brings more specialized concepts and relations. As shown in Figure 9, Site, Building, Storey and Space are all subclasses of the zone concept of BOT. An object of type bot:Zone can contain other zones. In this way the bot:Zone seems equivalent to the saref4bldg:BuildginsSpace. Whereas bot:Space is used the represent a specific room in the building. Bot:Element is the same concept as saref4bldg:BuildingObject. Topological indoor relations are also aligned as bot:containsZone is equivalent to saref4bldg:hasSpace and bot:containsElement is equivalent to saref4bldg:contains.

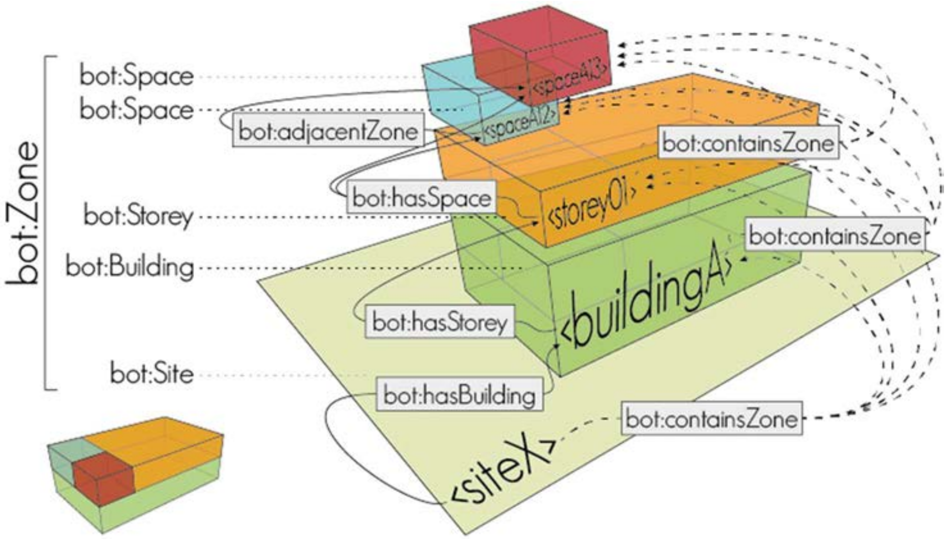

Figure 9: BOT overview [i.28]

Topology at building / component scale (BOT)

BOT also includes relations between building components. Indeed walls are connected to each other to bound spaces. Pipes are connected to each other to describe water distribution networks. Window, doors and wall are bounding a space. While those relation are specialized in IFC they are all classified under the bot:Interface concept and the bot:interfaceOf topological relation as depicted in Figure 10.

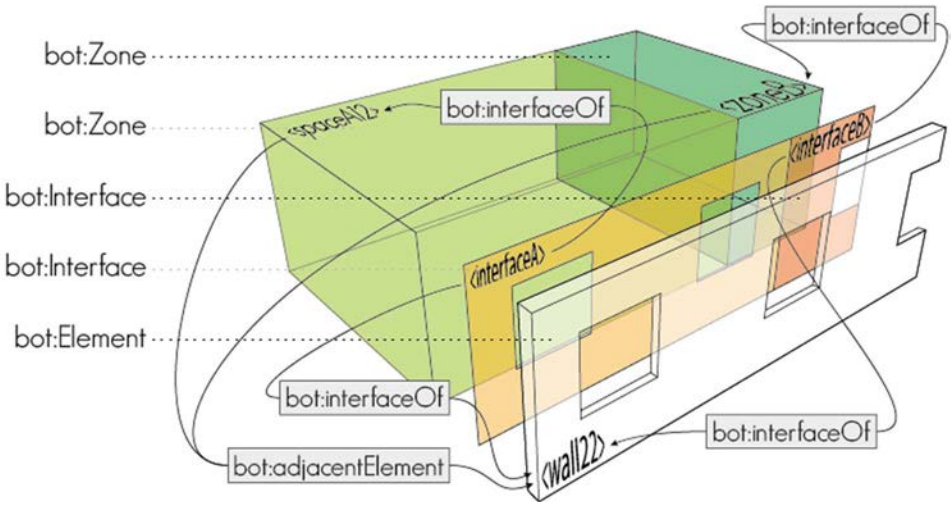

Figure 10: Objects involved in Interfaces [i.28]

Topology at building / component scale (IFC)

IFC add a supplementary level of detail concerning topology by introduction of more specific relations:

- Relation between openings and wall (IfcRelFillsElement / IfcRelVoidsElement).
- Relation between walls and space (IfcRelSpaceBoundary).

- Connection between pipes (IfcRelConnectsPortToElement).
- Material layers (IfcRelAssociatesMaterial).

Alignments between IFC, BOT and SAREF

Figure 11 gives correspondences between ontologies at class level. For instance ifc:Space bot:Space and saref:Space have the same meaning.

Definition	IFC	BOT	SAREF
Object located in space with geometry			SpatialObject
Object located in the city			CityObject
Group of buildings	IfcSite	Zone	CityObject
Structure with roof and walls	IfcBuilding	Building	Building
Horinzontal slice of a building containg spaces	IfcStorey	Zone	Space
Group of spaces	IfcZone	Zone	Space
Room in a bulding	IfcSpace	Space	Space
Opening in a wall or roof to let in light and air	IfcWindow	Element	BuidingObject
Movable and provide access to a space	IfcDoor	Element	BuidingObject
Cylindrical object that is used to convey fluids	IfcPipe	Element	BuidingObject
Group of elements that provides a specific service	IfcSystem	Element	Device
Element that provides a specific function or service	IfcDevice	Element	Device
Device that measures properties	IfcSensor	Element	Sensor
Device that act on other physical objects	IfcActuator	Element	Actuator

Figure 11: Mapping between IFC, BOT and SAREF

8.3.3 Graph-based location

The graph base location represents relative location between elements using a graph structure. In such a graph, nodes represent locations (rooms, streets) and edges represent connections**.** For instance: "RoomA connectsTo RoomB", "StreetA connectsTo CrossingAB connectsTo StreetB". This kind of location enables indoor navigation and city-scale navigation through streets. The BOT ontology provides few graph-based location:

<Zone> adjacentZone <Zone>

<Zone> intersectsZone <Zone>

<Interface> interfaceOf <Zone>,<Element>

According to BOT an interface can describe any connection of two or more things.

8.3.4 Geometry

Geometry data have to mains uses. The first use consists in performing calculation or inferring on spatial measurements (distances, surfaces, volumes, relative angles, overlapping) from the building. The second use consists in displaying geometry on a graphic interface either in 2D (floor plan, city planning) or 3D (3D web UI, VR). Some standards includes both aspect of geometry such as (cityGML and IFC), some are dedicated to rendering (GLTF, B3DM, webML, DAE) and some others are flexible (BOT) and can include geometry at different level of details.

In the context of Building Information Modelling (BIM), LOD stands for Level of Development. It is a term used to describe the extent to which the elements of a BIM model have been developed or defined.

Level of Development (LOD) [i.5] is a way of specifying the detail and accuracy of a BIM model at different stages of a construction project. The LOD of a model can range from a conceptual level, where the model is used for initial planning and design, to a detailed level, where the model is used for fabrication and construction.

There are typically five LODs in BIM as shown in Figure 12:

- LOD 100: Conceptual Model - This level of development is used for initial planning and design. The model consists of basic geometric representations of building elements.
- LOD 200: Schematic Design Model - This level of development includes more detailed information about the building elements, such as size, shape, orientation, and location.

- LOD 300: Design Development Model - This level of development includes more detailed information about the building elements, such as specifications, materials, and connections.
- LOD 350: Construction Documentation Model - This level of development includes more detailed information about the building elements, such as fabrication and installation details.
- LOD 400: As-Built Model - This level of development includes all of the information from previous LODs, along with any changes made during construction, to create a complete and accurate representation of the building as it was constructed.

The LOD of a BIM model is important for ensuring that all stakeholders in a construction project have a clear understanding of the level of detail and accuracy of the model at each stage of the project. This helps to ensure that decisions are made based on accurate information, and that the model can be used effectively for its intended purpose.

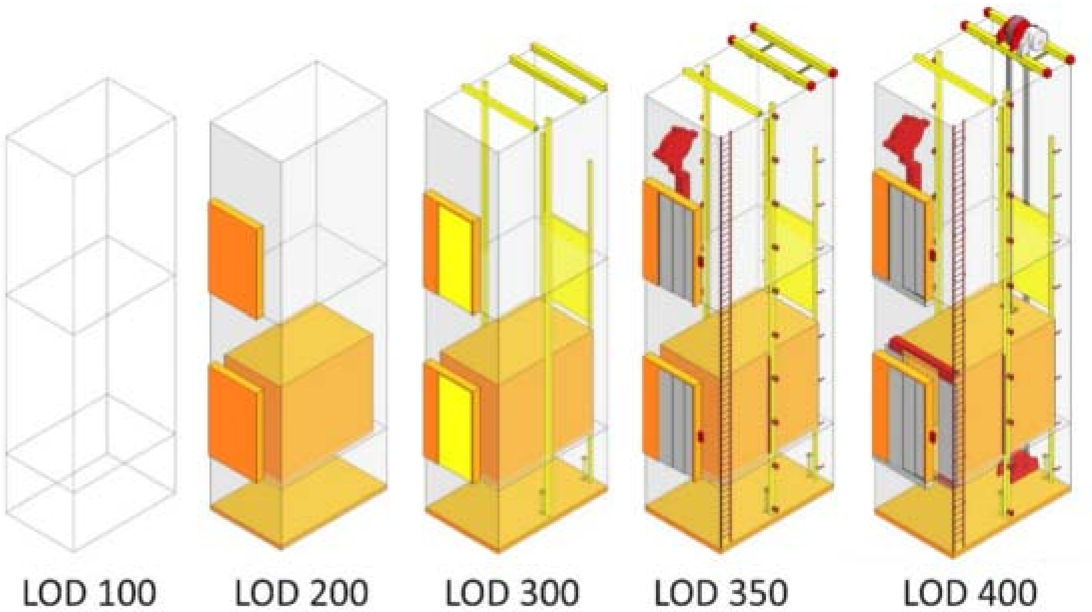

Figure 12: Progression of design across the LODs with an example of Elevator

The choice of the LOD depends on the construction stage (conception, execution plan, etc.) and on use cases. Furthermore, the LOD can be different for each component of the building. For instance, a building model dedicated to accessibility needs an accurate dimensions of rooms and doors but doesn't need any geometry concerning the roof.

For many use cases based on floorplan (floor planning, city planning, city pathways) LOD 100 is sufficient.

In IFC, the geometry can either be implicit or explicit. IFC can embed multiple representations of the same object. The implicit geometry consists of basic shapes (polygons, circles) and transformations (spatial extrusion, intersection, addition, subtraction). The explicit geometry is called B-Rep (Boundary Representation). It is a method of representing shapes using the limits. In other words, a solid object is represented as a set of connected surface elements, which enclose a volume in Euclidean space. B-rep is used in the IFC data model to define the geometric shape of building elements. The surfaces that make up the boundary can be planar or curved faces, and they together form a closed shell that defines the volume of the object. This allows for complex geometries to be accurately represented and exchanged between different software applications in the Architecture, Engineering, Construction, and Operations (AECO) industry. The IFC model uses this representation to ensure that the geometric data is consistent, accurate, and can be interpreted correctly by different systems, thus enabling interoperability.

In Linked Data standards based on ontologies such as SAREF and BOT the geometry can be described semantically through objects and properties (area, volume, height, width, depth, orientation) or through geometric literals by using the geoSPARQL ontology and the WKT notation [i.36] and [i.37]. The WKT notation allows to describe 2D polygons in the horizontal plan. LOD 100 can be expressed by using a floor polygon and a height property. WKT also allows 3D geometry description or 3D geometries by using the POLYHEDRAL form [i.34], [i.35] and [i.40]. When a high accuracy is needed, it is common to link semantic data to serialized 3D resources by using dedicated 3D standards such as GLTF or COLLADA. The File Ontology for Geometry formats (FOG) allows this kind of links to be expressed.

The FOG ontology recognizes that a single universal format is insufficient, and that supporting a variety of serialization options is necessary to enable the flexible exchange of building geometry data between diverse software systems and applications. It provides different serialization formats for building geometry to enable interoperability between various software tools and data sources. Some key reasons for supporting multiple serialization formats include:

- Different software tools may natively support or prefer certain geometry formats. Providing a mapping between these formats allows data to be easily exchanged between tools.
- Certain formats are optimized for specific use cases, such as compact file sizes for web delivery, or high precision for engineering applications. Supporting multiple formats enables the most appropriate one to be chosen for each scenario.
- Some formats provide additional metadata or semantic information alongside the geometry, which can be useful for downstream processing or analysis of the building data.
- Older legacy formats may still be in use, so supporting them ensures compatibility with existing workflows and data sources.

FOG provides geometry schema specific relations between things (e.g. building objects) and their geometry descriptions as depicted in Figure 13. These geometry descriptions can be:

- Ontology based (e.g. using specific ontologies such as GEOM, OntoBREP, etc.).
- Literals containing embedded geometry of existing geometry formats (WKT, geoJSON).
- Literals containing a reference to an original external geometry file.

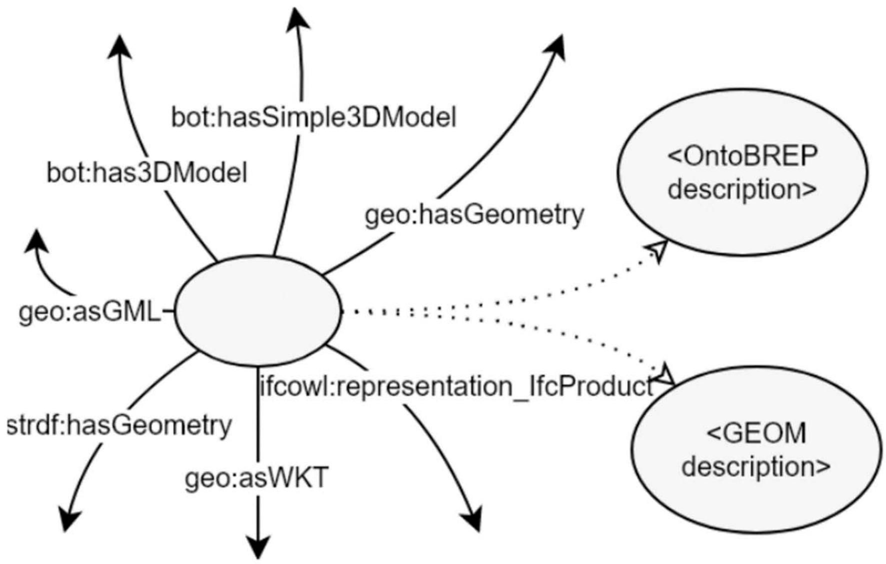

Figure 13: Relations between non-geometric objects and their geometry descriptions

Examples of Serialization Formats:

- Industry Foundation Classes (IFC): Used widely in BIM for sharing detailed and complex building information across various software platforms.
- DWG/DXF: Commonly used in CAD applications for detailed 2D and 3D design work.
- Scalable Vector Graphics (SVG): Suitable for web-based applications requiring lightweight 2D representations.
- OBJ/FBX: Often used in 3D modelling and animation software, supporting complex surface geometry.
- GL Transmission Format (GLTF): Optimized for transmitting 3D models over the web, balancing detail and performance.

By using FOG, a building object can have multiple representations depending on calculation, interoperability or rendering needs. For a particular use case where 3D shapes or volumes need to be transferred between two separate domains, it is possible to consider the use of point clouds represented as GeoJSON multipoints.

8.4 Time series

There is various types of high-frequency time series data and sensor data that can be collected and analysed in the context of building management or smart buildings. Here is a brief explanation of each:

- Number of occupants: This data can be used to optimize space usage and energy consumption. It can be collected using sensors or through access control systems.
- Availability of rooms: This information can help with space management and scheduling. It can be tracked through booking systems or occupancy sensors.
- Room temperature/humidity: These are important factors for comfort and health. They can be monitored using temperature and humidity sensors.
- Air pollutants concentration: Monitoring air quality is crucial for health and well-being. Specialized sensors can measure various pollutants.
- Lighting conditions: This data can help optimize energy usage and create a comfortable environment. Light sensors can provide this information.
- Energy consumption at delivery points: This data can help identify patterns and opportunities for energy savings. It can be collected using smart meters.
- Renewable energy production tracking: This data can help manage energy usage and reduce reliance on non-renewable sources. It can be collected from renewable energy systems like solar panels or wind turbines.
- Security and access control: This data is crucial for maintaining safety and security. It can be collected through access control systems, surveillance cameras, and alarm systems.
- Status of critical systems and equipment: Monitoring the status of systems like elevators or safety equipment can help prevent breakdowns and maintain safety. This data can be collected directly from the equipment or through connected sensors.
- Scheduled maintenance activities: Tracking maintenance activities can help plan for disruptions and maintain the building effectively. This data can be collected through maintenance management systems.
- Status update during emergency situations: This information is crucial for ensuring safety during emergencies. It can be collected through various systems like fire alarms, emergency exits, and communication systems.
- Weather conditions: This data can affect many aspects of building management, from energy usage to safety. It can be collected from weather stations or online weather services.
- Occupants' behaviour: Understanding how occupants use the building can help optimize its management. This data can be collected through surveys, sensors, or other tracking methods.

Each of these data points can provide valuable insights when analysed over time, helping to improve the efficiency, safety, and comfort of buildings.

An NGSI-LD Entity (e.g. "TemperatureSensor") can have Properties (e.g. "temperature") that represent the current value of each of the series. Entities can also have Relationships with other entities, which can be used to represent the relationships between different time series and which can also evolve over time. For example, a "TemperatureSensor" Entity could have a relationship with a "Room" Entity to indicate that the temperature sensor is currently located in that room. Each of these so-called Attributes (Properties or Relationships) can further have metadata in the form of sub-attributes that provide additional information about the Attribute. For example, by using the "observedAt" sub-property, metadata such as the timestamp of each measurement can be recorded and later accessed.

Time series data are represented and managed in NGSI-LD using a dedicated Temporal API. The Temporal API enhances the above model, thus increasing the expressive possibilities of Entities, allowing the storage of multiple Attribute instances over time. These Attribute instances make it possible to capture and represent the alteration over time of the content of the Entities. Such information can then be used to evaluate their trend/behaviour, supporting external applications, for instance predictive algorithms.

The temporal evolution of an Attribute (for instance, its historical evolution or future predictions) is composed of the sequence of instances of the referred Attribute during a period of time within its lifetime.

The temporal representation of an Attribute is provided by the NGSI-LD Temporal API as an array of JSON-LD objects, each one representing an instance of the Attribute at a particular point in time, which is recorded using temporal sub-properties of the instance (typically "observedAt"). NGSI-LD systems maintain an instanceId for each such Attribute instance. Through the Temporal API it is possible to manipulate the single instances, as well as the whole time series.

A specific Temporal Query Language adds the support to time queries and aggregate queries. It is for instance possible to apply temporal filters (e.g. "return temperature between two dates") using a temporal property and it is also possible to obtain the aggregated temporal representation of an Entity (e.g. "return the average temperature of the TemperatureSensor").

In the BIM context, Building or building element can either be sensors, features of interest or location. A sensor (Building Element), located in the main room (Space as location) measures the humidity of the whole dwelling (Zone as feature of interest). Describing time series by using those three kinds of relations allows then to calculate indicators based on building feature familiar for used.

8.5 Additional data

Several other aspects related to building information and data frameworks are typically managed within the context of construction and building management. Here is a refined breakdown:

- Services Provided: Specifies the services available within the building, such as utilities, maintenance, security, and amenities.
- Building Usage: Defines the primary purpose for which the building is intended, such as residential, commercial, industrial, or mixed-use.
- Environmental Footprint: Evaluates the building's impact on the environment, including energy efficiency, sustainability practices, and carbon footprint.
- Quantities: Quantitative data about building components, materials, and resources used in construction and maintenance.
- Materials: Detailed information on the materials used in construction, including specifications, suppliers, and sustainability attributes.
- Building Insurances and Certifications: Documentation of insurance coverage and certifications (e.g. LEED certification) that validate compliance with environmental standards.
- Building Digital Logbook: A digital repository for storing and managing information related to the building's lifecycle, including maintenance records, upgrades, and inspections.
- Parcel: Information about the land parcel on which the building is situated, including legal boundaries and zoning details.
- Owner Information: Details about the current owner or owners of the building, including contact information and ownership history.
- Costs: Financial data related to the construction, operation, and maintenance of the building, including initial costs, ongoing expenses, and depreciation.

8.6 Element classification

Element classifications in the context of building information management refer to standardized systems used to categorize and organize building components and materials. Two commonly used classification systems are UniFormat and MasterFormat. Both UniFormat and MasterFormat provide standardized frameworks for organizing building information, which helps improve communication and coordination among stakeholders in the construction industry.

Lifecycle Management: They facilitate effective management of building components and materials throughout the project lifecycle, from design and construction to operation and maintenance.

Integration: These classification systems are often integrated with Building Information Modelling (BIM) software and other digital tools to enhance data interoperability and project efficiency.

UniFormat is developed by the National Institute of Building Sciences (NIBS), UniFormat organizes building information based on functional elements or systems rather than construction trades. It is primarily used during the early design stages to organize project information and facilitate cost estimating, analysis, and lifecycle costing. Categories in UniFormat include elements like Substructure, Shell, Interiors, Services, Equipment, Furnishings, Special Construction, and Building Site Work as shown in Figure 14.

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations
		A1020 Special Foundations
		A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation
		A2020 Basement Walls
B SHELL	B10 Superstructure	B1010 Floor Construction
		B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls
		B2020 Exterior Windows
		B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings
		B3020 Roof Openings
C INTERIORS	C10 Interior Construction	C1010 Partitions
		C1020 Interior Doors
		C1030 Fittings
	C20 Stairs	C2010 Stair Construction
		C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes
		C3020 Floor Finishes
		C3030 Ceiling Finishes
D SERVICES	D10 Conveying	D1010 Elevators & Lifts
		D1020 Escalators & Moving Walks
		D1090 Other Conveying Systems
	D20 Plumbing	D2010 Plumbing Fixtures
		D2020 Domestic Water Distribution
		D2030 Sanitary Waste
		D2040 Rain Water Drainage
		D2090 Other Plumbing Systems
	D30 HVAC	D3010 Energy Supply
		D3020 Heat Generating Systems
		D3030 Cooling Generating Systems
		D3040 Distribution Systems
		D3050 Terminal & Package Units
		D3060 Controls & Instrumentation
		D3070 Systems Testing & Balancing
		D3090 Other HVAC Systems & Equipment
	D40 Fire Protection	D4010 Sprinklers
		D4020 Standpipes
		D4030 Fire Protection Specialties
		D4090 Other Fire Protection Systems
	D50 Electrical	D5010 Electrical Service & Distribution
		D5020 Lighting and Branch Wiring
		D5030 Communications & Security
		D5090 Other Electrical Systems
E EQUIPMENT & FURNISHINGS	E10 Equipment	E1010 Commercial Equipment
		E1020 Institutional Equipment
		E1030 Vehicular Equipment
		E1090 Other Equipment
	E20 Furnishings	E2010 Fixed Furnishings
		E2020 Movable Furnishings
F SPECIAL CONSTRUCTION & DEMOLITION	F10 Special Construction	F1010 Special Structures
		F1020 Integrated Construction
		F1030 Special Construction Systems
		F1040 Special Facilities
		F1050 Special Controls and Instrumentation
	F20 Selective Building Demolition	F2010 Building Elements Demolition
		F2020 Hazardous Components Abatement

Figure 14: ASTM Uniformat Classification for Building Elements

MasterFormat is a standard for organizing specifications and other written information for commercial and institutional building projects in the United States and Canada. It provides a standardized structure for organizing project manuals, cost information, and other documents related to construction projects. MasterFormat organizes information into Divisions (e.g. Division 03 - Concrete, Division 08 - Openings, Division 23 - Heating, Ventilating, and Air Conditioning (HVAC), etc.) and further subdivides them into Sections (e.g. Section 03 30 00 - Cast-in-Place Concrete, Section 08 11 13 - Hollow Metal Doors and Frames, Section 23 05 93 - Testing, Adjusting, and Balancing for HVAC).

8.7 Overall model

By combining SAREF and BOT ontologies, it is possible to create a comprehensive model of a city and its buildings, including their physical structure, systems, and geospatial context as depicted in Figure 15. The ontology defines a structured hierarchy for city-scale objects, building-scale structures, and component-level details.

Subclass Relationships are denoted with white arrows, indicating inheritance and specialization. Other Relationships (black arrows) indicate functional associations, such as spatial containment (bot:containsZone) or adjacency (bot:adjacentZone). This ontology is useful for modelling the relationships and spatial hierarchies of cities, buildings, and components within an urban or architectural context, enabling a layered representation from a broad city perspective down to individual building components and systems. This can support a wide range of applications, from energy management and urban planning to transportation and emergency response. The following diagram represents an ontology that organizes various entities and relationships across three different spatial scales: City Scale, Building Scale, and Component Scale:

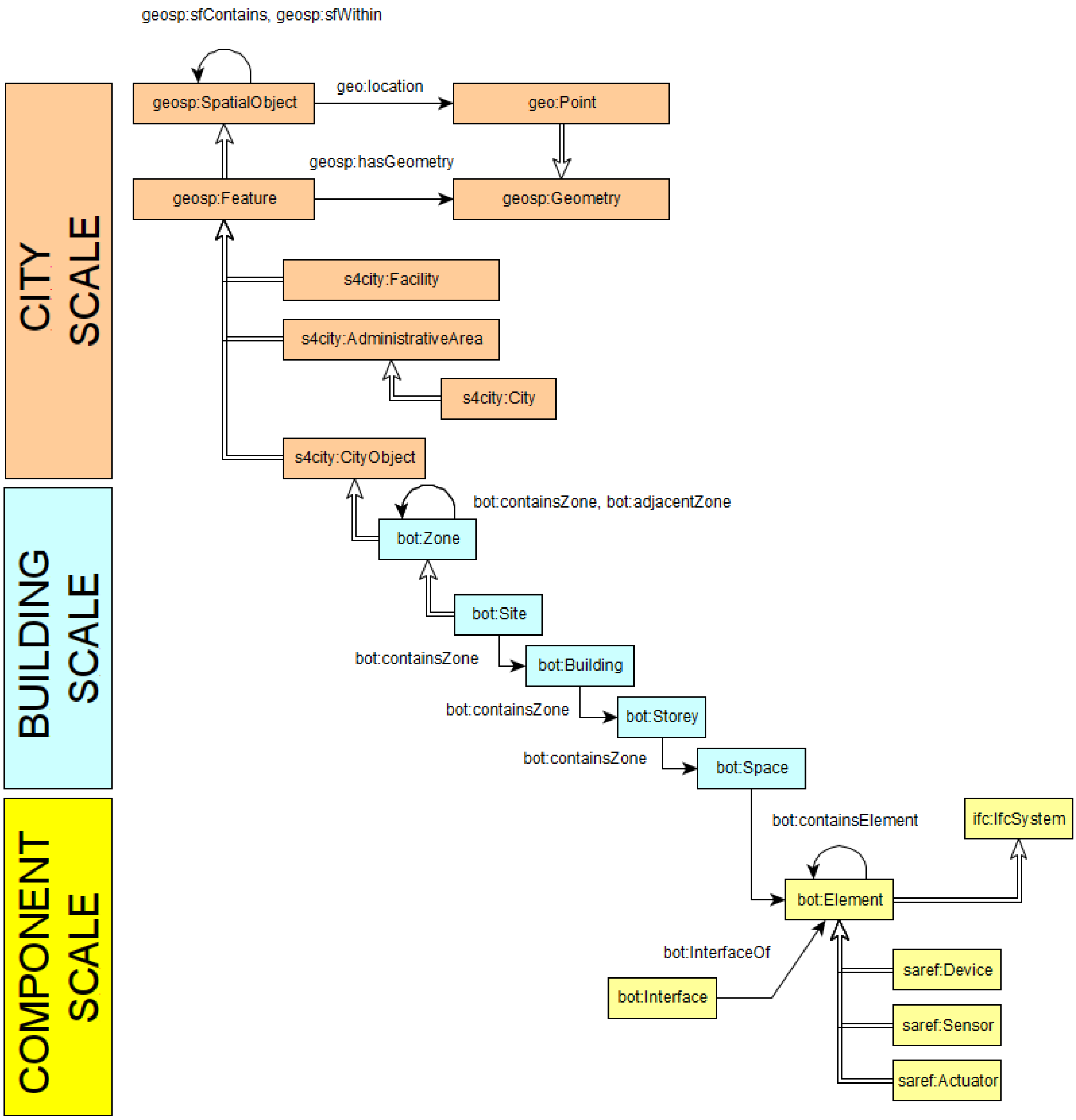

Figure 15: Multi-scale model interoperability based on BOT and SAREF

City scale entities (orange section):

- *geosp:SpatialObject:* Represents a general spatial object in the geographical space.
- *geosp:Feature:* A type of spatial object that can represent real-world features.

- *s4city:Facility, s4city:AdministrativeArea, and s4city:City*: Represent specific types of facilities, administrative areas, and cities within the city scale.
- *geo:Point and geosp:Geometry*: These represent the geometric aspects of spatial objects.

City scale relationship (orange section):

- *s4city:CityObject* is a subclass of *geosp:Feature*, indicating it inherits characteristics of a feature.
- *s4city:City*, *s4city:AdministrativeArea*, and *s4city:Facility* are all types of *s4city:CityObject*.
- *geosp:SpatialObject* is connected to *geo:Point* through the *geo:location* property, which likely defines its location in space.
- *geosp:SpatialObject* is also connected to *geosp:Geometry* through the *geosp:hasGeometry* property, defining its geometric structure.

Building scale entities (blue section):

- *bot:Zone, bot:Site, bot:Building, bot:Storey, and bot:Space:* These are hierarchical entities representing physical and functional subdivisions within a building environment.

Building scale relationships (blue section):

- *bot:Zone* connects to other *bot:Zone* objects through the *bot:containsZone* and *bot:adjacentZone* properties, indicating zones can contain or be adjacent to each other.
- *bot:Site* contains *bot:Zone* through the *bot:containsZone* property.
- *bot:Building* contains *bot:Site* and can contain multiple *bot:Storey* levels through *bot:containsZone*.
- *bot:Storey* contains individual *bot:Space* entities, each defining distinct areas within a floor.

Component scale entities (yellow section):

- *bot:Element, bot:Interface, ifc:IfcSystem, saref:Device, saref:Sensor, and saref:Actuator*: Represent specific components or systems within building spaces, such as devices and interfaces for various functional elements.

Component scale relationships (yellow section):

- *bot:Interface* is a subclass of *bot:Element*
- *bot:Space* contains *bot:Element* via the *bot:containsElement* property.
- *bot:Element* connects to *bot:Interface* via the *bot:InterfaceOf* relationship, indicating it has an interface.
- *bot:Element* is connected to *ifc:IfcSystem, saref:Device, saref:Sensor, and saref:Actuator*, showing that elements can belong to systems or be represented as specific devices, sensors, or actuators.

The component scale is partially based on the SAREF ontology. The ETSI SmartM2M Technical Committee already defined the SAREF suite of ontologies, with a definition of generic classes and its mapping toward the NGSI-LD cross-domain ontology. The alignment from SAREF to NGSI-LD has been covered by Group Specification ETSI GS CIM 006 [i.4].

9 BIM / NGSI-LD Integration strategies

9.1 Introduction

Several strategies can be implemented to integrate the BIM (Building Information Modelling) context into NGSI-LD (Next Generation Service Interface - Linked Data). These include: linking BIM entities to NGSI-LD entities using Linked Data principles, simplifying BIM models to include only relevant information, and mapping entire BIM models to the NGSI-LD context. Semantic enrichment, where semantic information is added to BIM models for better interoperability, and the use of BIM-to-NGSI-LD converters can also aid in this process. These strategies aim to ensure accurate data interpretation and efficient management in the NGSI-LD context. The main criteria to choose the best strategy are the complexity data conversion, the effort needed to build and maintain schemas and the level of interoperability (interoperability made by applications, service level interoperability, native data interoperability).

9.2 OPTION A - BIM as a Link: Linking the data

In this scenario, BIM data (using the IFC data model) and NGSI-LD data would be kept in their own separate systems or "silos". NGSI-LD basic Entities can be connected to external data models, which do not need to be totally NGSI-LD-friendly. As long as a thing can be identified by a URI, one can link it to NGSI-LD by using the Linked Data principles. BIM data can be stored in a RDF store and exposed through a SPARQL Endpoint as specified API as defined by **Building Smart international** [i.6]. A SPARQL Endpoint follow a standard specification provided by **W3C**® The integration would happen through the use of Uniform Resource Identifiers (URIs) to link related data between the two systems. For example, an Entity in the NGSI-LD system could have a Property that is a URI, which points to a related entity in the BIM system. This approach allows each system to continue using its own data model, but still provides a way to find related data in the other system. However, it requires a way to manage and maintain these URI links, and the data in each system may still be quite different.

This approach involves creating links or references between Entities in NGSI-LD and entities in BIM. Instead of trying to fully represent BIM data in NGSI-LD, this approach keeps the data in BIM and only links to it from NGSI-LD. For example, an NGSI-LD entity for a building might have a property that is a URL pointing to the corresponding BIM model. This approach allows each system to focus on what it does best but may require more complex querying to get all the necessary data.

Wikidata is a public SPARQL endpoint giving access to Open Data as Linked Data resources. The following example describes the Montparnasse railway station and links it to its RDF definition in wikidata:

```
{
  "@context": [
    "https://uri.etsi.org/ngsi-ld/v1/ngsi-ld-core-context.jsonld",
    "https://example.org/context"
  ],
  "id": "urn:ngsi-ld:Entity:01",
  "type": "Entity",
  "name": {
    "type": "Property",
    "value": "Montparnasse Paris Railway Station"
  },
  "isDefinedByURI": {
    "type": "Relationship",
    "object": " http://www.wikidata.org/entity/Q631114"
  }
   }
```

The referenced URI can be solved by querying the web as illustrated in Figure 16 or a SPARQL endpoint (Figure 17).

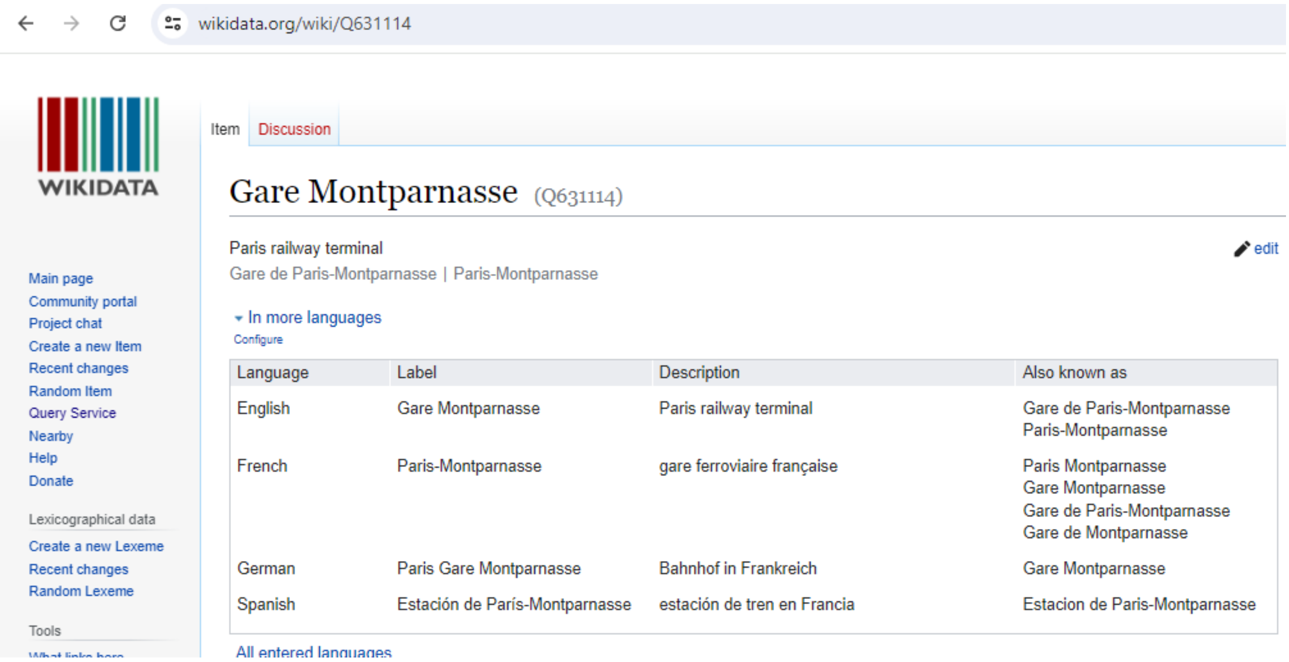

Figure 16: Web query of the referenced URI

```
#Railway Station
#TEMPLATE={"template":"metro station of ?city","variables":{"?city":{"query":"SELECT DISTINCT ?cityLabel where {?city wdt:P31/wdt:P279*
#defaultView:Map{"hide":["?comm1Label","?coord1", "?comm2","coord2","?layer","?str","?line", "?rgb"],"layer":"?connectingLine1Label"}
SELECT ?comm1 ?comm1Label ?coord1 ?comm2 ?coord2 ?line ?connectingLine1 ?connectingLine1Label ?layer ?rgb WHERE {
  BIND(wd:Q8686 AS ?city)
  ?comm1 wdt:P31/wdt:P279* wd:Q928830 ;
         wdt:P131*/wdt:P279* ?city;
         wdt:P625 ?coord1 ;
         wdt:P81 ?connectingLine1;
         wdt:P197 ?comm2 .
  ?connectingLine1 wdt:P465 ?rgb.
  ?comm2 wdt:P81 ?connectingLine2;
         wdt:P625 ?coord2 .
  FILTER (?connectingLine1 = ?connectingLine2)

  ?comm1 p:P625 [# ps:P625 [];
                 psv:P625 [ wikibase:geoLongitude ?coord1lon; wikibase:geoLatitude ?coord1lat; ] ] .
  ?comm2 p:P625 [# ps:P625 [];
                 psv:P625 [ wikibase:geoLongitude ?coord2lon; wikibase:geoLatitude ?coord2lat; ] ] .

  BIND(CONCAT('LINESTRING (', STR(?coord1lon), ' ', STR(?coord1lat), ',', STR(?coord2lon), ' ', STR(?coord2lat), ')') AS ?str) .
  BIND(STRDT(?str, geo:wktLiteral) AS ?line) .
  BIND(?connectingLine1 AS ?layer)

  SERVICE wikibase:label { bd:serviceParam wikibase:language "[AUTO_LANGUAGE],mul,en". }
}

ORDER BY (?connectingLine1Label)
```

Figure 17: SPARQL query of the referenced URI

Pros:

- This approach allows each system to focus on its strengths and maintain its own data model, reducing the need for complex mapping or extension.
- It can provide a more flexible and scalable way to integrate the two systems, allowing for loose coupling and easy evolution.
- It can support a wider range of use cases, as each system can provide its own functionality and services.

Cons:

- It may require more complex querying and data integration to get a complete view of the data across both systems.
- It may introduce performance issues if there are many links between the systems and the data needs to be fetched in real-time.
- It may require additional effort to maintain the links and ensure that they remain valid as the data in each system changes.

This approach involves creating links or references between objects in NGSI-LD and entities in BIM. Instead of trying to fully represent BIM data in NGSI-LD, this approach keeps the data in BIM and only links to it from NGSI-LD. For example, an NGSI-LD entity for a building might have a property that is a URL pointing to the corresponding BIM model. This approach allows each system to focus on what it does best but may require more complex querying to get all the necessary data.

In this scenario, data remains in existing BIM data repositories and NGSI-LD instances are referring the BIM data. NGSI-LD basic Entities can be connected to external data models, which do not need to be totally NGSI-LD-friendly. As long as a thing can be identified by a URI, one can link it to NGSI-LD: the Linked Data principle.

9.3 OPTION B - Mapping main BIM concepts through an NGSI-LD domain model

In this scenario, the BIM data collected from the BIM system would be converted into the NGSI-LD data model, using existing NGSI-LD cross-domain ontologies as shown in Figure 18. This would involve mapping each class to a corresponding NGSI-LD entity, and converting the data accordingly. This approach would allow the BIM data to be directly used and queried in the NGSI-LD system, without needing to maintain separate URI links. However, it may not be possible to exactly map all IFC classes to NGSI-LD entities, due to differences in the data models. Some information may be lost or changed in the conversion process.

This approach should be driven by use cases and limits to the only needed classes, relationship and properties. The BOT ontology as a simplification of the IFC ontology that fits with most simple use case needs. It could be a good intermediate stage between IFC and NGSI-LD conversion.

```
{
    "@context": [
        "https://forge.etsi.org/gitlab/NGSI-LD/NGSI-LD/raw/master/coreContext/ngsi-ld-core-context.json",
        "https://raw.githubusercontent.com/GSMADeveloper/NGSI-LD-Entities/master/examples/Building-context.jsonld"
    ],
    "id": "urn:ngsi-ld:Building:ba2d4fd9-f57f-4610-a589-2d52670d14f3",
    "type": "Building",
    "name": {
        "type":"Property",
        "value":"Paris MontParnasse Railway"
    },
    "description": {
        "type":"Property",
        "value":"The Montparnasse Railway Building, also known as Gare Montparnasse, is a major train station in Pa
    },
    "hasStorey": {
        "type": "Relationship",
        "object": "urn:ngsi-ld:Storey:ba2d4fd9-f57f-4610-a589-2d52670d14d8"
    },
    "hasZeroPoint": {
        "type": "GeoProperty",
        "value": {
            "type": "Point",
            "coordinates": [7.0506807,43.6142898]
        },
        "crs" : {
            "type" : "name",
            "properties" : {
                "name" : "urn:ogc:def:crs:EPSG:3948"
        }
    },
    "hasSimpleGeometry": {
        "type" : "3DProperty",
        "value": {
            "type": "Tin Z",
            "coordinates": [
                [[0 0 0, 0 0 25, 0 50 0, 0 0 0]],
                [[0 0 0, 0 50 0, 40 0 0, 0 0 0]],
                [[0 0 0, 40 0 0, 0 0 25, 0 0 0]],
                [[40 0 0, 0 50 0, 0 0 40, 40 0 0]]
        ],
        "unitCode": "MTR"
    },
    "hasGeometry": {
        "type":"Property",
        "value":"https://assets.ion.cesium.com/us-east-1/40866/3/0003.b3dm"
    }
}
```


Figure 18: Railway scenario converted to NGSI-LD data model

The approach taken to convert input RDF (BOT instances) data to NGSI-LD is the following:

- Map source input data to target data structure at the semantic (= RDF triple) level [i.7].
- This can be done in a number of ways, the proposed approach is to describe a series of transformation rules using SHACL rules: this way each rule can be precisely identified, described, maintained, shared, etc. following linked data principles.
- Rules are executed using a SHACL processor mapping rules deal exclusively with the semantic mapping from one model to another, they do not care about serialization. They could be reused in other technical/implementation contexts.
- The approach is only applicable to input RDF data.
- Then serialize the output RDF in JSON-LD (any RDF library can do that) [i.17].
- Then use JSON-LD Framing (https://www.w3.org/TR/json-ld11-framing/) to specify how the output triples should be serialized in a clean JSON-LD.
- Then, if needed, split the JSON-LD in multiple files.

Pros:

- This approach is relatively simple and does not require significant changes to either system.
- It allows for interoperability between the two systems without duplicating data.

- It can be implemented using standard mapping techniques and tools.

Cons:

- The mapping may not be perfect, and some information may be lost or distorted in the translation between systems.
- It may be difficult to maintain the mapping as the systems evolve and change over time.
- It may not be possible to map all concepts, especially if the two systems have fundamentally different data models.

In this scenario, Building Context are described through NGSI-LD models: domain models / smart models / data spaces.

9.4 OPTION C - BIM Smart Model: Creating an NGSI-LD domain model equivalent to IFC concepts

This approach involves creating an NGSI-LD domain specific model. The idea is to identify similar or equivalent concepts in both systems and then create a mapping between them. This allows data to be translated or transformed from one system to another, enabling interoperability. For example, a building in BIM might be mapped to a Building entity in NGSI-LD. This approach is straightforward but may not capture all the nuances of each system.

This scenario consists in aligning NGSI-LD models with IFC model. Some data will be replicated from BIM to the context broker.

In this approach, the NGSI-LD model is expanded to include concepts from BIM that may not already exist in it. This could involve adding new entity types, properties, or relationships that are specific to BIM. For example, BIM concepts like space, storey, or building element could be added to the NGSI-LD model. This approach allows for a richer representation of BIM data in NGSI-LD but may require significant modifications to the NGSI-LD model.

In this scenario, a new NGSI-LD domain model would be defined that is specifically designed to fit with the IFC data model. This would involve creating new NGSI-LD entities and relationships that correspond to the IFC classes and their relationships. This approach would allow the BIM data to be directly used and queried in the NGSI-LD system, while preserving more of the original IFC data structure. However, it would require significant effort to define this new domain model and map the IFC data to it. It could also result in a more complex NGSI-LD system, due to the addition of this new domain model.

Pros:

- This approach allows for a richer representation of BIM data in NGSI-LD, making it possible to use NGSI-LD for a wider range of applications.
- It can improve the integration between the two systems, making it easier to query and analyse data across both systems.
- It can help to standardize the representation of BIM data in NGSI-LD, making it easier for different organizations to share and reuse data.

Cons:

- Extending the NGSI-LD model may require significant effort and expertise, especially if the BIM concepts are complex or numerous.
- It may introduce complexity and redundancy into the NGSI-LD model, making it more difficult to understand and use.
- It may require changes to existing applications that use the NGSI-LD model, which could be costly and time-consuming.

10 Recommendations

10.1 Integrating BIM with NGSI-LD: Three options.

Option A defines an architecture with heterogeneous services (BIM services, GIS services, Context broker). This option simplifies data modelling but forces the client application to interoperate with heterogeneous services. Option B and C take advantage of a homogeneous NGSI-LD architecture but require synchronization mechanisms and data conversion. All options require dereferencing system supported for Linked Data identifiers.

10.2 Identifying BIM elements

All options require non ambiguous identifier. Identifiers have to be unique and if possible rely on official registers (such as national building register). Smart object can be identified by their Smart objects or Internet of Things (IoT) devices are typically identified using Unique Identifiers (UIDs). These UIDs can include a serial number, a MAC address, or an IP address. The most common standard for identifying IoT devices is the IPv6 protocol, which provides a vast address space, allowing for a unique IP address to be assigned to every IoT device. For classical element GS1 serial number can be used. Linked Data approach to format as URI to enable web protocol capability such as dereferencing.

In IFC models each elements are identified by a Globally Unique Identifier (GUID). The probability of two different elements from two different models getting the same GUID is extremely low but not impossible. To avoid any identifier collision with recommend building a Uniform Resource Identifier (URI) according to the following template.

Template: https://[domainname]/[building identifier]/[IFC local identifier]

EXAMPLE: https://www.theowner.com/ifc/518eb92d967be88bd05f4ff8e68b7b30/IfcWindow_4553

The GUID of the element can be stored as a dedicated attribute (ifc:GUID) of the element to keep the link with the original data.

10.3 Converting data to NGSI-LD

Data conversion allows to initiate context for objects already serialized by using heterogeneous format. In option A data remain in their original schema. In option B, only relevant information is converted. The conversion progress can be automated through three steps:

- (Step 1) from original format to JSON-LD;
- (Step 2) from input schema to target schema;
- (Step 3) from JSON-LD to NGSI-LD.

Step 1 can be performed be using existing converter. Various mappings standards are available such as RML, SPARQL-generate or Open Refine in order to implement Step 2. Step 2 also includes values transformations such as Unit conversion, CRS conversion, aggregation, taxonomy mapping. Step 3 follows the JSON-LD framing specifications to transform JSON structure to NGSI-LD specifications. Synchronization mechanism should be implemented to keep NGSI-LD context updated according to the master data source.

10.4 Synchronizing data

The subscription mechanism in NGSI-LD is used to synchronize data over brokers by allowing clients to subscribe to specific data changes in the context broker. This mechanism is based on the publish/subscribe pattern, where publishers send messages to a topic without knowing who will receive them, and subscribers receive messages from a topic without knowing who sent them.

In NGSI-LD, a client can create a subscription by sending a POST request to the context broker's /ngsi-ld/v1/subscriptions endpoint with a JSON payload containing the subscription details. The subscription includes information such as the entities to be monitored, the attributes to be observed, the notification format, and the endpoint where notifications should be sent.

Once a subscription is created, the context broker monitors the specified entities and attributes for changes. When a change occurs, the context broker sends a notification to the subscriber's endpoint using the specified format. The notification includes information about the changed entity, the attribute values, and any other relevant data.

Subscribers can also configure the subscription to filter notifications based on certain conditions. For example, they can specify that they only want to receive notifications when a particular attribute value exceeds a certain threshold. This allows subscribers to receive only the data that is relevant to them, reducing the amount of unnecessary data transfer and processing.

Various BIM servers implements a subscription mechanism. BIM servers usually use web-based API for storing, querying, and exchanging BIM data. They include subscription mechanisms that allows Context Broker to subscribe to specific changes in the BIM data. This mechanism is based on the WebSocket protocol, which provides a bidirectional communication channel between the client and the server. Clients can subscribe to specific events, such as changes to a particular IFC object or attribute, and receive real-time notifications when those events occur. Partial data conversion process can be used to convert data on the fly.

BIM servers that implement a subscription mechanism typically provide different kinds of notifications to inform clients about changes to IFC data. The specific types of notifications may vary depending on the BIM server implementation, but here are some common types of notifications that are typically provided:

- Object creation: This notification is sent when a new IFC object is created in the BIM model. It typically includes information about the object, such as its type, attributes, and relationships to other objects.
- Object modification: This notification is sent when an existing IFC object is modified in the BIM model. It typically includes information about the changes made to the object, such as which attributes were modified or which relationships were added or removed.
- Object deletion: This notification is sent when an IFC object is deleted from the BIM model. It typically includes information about the object that was deleted, such as its type and unique identifier.
- Attribute change: This notification is sent when a specific attribute of an IFC object is modified. It typically includes information about the attribute that was changed, such as its name, old value, and new value.
- Relationship change: This notification is sent when a relationship between two or more IFC objects is added or removed. It typically includes information about the objects involved in the relationship and the type of relationship that was changed.
- Transactional notifications: Some BIM servers may provide transactional notifications that group multiple changes together into a single notification. This can be useful for optimizing performance and reducing the number of notifications that need to be sent.

Various GIS servers also implement subscription mechanism such as ArcGIS or Geoserver that implements the Web Notification Standard (WNS).

10.5 Rendering geometry

Context Broker is primarily designed for managing context information in IoT and smart city applications. While it can handle various types of data, including 3D data, it is not specifically optimized for handling 3D rendering data.

The Context Broker is designed to store and retrieve context information, such as sensor data, geolocation data, and other types of metadata. It provides a flexible data model based on the NGSI-LD standard, which allows for the representation of complex data structures, including 3D data. However, Context Broker does not provide any built-in 3D rendering capabilities or optimizations for handling large 3D datasets.

In order to handle and render large 3D datasets, it is recommended to use a specialized 3D rendering software or platforms that are optimized for this purpose. These tools typically provide advanced features for handling 3D data, such as level-of-detail optimization, texture mapping, and real-time lighting and shading.

The recommendation is to link the geometric representation (meshes) in a GLTF file to the corresponding BOT element by using the File Ontology for Geometry (FOG) formats. The BOT ontology describes building topology, i.e. the spatial structure and relations of a building, such as spaces, elements, and boundaries whereas the FOG ontology describes file formats, including geometry formats like GLTF, and provides a way to link geometric representations to semantic models. Here is an example on how to use BOT together with FOG:

```
@prefix fog: <https://w3id.org/fog#> .
@prefix ex: <http://example.org/> .

ex:GLTFFile a fog:File ;
    fog:fileName "building.gltf" ;
    fog:hasGeometry ex:Wall1Geometry .

ex:Wall1Geometry a fog:Geometry ;
    fog:hasMesh "mesh_id_for_wall1" ;  # The mesh ID in the GLTF file
    bot:represents ex:Wall1 .  # Link to the BOT element
```

Figure 19: Link between a building element and its 3D representation

When interacting with the 3D representation the viewer [i.8] should be able to identify the corresponding in order the request the broker. For this reason the GLTF should store the element identifier attached to the corresponding mesh.

The Context Broker can still be used in conjunction with 3D rendering software or platforms to provide context information and metadata about 3D models. For example, Context Broker could be used to store and retrieve information about the location, orientation, and other attributes of 3D models, while a separate 3D rendering engine is used to render the models in real-time.

Existing GIS systems lack support for 3D geometry, as they primarily rely on the ISO/OGC Simple Features Access - Common Architecture (SFA-CA). While the GeoSparql ontology is built upon simple features, it is not applicable to all geometries. For instance, geojson and kml do not accommodate Triangulated Integrated Network (TIN) or Triangle geometry. Although points in geometry may have a z-coordinate, and lines or planes may include a single z-value (considered 2.5D geometry), this z-value is projected onto the Z=0 level during calculations.

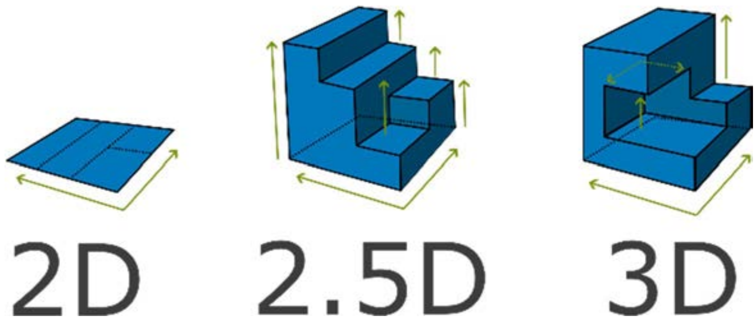

Figure 20: Adapting geometry accuracy to scale

To effectively utilize geometric data, understanding the units of measure is crucial. This can be achieved by linking a Spatial Reference System (SRS) and concepts from the QUDT ontology to the geometry. To integrate GIS and BIM representations, the suggestion is to use 2D geometry (LOD1) for large scales (territory, city), 2.5D geometry (LOD2) for mid-range scales (district, neighbourhood), and 3D geometry (LOD3) for detailed building envelopes and indoor elements.

11 Conclusion

The integration of Building Information Modelling (BIM) with NGSI-LD models and APIs presents a promising approach to enhance data sharing, collaboration, and innovation in the construction and management of buildings. By adopting a multi-scale approach that considers semantic, geospatial, and temporal aspects, stakeholders can achieve seamless data exchange and improved decision-making throughout the building lifecycle.

The present document provides a comprehensive framework and practical solutions for implementing this integration, paving the way for future advancements in the field. Through the analysis of significant use cases, the present document identifies mandatory data requirements and suggested data patterns to aid in building an NGSI-LD domain model. Various integration scenarios have been evaluated, ranging from simple, loosely coupled modules to a fully integrated BIM/NGSI-LD architecture. Each scenario offers unique advantages and drawbacks in terms of efficiency, complexity, and maintenance cost.

As a first guide for further specification, the suggestion is to follow the median scenario, which offers a good compromise between complexity and the level of automation. This scenario involves building a specific domain model aligned with the Building Topology Ontology (BOT). Other data formats, such as CityGML and IFC, can be easily converted on-the-fly into BOT [i.11], [i.12]. This scenario can then be enhanced with more complex synchronization rules to keep NGSI-LD data up-to-date. The full lifecycle is use-case dependent and should be adapted accordingly.

The BOT/NGSI-LD domain is complementary to other domain models like SAREF, covering the whole building monitoring aspect. To further advance BIM/NGSI-LD integration, the next steps should involve transposing the previous recommendations into specifications regarding data, models, and data flow aspects. In particular, the further specification should include a first version of the NGSI-LD domain model aligned with BOT.

It is crucial to ensure that identifiers are common between geospatial CIM and BIM to maintain consistency and interoperability. Geospatial 2D and BIM should be considered as two representations of the same object, rather than two distinct objects. This alignment will facilitate more accurate and coherent data management across different systems.

Future work should focus on developing detailed specifications that address data models, integration methods, and data flow processes. This includes creating a robust NGSI-LD domain model aligned with BOT, ensuring seamless conversion from other data formats, and establishing synchronization rules to maintain data accuracy and consistency. Additionally, collaboration with industry stakeholders and standardization bodies will be essential to promote widespread adoption and ensure the practical applicability of these specifications.

Annex A: Selection of relevant IFC (OWL) relations and properties

Identification and description

```
    globalId_IfcRoot,
    description,
    longName_IfcSpatialStructureElement,
    Manufacturer,
    Name
    objectType_IfcObject,
    predefinedType
```

Generic properties and quantities

```
  quantities_IfcElementQuantity,
    hasProperties_IfcPropertySet,
    hasPropertySets_IfcTypeObject,
    nominalValue_IfcPropertySingleValue,
    conversionFactor_IfcConversionBasedUnit,
    definedUnit_IfcPropertyTableValue,
    prefix_IfcSIUnit,
    unit_IfcDerivedUnitElement,
    unitBasis_IfcAppliedValue,
    unitComponent_IfcMeasureWithUnit,
    units_IfcUnitAssignment,
    unitsInContext_IfcProject,
    unitType_IfcDerivedUnit,
    unitType_IfcNamedUnit,
    name_IfcSIUnit,
    userDefinedType_IfcDerivedUnit,
    valueComponent_IfcMeasureWithUnit,
    hasBoolean,
    hasString,
    hasDouble,
    hasInteger,
    hasNext,
    isFollowedBy,
    hasContents
    relatingType_IfcRelDefinesByType,
    relatedObjects_IfcRelDefines,
```

Materials

```
    forLayerSet_IfcMaterialLayerSetUsage,
    layerSetName_IfcMaterialLayerSet,
    layerSetDirection_IfcMaterialLayerSetUsage,
    layerThickness_IfcMaterialLayer,
    material_IfcMaterialLayer,
    materialClassifications_IfcMaterialClassificationRelationship,
    materialLayers_IfcMaterialLayerSet,
    materials_IfcMaterialList,
    isVentilated_IfcMaterialLayer,
```

Geometry and location

```
trueNorth_IfcGeometricRepresentationContext,
volumeValue_IfcQuantityVolume,
lengthValue_IfcQuantityLength,
xDim_IfcBoundingBox,
yDim_IfcBoundingBox,
zDim_IfcBoundingBox,
elevation_IfcBuildingStorey,
_IfcSpace,
directionSense_IfcMaterialLayerSetUsage,
areaValue_IfcQuantityArea,
overallHeight
overallWidth
refLatitude_IfcSite,
refLongitude_IfcSite,
refElevation_IfcSite,
elevationOfRefHeight_IfcBuilding,
elevationOfTerrain_IfcBuilding,
  riserHeight_IfcStairFlight,
```

```
  siteAddress_IfcSite,
  postalCode_IfcPostalAddress,
  region_IfcPostalAddress,
  town_IfcPostalAddress,
  country_IfcPostalAddress,
  addressLines_IfcPostalAddress,
  region_IfcPostalAddress,
  town_IfcPostalAddress,
```

Topology

```
IfcGroup,
IfcObjectDefinition,
IfcRelAssigns,
IfcRelAssignsToGroup,
IfcRelAssociates,
IfcRelAssociatesMaterial,
IfcRelConnectsElements,
IfcRelConnectsPathElements,
IfcRelConnectsPorts,
IfcRelConnectsPortToElement,
IfcRelContainedInSpatialStructure,
IfcRelDecomposes,
IfcRelDefinesByProperties,
IfcRelFillsElement,
IfcRelSpaceBoundary,
IfcRelVoidsElement,
```

Selection of relevant IFC classes

```
  IfcActuator,
  IfcAirTerminal
  IfcAirTerminal,
  IfcAirTerminalBox,
  IfcAirToAirHeatRecovery,
  IfcAlarm,
  IfcApplication,
  IfcAreaMeasure,
  IfcBeam
  IfcBoundingBox,
  IfcBuilding,
  IfcBuildingElement,
  IfcBuildingElementProxy,
  IfcBuildingStorey,
  IfcBuildingSystem,
  IfcCableCarrierFitting,
  IfcCableCarrierSegment,
  IfcCableSegment,
  IfcChiller,
  IfcClassificationNotationSelect,
  IfcCoil
  IfcColumn,
  IfcCompressor,
  IfcCondenser,
  IfcConnection,
  IfcController
  IfcCooledBeam,
  IfcCoolingTower,
  IfcCovering,
  IfcCurtainWall,
  IfcDamper,
  IfcDerivedUnit,
  IfcDiscreteAccessory,
  IfcDistributionChamberElement,
  IfcDistributionControlElement,
  IfcDistributionElement,
  IfcDistributionFlowElement,
  IfcDistributionPort,
  IfcDistributionSystem,
  IfcDoor,
  IfcDuctFitting,
  IfcDuctSegment,
  IfcDuctSilencer,
  IfcElectricAppliance,
  IfcElectricDistributionPoint,
  IfcElectricFlowStorageDevice,
  IfcElectricGenerator,
  IfcElectricHeater,
```

```
IfcElectricMotor,
IfcElectricTimeControl,
IfcElementAssembly,
IfcElementComponent,
IfcElementQuantity,
IfcElementTy,
IfcEnergyConversionDevice
IfcEnergyConversionDevice,
IfcEvaporativeCooler
IfcEvaporator
IfcFan
IfcFastener
IfcFilter
IfcFireSuppressionTerminal
IfcFireSuppressionTerminal,
IfcFlowController
IfcFlowController,
IfcFlowFitting
IfcFlowFitting,
IfcFlowInstrument
IfcFlowMeter
IfcFlowMovingDevice
IfcFlowSegment
IfcFlowSegment,
IfcFlowStorageDevice
IfcFlowTerminal
IfcFlowTerminal,
IfcFlowTreatmentDevice
IfcFooting
IfcFurnishingElement
IfcFurnishingElement,
IfcFurniture
IfcFurniture,
IfcGasTerminal
IfcGeometricRepresentationContext,
IfcGroup,
IfcHeatExchanger
IfcHumidifier
IfcInventory
IfcJunctionBox
IfcLamp
IfcLightFixture
IfcLoadGroup
IfcMaterial,
IfcMaterial_List,
IfcMaterialDefinitionRepresentation,
IfcMaterialLayer,
IfcMaterialLayer_List,
IfcMaterialLayerSet,
IfcMaterialLayerSetUsage,
IfcMaterialList,
IfcMeasureWithUnit,
IfcMechanicalFastener
IfcMember
IfcMotorConnection
IfcObject
IfcObjectDefinition,
IfcOccupant
IfcOpeningElement,
IfcOutlet
IfcPhysicalQuantity,
IfcPile
IfcPipe,
IfcPipeFitting
IfcPipeFitting,
IfcPipeSegment
IfcPipeSegment,
IfcPlane,
IfcPlate
IfcPlate,
IfcPostalAddress,
IfcProcedure
IfcProject,
IfcProjectOrder
IfcProjectOrderRecord
IfcProperty,
IfcPropertySingleValue,
IfcProtectiveDevice
```

```
IfcPump
IfcQuantityLength,
IfcQuantityVolume,
IfcRailing
IfcRailing,
IfcRamp
IfcRampFlight
IfcRelAggregates,
IfcRelAssigns,
IfcRelAssignsToGroup,
IfcRelAssignsToProduct,
IfcRelAssignsToResource,
IfcRelAssociatesClassification,
IfcRelAssociatesMaterial,
IfcRelConnectsElements,
IfcRelConnectsPorts,
IfcRelConnectsPortToElement,
IfcRelContainedInSpatialStructure,
IfcRelDecomposes,
IfcRelDefinesBy
IfcRelDefinesByProperties,
IfcRelFillsElement,
IfcRelFlowControlElements,
IfcRelSpaceBoundary,
IfcRelVoidsElement,
IfcRepresentation,
IfcRoof
IfcRoof,
IfcSanitaryTerminal
IfcSanitaryTerminal,
IfcSection
IfcSensor
IfcSensor,
IfcServiceLife
IfcServiceLifeFactor
IfcSite,
IfcSIUnit,
IfcSIUnitName,
IfcSlab
IfcSlab,
IfcSpace
IfcSpace,
IfcSpaceHeater
IfcSpatialStructureElement
IfcStackTerminal
IfcStair
IfcStair,
IfcStairFlight
IfcStairFlight,
IfcStructuralSurface
IfcSwitchingDevice
IfcSwitchingDevice,
IfcSystem,
IfcSystemFurnitureElement
IfcTank
IfcTendon
IfcThermalLoad
IfcTimeSeriesData
IfcTimeSeriesSchedule
IfcTransformer
IfcTransportElement
IfcTransportElement,
IfcTubeBundle
IfcTypeObject,
IfcTypeProduct,
IfcValve,
IfcVibrationIsolator,
IfcWall
IfcWall,
IfcWallStandardCase,
IfcWasteTerminal
IfcWindow,
IfcWindowLiningProperties,
IfcWindowStyle,
IfcWorkControl
IfcZone
```

Annex B: BIM / NGSI-LD alignment

BOT Concept	NGSI-LD Representation
Building	Entity: Building
Building.id	@id
Building.name	name (Property)
Building.description	description (Property)
Building.location	location (GeoProperty)
Building.address	address (Property)
Building.floorCount	floorCount (Property)
Building.area	area (Property)
Building.constructionDate	constructionDate (Property)
Building.owner	owner (Relationship)
Building.manager	manager (Relationship)
Building.tenant	tenant (Relationship)
Building.containsElement	containsElement (Relationship)
Building.hasStorey	hasStorey (Relationship)
Building.hasSpace	hasSpace (Relationship)
Floor	Entity: Floor
Floor.id	@id
Floor.name	name (Property)
Floor.description	description (Property)
Floor.level	level (Property)
Floor.area	area (Property)
Floor.building	building (Relationship)
Floor.containsElement	containsElement (Relationship)
Floor.hasSpace	hasSpace (Relationship)
Room	Entity: Room
Room.id	@id
Room.name	name (Property)
Room.description	description (Property)
Room.area	area (Property)
Room.floor	floor (Relationship)
Room.building	building (Relationship)
Room.containsElement	containsElement (Relationship)
Room.hasSpace	hasSpace (Relationship)
Space	Entity: Space
Space.id	@id
Space.name	name (Property)
Space.description	description (Property)
Space.area	area (Property)
Space.building	building (Relationship)
Space.floor	floor (Relationship)
Space.containsElement	containsElement (Relationship)
Space.hasSpace	hasSpace (Relationship)
Zone	Entity: Zone
Zone.id	@id
Zone.name	name (Property)
Zone.description	description (Property)
Zone.area	area (Property)
Zone.building	building (Relationship)
Zone.floor	floor (Relationship)
Zone.room	room (Relationship)
Zone.containsElement	containsElement (Relationship)
Zone.hasSpace	hasSpace (Relationship)

Annex C: Schemas

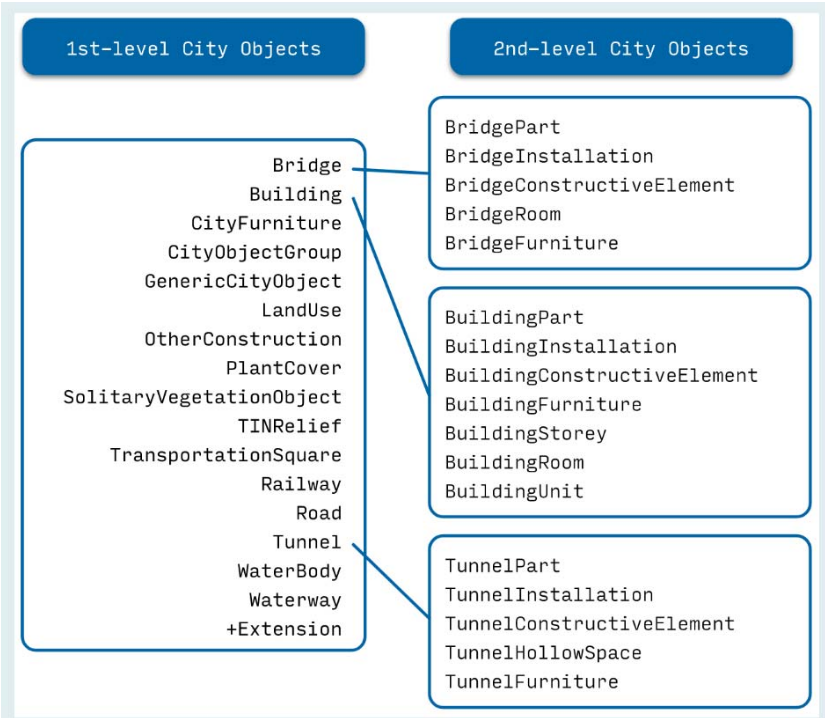

Figure C.1: Kinds of City Objects in CityJSON

Annex D: BIM Standards

Table D.1: BOT description

Standard name	BOT (NB) + TOP
Full name	Building Topology Ontology
Version	Public Draft
Status	Published on W3C®
Documentation	https://w3c-lbd-cg.github.io/bot/
Ontology	http://www.w3id.org/bot/bot.ttl
Formats	Turtle
Description	The Building Topology Ontology (BOT) is a minimal OWL DL [owl2-primer] ontology for defining relationships between the sub-components of a building. It was suggested as an extensible baseline for use along with more domain specific ontologies following general W3C® principles of encouraging reuse and keeping the schema no more complex than necessary. Any bot:Zone or bot:Element can be assigned a 3D Model (including geometry, material, etc.), using some existing data format for 3D models.
Main concepts	Bot:Building, bot:Element, bot:Site, bot:Site, bot:Spaces, bot:Storey, bot:Zone
Maturity	Commonly accepted as a reference ontology.
Committees	Linked Building Data Community Group (LBD).
Advantages	BOT is lightweight and simple and easy to integrate. BOT is extensible.
Limitations	BOT rely on the BEO [i.25] ontology for element taxonomy BOT rely on the PROP [i.26] ontology for element properties BOT rely on MEP ontology to classify mechanical, electrical and plumbing elements.

Table D.2: DiCon description

Standard name	DiCon
Full name	Digital Construction Ontologies (DiCon) [i.27]
Version	0.5
Status	Ontology Specification Draft
Documentation	https://digitalconstruction.github.io/v/0.5/index.html
Ontology	Contexts, Variables, Entities, Processes, Agents, Information, Materials, Occupancy, Lifecycle, Energy
Formats	Turtle
Description	The purpose of the Digital Construction Ontology Suite is to address the semantic level of this challenge, by providing the essential concepts and properties of construction and renovation projects, thus paving the way to the ultimate integration of information from different decentralized sources over construction lifecycle.
Main concepts	• Contexts https://w3id.org/digitalconstruction/0.5/Contexts# dicc: Multi-contexts data: planned/actual, as-designed/as-built, levels of detail • Variables https://w3id.org/digitalconstruction/0.5/Variables# dicv: Objectified properties for time varying values, constraints and value metadata • Entities https://w3id.org/digitalconstruction/0.5/Entities# dice: Basic categories with identifiers, classifications, breakdowns, and groupings • Processes https://w3id.org/digitalconstruction/0.5/Processes# dicp: Activities and resources, resource assignments, and objects of activities • Agents https://w3id.org/digitalconstruction/0.5/Agents# dica: Actors, stakeholders, roles, legal persons, capabilities, capacities • Information https://w3id.org/digitalconstruction/0.5/Information# dici: Information content entities, information containers, designs, plans, events, and issues • Materials https://w3id.org/digitalconstruction/0.5/Materials# dicbm: Building materials, material object structures, material properties and material batches • Occupancy https://w3id.org/digitalconstruction/0.5/Occupancy# dicob: Occupant behaviour, comfort, safety and health; indoor air quality and building acoustics • Lifecycle https://w3id.org/digitalconstruction/0.5/Lifecycle# dicl: Evolution of information through LOD levels and over the construction lifecycle • Energy https://w3id.org/digitalconstruction/0.5/Energy# dices: Energy efficiency including energy systems
Maturity	DiCon is relatively new compared to more established ontologies like SSN/SOSA or SAREF. It is still in the process of gaining traction within the industry.
Advantages	Interoperability, alignment with various BIM standards.
Limitations	Complexity, lack of tools and solution integration.

Table D.3: Interconnect description

Standard name	Interconnect
Full name	TNO InterConnect Ontology series
Version	5.4
Status	Research project
Documentation	https://gitlab.inesctec.pt/groups/interconnect-public/-/wikis/home#interconnect-ontology
Formats	Turtle
Description	The interconnect ontology is based on the ETSI SAREF or Smart Applications Reference ontology with its distributions for energy and buildings. It extends this ontology family with concepts specific to the cross-domain semantic interoperability: extensions for representing the user information and profiles, device and sensor information and profiles, forecast and flexibility information.
Main concepts	• ic-data http://ontology.tno.nl/interconnect/datapoint# Datapoint, TimeSeries, Message, Utility Purpose • ic-dev http://ontology.tno.nl/interconnect/device# Device, State, Function • ic-flex http://ontology.tno.nl/interconnect/flexibility# Flex Offer, Flexibility Source, Control Type, Power Envelope • ic-fc http://ontology.tno.nl/interconnect/forecast# Forecast, Point Forecast, Stochastic Forecast (Gaussian, Quantile, Trajectory), Gaussian Data Point • ic-inc http://ontology.tno.nl/interconnect/incentivetable# Incentive Table, Incentive Tiers, Scope and Type • ic-pwlm http://ontology.tno.nl/interconnect/powerlimit# Power Limit (Nominal, Contractual and Failsafe) • ic-tplg http://ontology.tno.nl/interconnect/topology# Topological Location, Grid Segment, Market Segment, Regulation Zone, Electrical Phases • ic-uom http://ontology.tno.nl/interconnect/units# Additional Units of Measure (not considered yet in SAREF) • ic-user http://ontology.tno.nl/interconnect/user# User, User Profile, Preference, Priority, Interest, Activity, Time, Location
Maturity	Research project.
Committees	TNO.
Limitations	Research work.

Table D.4: SSN/SOSA description

Standard name	SSN / SOSA
Full name	Semantic Sensor Network Ontology / Sensor, Observation, Sample and Actuator (SSN/SOSA)
Version	OGC 16-079 / W3C® Recommendation 19 October 2017
Status	W3C® Recommendation
Documentation	https://www.w3.org/TR/vocab-ssn/
Ontology	https://github.com/w3c/sdw/blob/gh-pages/ssn/rdf/sosa.ttl
Formats	RDF, TTL
Description	The Semantic Sensor Network (SSN) ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators. SSN follows a horizontal and vertical modularization architecture by including a lightweight but self-contained core ontology called Sensor, Observation, Sample, and Actuator (SOSA) for its elementary classes and properties. With their different scope and different degrees of axiomatization, SSN and SOSA are able to support a wide range of applications and use cases, including satellite imagery, large-scale scientific monitoring, industrial and household infrastructures, social sensing, citizen science, observation-driven ontology engineering, and the Web of Things. Both ontologies are described below, and examples of their usage are given.
Main concepts	
Maturity	SSN has already been broadly accepted as a de-facto standard for representing sensor data on the Web and has been the inspiration for multiple ontologies layered on top of SSN. With the standardization of the SSN and SOSA ontologies through the OGC and the W3C® and the introduction of different modules for different audiences, the ontology is likely to be used in even more varied use cases, especially for use cases in the Internet-of-Things domain.
Committees	W3C, OGC
Advantages	Interoperability, comprehensive coverage, alignment with existing standards, wide adoption, and flexibility.
Limitations	Complexity, performance, tooling, and data integration.

Table D.5: SAREF4BLDG

Standard name	SAREF4BLDG
Full name	SAREF extension for building [i.22]
Version	V1.1.2
Status	Published (2020-04-13)
Documentation	https://saref.etsi.org/saref4bldg/v1.1.2/
Ontology	https://saref.etsi.org/saref4bldg/v1.1.2/saref4bldg.ttl
Formats	JSON-LD, N3, N-Triples, RDF/XML, Turtle
Description	SAREF4BLDG is an extension of the SAREF ontology that was created based on the Industry Foundation Classes (IFC) standard for building information. It should be noted that not the whole standard has been transformed since it exceeds the scope of this extension, which is limited to devices and appliances within the building domain. SAREF4BLDG is meant to enable the (currently missing) interoperability among various actors (architects, engineers, consultants, contractors, and product component manufacturers, among others) and applications managing building information involved in the different phases of the building life cycle (Planning and Design, Construction, Commissioning, Operation, Retrofitting/Refurbishment/Reconfiguration, and Demolition/Recycling). By using SAREF4BLDG, smart appliances from manufacturers that support the IFC data model will easily communicate with each other. Towards this aim, SAREF4BLDG should be used to annotate (or generate) neutral device descriptions to be shared among various stakeholders.
Main Concepts	Building, Building Device, Building Object, Building Space, Actuator.
Maturity	Promising and still maturing ontology. Benefits from the maturity of SAREF Ontology.
Committees	ETSI
Advantages	Comprehensive modelling and alignment with IoT ecosystems.
Limitations	Quite complex to use. Limited availability of compatible tools and solutions.
Potential improvements	Developing advanced tools, promoting broader adoption, optimizing performance.

Table D.6: Smart data model description

Standard name	Smart Data Model / Building
Full name	Smart Data Model for models
Version	0.0.3
Status	FIWARE community effort the share models
Documentation	https://swagger.lab.fiware.org/?url=https://smart-data-models.github.io/dataModel.Building/Building/swagger.yaml
Ontology	https://github.com/smart-data-models/dataModel.Building/tree/master
Formats	YAML, NGSI-LD
Description	This entity contains a harmonised description of a Building. This entity is associated with the vertical segments of smart homes, smart cities, industry and related IoT applications. This data model has been partially developed in cooperation with mobile operators and the GSMA, compared to GSMA data model following changes are introduced the reference to BuildingType is removed, since BuildingType compared to category attribute does not introduce significant information. category attribute is required. openingHours is introduced following schema.org data model to allow fine-grained on building opening times. GSMA supported this as free text in the notes attribute (removed as well). refSubscriptionService is not supported, since SubscriptionService model is not supported currently https://github.com/smart-data-models/SmartCities/tree/61f5a1d45e04fe256defadd7123ccabd0c98de78 https://github.com/sj-doyle/NGSI-LD-Entities/blob/master/definitions/Building.md
Main concepts	Building, Building operation, Building type.
Committees	FIWARE community effort the share models.

Table D.7: CityGML description

Standard name	CityGML
Full name	OGC City Geography Markup Language
Version	Version 3.0
Status	Released
Documentation	https://docs.ogc.org/is/21-006r2/21-006r2.html
Data model	https://github.com/opengeospatial/CityGML-3.0CM/tree/master/Implementations
Formats	GML, Json, SQL
Description	The CityGML standard defines a conceptual model and exchange format for the representation, storage and exchange of virtual 3D city models. It facilitates the integration of urban geodata for a variety of applications for Smart Cities and Urban Digital Twins, including urban and landscape planning; Building Information Modelling (BIM); mobile telecommunication; disaster management; 3D LAND registry; tourism; vehicle & pedestrian navigation; autonomous driving and driving assistance; facility management, and; energy, traffic and environmental simulations.
Maturity	CityGML has gained significant adoption in urban planning, geospatial industries, and 3D city Modelling projects worldwide. Its adoption indicates a degree of maturity and acceptance within the relevant communities.
Competitors	IndoorGML Proprietary formats
Use for the project	Import City data models into the digital twin.
Limitations	CityGML can be quite complex, especially for users who are new to 3D geospatial data. Creating, manipulating, and interpreting CityGML data may require a certain level of expertise. 3D city models in CityGML format can be data-intensive due to the level of detail and the inclusion of geometric and semantic information. Handling large datasets can be a challenge.
Committees	Open Geospatial Consortium.

Table D.8: IFC description

Standard name	IFC
Full name	Industry Foundation Classes [i.23]
Version	4.0.2.1 (Version 4.0 - Addendum 2 - Technical Corrigendum 1)
Status	ISO 16739-1:2018 [i.50]
Documentation	https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML
Ontology	https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2/OWL/index.html
Formats	Express, XSD, RDF, TTL (IFCOWL)
Description	The Industry Foundation Classes, IFC, are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well.
Main concepts	• Spatial structures: Site, Building, Storey, Space. • Building elements: Wall, Roof, Slab, Beam, Door, Window, etc. • Equipment and systems: Electricity, HVAC, Plumbing, etc. • All types of relations between the previous elements. • Specific properties (Psets) and quantities (Qto) for each element type.
Maturity	Widely used for building design and construction phases. Starting to be used in building exploitation phase.
Limitations	All equipment is not described with the same level of details.
Potential improvements	Define a more homogeneous description of all building equipment.
Committees	buildingSMART International, CEN/TC 442 [i.52], ISO/TC 59/SC 13 [i.53].

Table D.9: geoSPARQL description

Standard name	geoSPARQL
Full name	Geographic Vocabulary and Query Language for RDF Data
Version	Approved 1.1 Draft
Status	Approved OGC Implementation Standard
Documentation	https://www.ogc.org/standards/geosparql (v1.0)
Ontology	geo: http://www.opengis.net/#geosparql geof: http://www.opengis.net/def/function/geosparql/ w3cGeo: http://www.w3.org/2003/01/geo/wgs84_pos# geor: http://www.opengis.net/def/rule/geosparql/ sf: http://www.opengis.net/ont/sf#
Formats	RDF, geoJSON-LD. Compatible with geoJSON, KML, GML, WKT
Description	This ontology is related to other complementary OGC standards and ontologies: WKT, GML, WGS84.
Maturity	GeoSPARQL is a well-established standard developed by the Open Geospatial Consortium (OGC) for representing and querying geospatial information in Resource Description Framework (RDF) data stores. The standard has been widely adopted in the geospatial and semantic web communities, and it has seen implementation in various systems and applications. It is important to note that the maturity of a standard can be assessed based on factors such as its adoption rate, the existence of compliant implementations, and ongoing community support. GeoSPARQL has been implemented in various RDF triple stores, and there are tools and libraries available that support its use.
Limitations	Concerning geoSPARQL 1.0, various serializations of geometry data (e.g. KML, GeoJSON, GML) are still expected. Work remains in expanding GeoSPARQL vocabularies with axioms for logical spatial reasoning. Standard processes for converting GML file to RDF would be beneficial.
Potential improvements	The GeoSPARQL 1.1 release incorporates many additions requested of the GeoSPARQL 1.0 Standard, including the use of new serializations. Where GeoSPARQL 1.0 supported GML & WKT, GeoSPARQL 1.1 also supports GeoJSON, KML and a generic DGGS literal. GeoSPARQL 1.1 also supports spatial scalar measurements. Plans for future GeoSPARQL will be discussed and decided by the OGC GeoSPARQL Standards Working Group and related groups.
Committees	ISO, OGC (GeoSPARQL Standards Working Group), W3C.

Table D.10: GITF description

Standard name	GITF
Full name	GL Transmission Format
Version	GITF 2.0
Status	Released
Documentation	https://registry.khronos.org/glTF/specs/2.0/glTF-2.0.html
Description	glTF is a royalty-free specification for the efficient transmission and loading of 3D scenes and models by engines and applications. glTF minimizes the size of 3D assets, and the runtime processing needed to unpack and use them. glTF defines an extensible, publishing format that streamlines authoring workflows and interactive services by enabling the interoperable use of 3D content across the industry. glTF 2.0 has been released as ISO/IEC 12113:2022 [i.54].
Main concepts	Scene, node, mesh, camera, material, texture.
Maturity	glTF is a mature, robust, and widely adopted 3D file format, well-suited for a variety of applications from web to VR/AR.
Advantages	Compact size, efficiency, interoperability, and modern graphics support.
Limitations	Performances with large models, lack of advanced animation features, and limited metadata support.
Potential improvements	Enhancing metadata and animation support, integrating texture compression, optimizing performance, developing more robust tools, and expanding documentation.

Table D.11: FOG description

Standard name	FOG
Full name	File Ontology for Geometry formats
Version	0.0.4
Status	Released 2020-01-14
Documentation	https://mathib.github.io/fog-ontology/#
Ontology	https://mathib.github.io/fog-ontology/ontology.ttl
Formats	JSON-LD, RDF/XML, N-Triples, TTL
Description	The File Ontology for Geometry formats (FOG) provides geometry schema specific relations between things (e.g. building objects) and their geometry descriptions. These geometry descriptions can be: 1) RDF-based (e.g. using specific ontologies such as GEOM, OntoBREP, etc.); 2) RDF literals containing embedded geometry of existing geometry formats; and 3) RDF literals containing a reference to an external geometry file. The FOG ontology extends the Ontology for Managing Geometry (OMG) and consists of three taxonomies of properties.
Main concepts	Two Taxonomies of properties standalone geometry descriptions: • one for RDF-based geometry schemas with as root object property the [omg:hasComplexGeometryDescription]; • one for existing geometry schemas that can be represented using RDF literals with as root datatype property [omg:hasSimpleGeometryDescription]. One taxonomy of properties extends the OMG datatype property [omg:hasReferencedGeometryId].
Maturity	Mid-stage of maturity, with solid foundational elements in place and active development and adoption ongoing.
Advantages	Geometry descriptions can be: 1) RDF-based (e.g. using specific ontologies such as GEOM, OntoBREP, etc.); 2) RDF literals containing embedded geometry of existing geometry formats; and 3) RDF literals containing a reference to an external geometry file.
Limitations	The FOG ontology is incomplete by nature, as it is impossible to contain all existing geometry schemas.

History

Document history		
V1.1.1	February 2025	Publication