A Survey of Industry Data Models and Reference Data Libraries

To identify requirements for, and provide input to, a Foundation Data Model

Version 1

CONSTRUCTION INNOVATION HUB

INDUSTRIAL STRATEGY

UK Research and Innovation

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1 Introduction

1.1 Objectives of the review

The review of existing industry data models and reference data libraries will support the development of the National Digital Twin Information Management Framework. The review will have different roles during the development. The envisaged roles are as follows:

existing industry data models and reference data libraries are identified:

Their scopes are summarised so that their relevance to the National Digital Twin can be evaluated. The scope of the National Digital Twin will grow over time, and the scopes for existing data models defined by organizations such as OCG (Open Geospatial Consortium) or bSI (Building Smart International) may be a guide.

the structure of the models and libraries is summarised:

Most of the models and libraries do not claim to be based upon a formal Top-Level Ontology (TLO). Instead the models have been developed pragmatically over years, and have been validated by practice. Development of the National Digital Twin will require an understanding of how the structures of the existing models relate to the chosen Top-Level Ontology.

the extensibility of the models is described:

The maintenance of an industry data model of broad scope requires continual extensions. The extensions in different areas may be carried out by different teams, so extension methodologies have been developed. The approach to extensions may be relevant to the development of the National Digital Twin.

the documentation of the models is described:

For industry data models of broad scope, managing the documentation is a challenge. The ease with which a domain expert can understand the IT solution is evaluated. There may be lessons for the documentation of the National Digital Twin.

the maintenance and usage of the models is described:

Models that are maintained by a long-lasting organization, and that have a significant level of industrial usage will persist alongside the National Digital Twin. Interfaces between the National Digital Twin and these models may be required.

1.2 Structure of the review document

1.2.1 Application areas

The review document has sections for application areas as follows:

1. Buildings
2. Geospatial - things in the landscape
3. Manufactured things
4. Process plants and networks

There are substantial overlaps between these areas. Buildings and process plants are assemblies of manufactured things. Buildings and process plants exist within the landscape.

Previous work on integrating building model with geospatial models is discussed in the Geospatial section.

Work on the internet of things, on metrology, and previous work on digital twins is discussed in the Manufactured things section.

1.2.2 Models within application areas

For each of the industrial data models and reference data libraries within an application area, there is the following subsections:

1. Defining organization
2. Objectives and scope
3. Structure of the model
4. Extensibility
5. Documentation
6. Maintenance and usage

1.3 Abbreviations

AP	Application Protocol
ASAM	Association for Standardization of Automation and Measuring Systems
BIM	Building Information Modelling
BOD	Business Object Document
bSI	Building Smart International
CCOM	Common Concept Object Model
CIM	Common Information Model
CDD	Common Data Dictionary
CGI	Commission for the application and management of Geoscience Information
DMSC	Digital Metrology Standards Consortium
DTC	Digital Twin Consortium
EPRI	Electrical Power Research Institute
GIS	Geographic Information System
GML	Geographic Markup Language
IDBE	Integrated Digital Built Environment
IEC	International Electro-technical Commission
IES	Information Exchange Standard
IFC	Industry Foundation Class
IFCD	INSPIRE Feature Concept Dictionary
ILAP	Integrated Lifecycle Asset Planning
IMF	Information Management Framework
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Standardization Organization
ISA	International Society of Automation
IUGS	International Union of Geological Sciences
LOD	Level Of Detail
LOTAR	Long Term Archiving and Retrieval
MBD	Model Based Definition
MESA	Manufacturing Enterprise Solutions Association
MIMOSA	formerly Machinery Information Management Open System Alliance, now just a name
NBS	formerly National Building Specification, now just a name
OAGi	Open Applications Group Inc.
OGC	Open Geospatial Consortium
OGI	Oil and Gas Interoperability
OPC	Open Platform Communications
O&M	Operations and Maintenance
PDM	Product Data Management
QIF	Quality Information Framework
RDL	Reference Data Library
SCADA	Supervisory Control And Data Acquisition
SMRL	STEP Module and Resource Library
STEP	STandard for the Exchange of Product data
SWE	Sensor Web Enablement
TLO	Top-Level Ontology
VOIP	Voice Over Internet Protocol

2 Roadmap showing the application areas of the sources

The application areas of the source industrial data models and reference data libraries are shown in Figure 1.

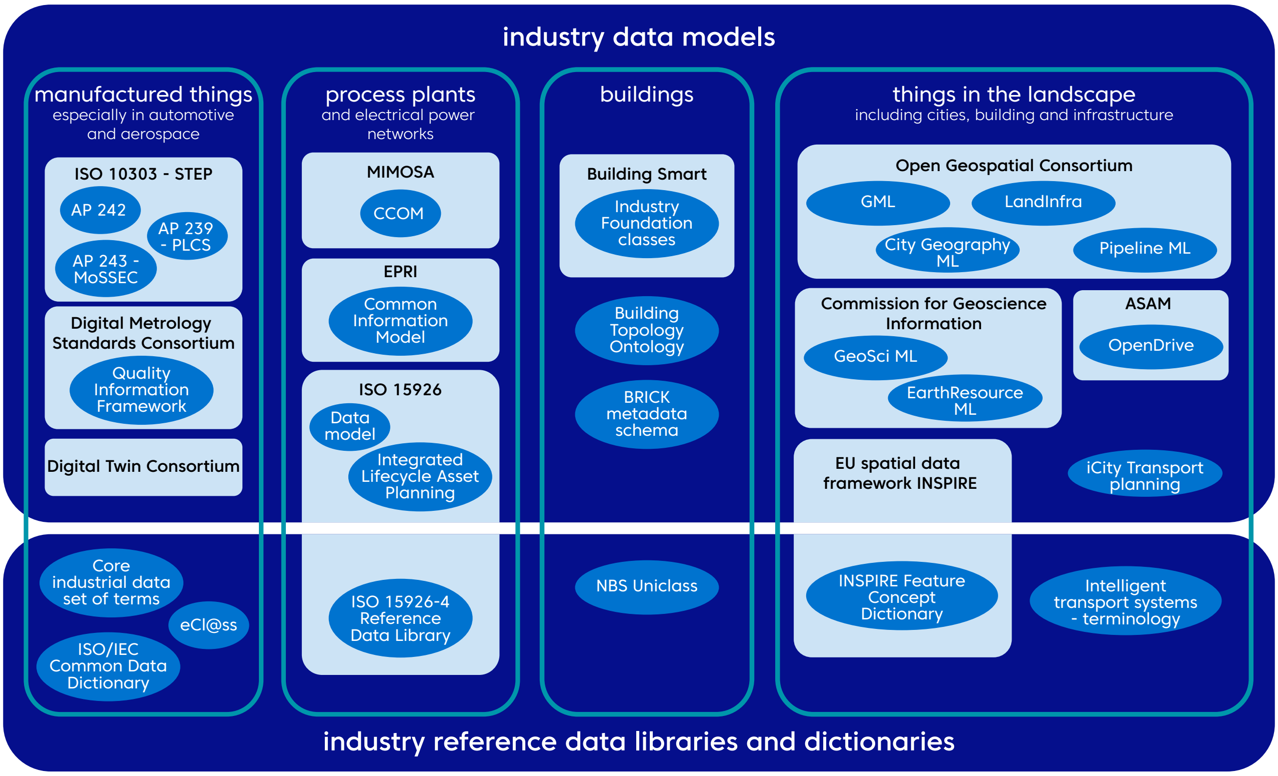

Figure 1 - Application areas of the industry data models and libraries

The industry data models and libraries are also summarised in Appendix A.

The UK Government Information Exchange Standard (IES) is also included within the scope of this report. The industry sector data models shown in Figure 1 are principally concerned with things, whereas the IES is principally concerned with activities performed by Government.

3 Building Information Models

3.1 buildingSMART

https://technical.buildingsmart.org/standards/ifc/ifc-schema-specifications/

3.1.1 Defining organization

buildingSMART International (bSI) is a not for profit company incorporated in the UK in 1995. It has members organised in regional chapters.

The home page of building SMART international says:

> buildingSMART has focused on solving industry interoperability challenges. buildingSMART is a neutral, international forum for initiating, developing, creating and adoption of open digital standards for BIM processes.

3.1.2 Objectives and scope

buildingSMART has developed a library of Industry Foundation Classes (IFCs) for the building industry. The IFCs have been standardised by ISO/TC 59/SC 13 “Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)”, and are also published as ISO 16739-1:2018 “Industry Foundation Classes (IFC) For data sharing in construction and facility management industries - Part 1: Data Schema”.

The summary page for the standards says:

> buildingSMART standards cover wide range of process and information capabilities unique to the built environment industry, including:

- An industry-specific data model schema - Industry Foundation Classes [IFC]
- A methodology for defining and documenting business processes and data requirements - Information Delivery Manual [IDM]
- Data model exchange specifications - Model View Definitions [MVD]
- Model-based, software-independent communication protocols - BIM Collaboration Format [BCF]
- A standard library of general definitions of BIM objects and their attributes - buildingSMART Data Dictionary [bSDD]

The list continues to grow as stakeholders in the industry work together to identify opportunities to be more efficient and create greater value by applying standard processes and technologies where needed.

3.1.3 Structure of the model

The top of the IFC model is shown in Figure 2.

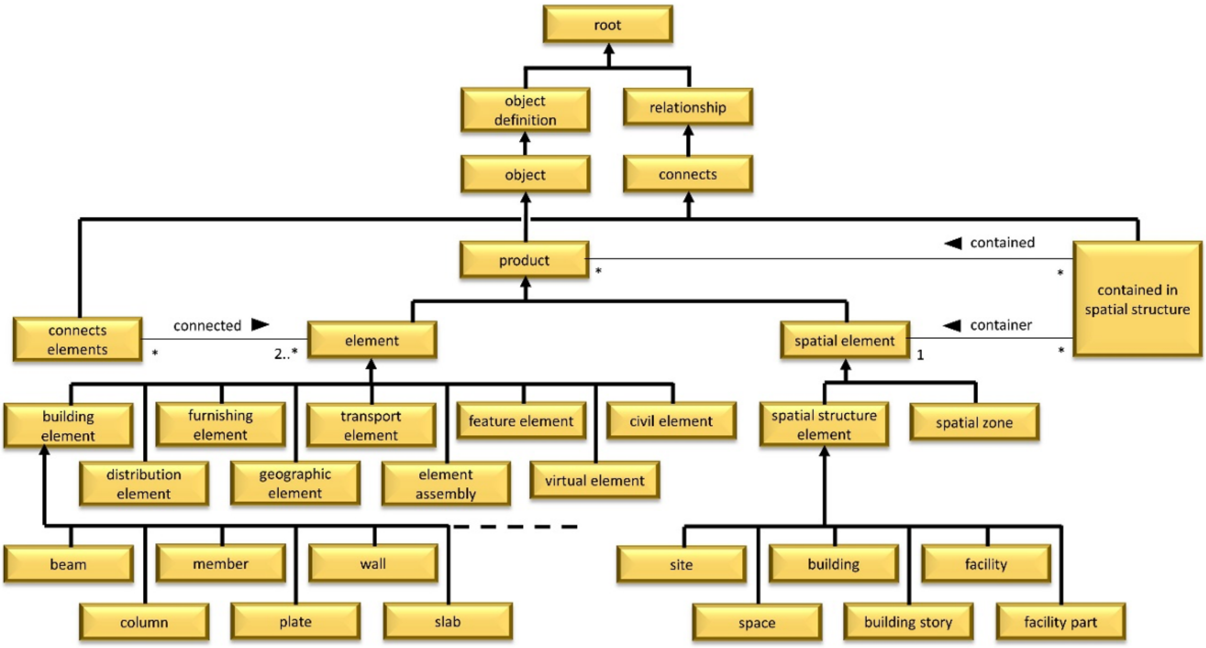

Figure 2 - Top of the IFC model

Comments on Figure 2:

1. The model has an ISO 10303 flavour, with **product** as a top object and a reified product relationship. The production relationship object is called **connect**, but encompasses containment as well as connection. The model also has a formal structure with a **root** class.
2. There is a distinction between **element** and **spatial element**, where a part of a **building** such as a **beam** or **column** is an **element**, but a **building** as a whole is a **spatial element.**

The distinction between spatial element and element is replicated in the Building Topology Ontology, LandInfra and CityGML, as follows:

IFC	spatial element (e.g. site, building, facility)	element (e.g. beam, column, wall, slab)
Building Topology Ontology	zone (e.g. site, building, space, storey)	element
LandInfra	facility part (e.g. building, railway, road)	physical element (e.g. railway element such as ballast, sleeper, switch)
CityGML	site (e.g. building, tunnel, bridge)	building installation (with physical bounds such as interior and exterior wall surfaces)

The subclasses under **element** have partners which are "types". Hence there is **beam** and **beam type**, **column** and **column type**, etc.. Several different **beams** within a **building** can be of the same **beam type**. Properties assigned to a **beam type** are inherited by each **beam** of that type.

3.1.4 Documentation

The top level documentation follows the style of ISO 10303 (STEP), but is much simpler and clearer. There are easily understandable EXPRESS-G diagrams.

The documentation of subclasses under **element** is less well presented and no longer has clear EXPRESS-G diagrams. Nonetheless the UML-like diagrams are understandable.

3.1.5 Maintenance and usage

buildingSMART International is an active organization, and the latest [in August 2020] revision of the IFCs was published in April 2020.

The IFCs can be implemented in EXPRESS, XSD/XML and OWL. They are widely used within the building industry.

3.2 NBS Uniclass

https://www.thenbs.com/our-tools/uniclass-2015

3.2.1 Defining organization

NBS Enterprises Limited is a company registered in England, which is a commercialisation of the UK's National Building Specification.

NBS Enterprises Limited maintains Uniclass-2015, which is a classification system for the construction industry.

3.2.2 Objectives and scope

The introduction to Uniclass-2015 says:

> Uniclass is a consistent classification structure for all disciplines in the construction industry. It contains tables classifying items of any scale from a large facility such as a railway, down to products such as a CCTV camera in a railway station.
>
> It's an essential way of identifying and managing the vast amount of information that's involved in a project, and it's a requirement for BIM projects, as set by the BS EN ISO 19650 [Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling] series of standards.

3.2.3 Structure of the model

The content of Uniclass-2015 is divided into tables as follows:

Co	Complexes
En	Entities
Ac	Activities
SL	Spaces/ locations
EF	Elements/ functions
Ss	Systems
Pr	Products
TE	Tools and Equipment
PM	Project management
FI	Form of information
Ro	Roles
Zz	CAD

Within each table, there are named objects arranged into hierarchies. The objects do not have definitions, although in most cases the names are self-explanatory. The objects do not have properties.

3.2.4 Documentation

Uniclass-215 tables are published as simple EXCEL spreadsheets, from which hierarchies and codes can be easily extracted and represented in other formats.

3.2.5 Maintenance and usage

NBS Enterprises Limited is an active organization. The latest [in August 2020] revision of the tables was published in July 2020.

The Uniclass codes are widely used in the UK construction industry.

3.3 Brick - a uniform metadata schema for buildings

https://brickschema.org

3.3.1 Defining organization

The Brick project was initiated by universities in the USA and Denmark and by IBM research. There is no organization, except an open source development community.

3.3.2 Objectives and scope

What is Brick? says:

> Brick is an open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them. Brick consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, ...

The schema principally addresses control systems within buildings.

3.3.3 Structure of the model

The model has two principal top classes:

equipment:

> within the scope of the model, this is control system equipment. There are subclasses such as **HVAC**, and below this **air handler unit**.

location:

> within the scope of the model, this is where equipment can be. There are subclasses such as **room**, and below this **server room**.

The model is concerned with how equipment items are connected and what their properties are. The properties can include set point values.

The documentation of the model is not uninteresting, because it recognises limits to what has been done. An interesting discussion concerns an **air temperature sensor**. This is defined as a **temperature sensor** that measures **air**. Naïve rendering in OWL, shows this as a relationship between a particular **temperature sensor** and the class **air**, which is not OWL-DL and requires punning. Actually, it is a relationship between a particular **temperature sensor** and the particular **air** at the location of the sensor.

3.3.4 Documentation

There is some discussion of the model, but for the details the user is left to hack the TURTLE files. The definitions are sparse.

3.3.5 Maintenance and usage

This is unclear. A new version of the schema is shown, but there are no dates.

3.4 Building Topology Ontology

https://w3c-lbd-cg.github.io/bot/

3.4.1 Defining organization

The W3C Linked Building Data Community Group (https://www.w3.org/community/lbd/) is an informal group under W3C. Its home page says:

> This group brings together experts in the area of building information modelling (BIM) and Web of Data technologies to define existing and future use cases and requirements for linked data based applications across the life cycle of buildings.

3.4.2 Objectives and scope

The Building Topology Ontology is a Draft Community Group Report of 07 April 2020. The introduction to the ontology says:

> The Building Topology Ontology (BOT) is a minimal OWL 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.

3.4.3 Structure of the model

The Building Topology Ontology model is admirably simple. A UML representation of most of it is shown in Figure 3.

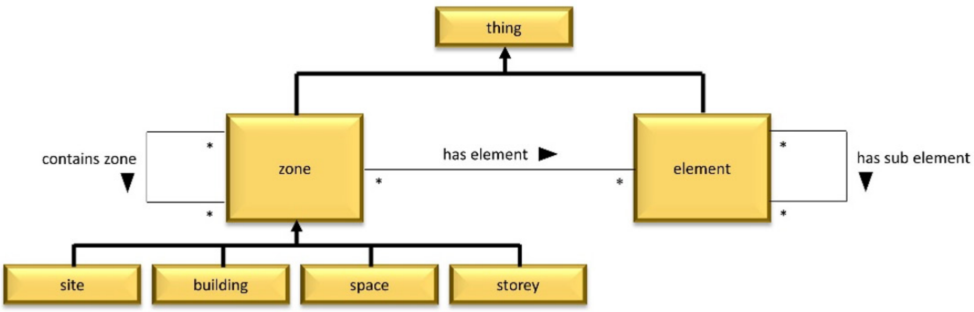

Figure 3 - Building Topology Ontology model

The Building Topology Ontology defines interfaces to other standards, including the IFCs and Brick. The interfaces are expressed as rdfs:subClassOf and rdfs:subPropertyOf relationships. Hence:

Building Topology Ontology to IFCs:

ifc:IfcSite subclass of bot:Site

ifc:IfcBuilding subclass of bot:Building

ifc:IfcBuildingStorey subclass of bot:Storey

ifc:IfcSpace subclass of bot:Space

ifc:IfcElement subclass of bot:Element

Building Topology Ontology to Brick:

brick:Building subclass of bot:Building

brick:Space subclass of bot:Zone

brick:Room subclass of bot:Space

brick:Equipment subclass of bot:Element

brick:contains subclass of bot:hasElement

brick:hasPart sub-property of bot:hasElement

brick:hasPart sub-property of bot:containsZone

brick:hasPart sub-property of bot:hasSubElement

[The relationships between the properties do not look right to me. DL]

3.4.4 Documentation

Being so simple, the documentation of the Building Topology Ontology is adequate. However, you have to load the ontology into Protégé, or similar tool, to understand it. No graphical representation of the model is provided.

3.4.5 Maintenance and usage

The Building Topology Ontology is work in progress, and the latest [in August 2020] draft is June 2020.

There is no evidence of any industrial use.

4 Graphical Information Systems

4.1 Open Geospatial information

https://www.ogc.org/

4.1.1 Defining organization

GIS models are developed and standardized by Open Geospatial Consortium (OGC) and ISO/TC 211 “Geographic information/Geomatics”.

4.1.2 Objectives and scope

The OGC core GIS model is the basis for many domain specific models which are concerned with the representation of things distributed over the surface of the Earth. Some of these are standardised within OGC, and other outside. Domain specific models standardised within OGC include:

- the CityGML (clause 5.2) and Landinfra (clause 5.3) models for the built environment;
- the GeoSCiML (clause 4.3) model for geology;
- domain specific models, such as PipelineML (clause 4.2) model.

The OGC core GIS model is also at the heart of the EU INSPIRE spatial data infrastructure (clause 5.4).

The OGC also defined models for observations and measurements and sensor networks. In June 2020, the OGC adopted the HDF5 standard for the efficient representation of structured data.

4.1.3 Structure of the model

At the heart of the GML schemas is the element **feature**. This is a spatio-temporal object comparable to **physical object** in ISO 15926-2. A **feature** can have states or time varying relationships. An outline of the approach to feature represented in UML is shown in Figure 4.

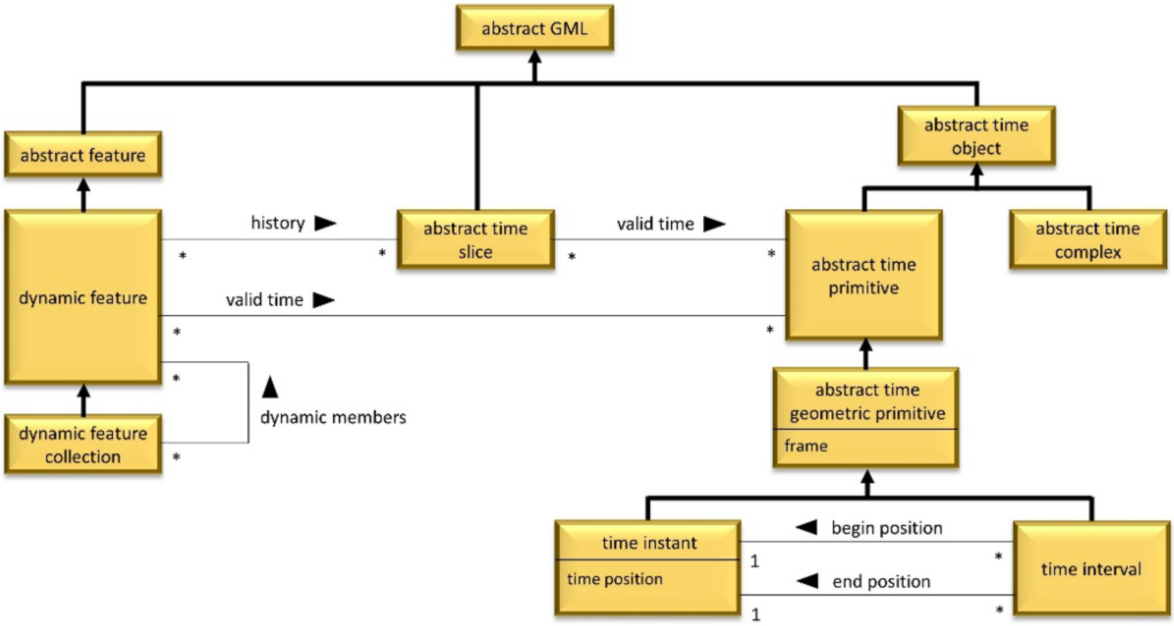

Figure 4 - Feature in GML

Comments on Figure 4:

1. A **dynamic feature** exists at an instant in time or during a period of time. If a **dynamic feature** has states, then it is regarded as a **dynamic feature collection**.
2. The relationship between a **dynamic feature** and time is directly analogous to the relationship between a feature and space.
3. An **abstract time slice** is specialised by relationships which are different at different times.
4. The GML time model also contains the time topology relationships of Allen's interval algebra.

The relationship **valid time** is a specialisation of **time primitive property**. Other specializations can be defined in an application schema.

The top of the model for geometry is shown in Figure 5.

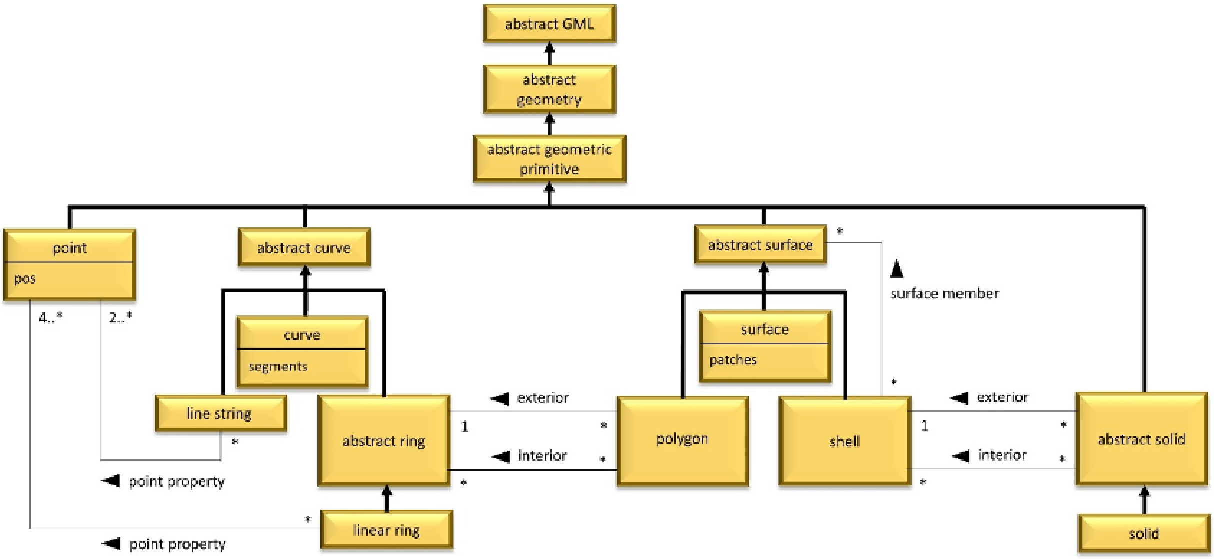

Figure 5 - Geometry in GML

Comments on Figure 5:

1. The **segments** of a **curve** are explicitly defined finite bounded curves, but which are not part of the geometric hierarchy. Similarly the **patches** of a **surface** are explicitly defined finite bounded surfaces, but which are not part of the geometric hierarchy.
2. The overall structure of this model is very similar to that of ISO 10303-42. A **line string** corresponds to a polyline in ISO 10303-42, and a **linear ring** corresponds to a poly_loop and a polygon corresponds to a **polygonal_area**.
3. GML seeks to separate geometry from topology in a way that is similar to ISO 10303-42. Nonetheless, the relationships shown explicitly in this figure are all topological.

The relationships between a feature and geometry are not defined in GML, but are left to an application schema. GML defines **curve property** as a relationship with an **abstract curve**. An application schema can specialised this to be a centre line.

The GML model recognises that as a feature changes through time, its geometry can change whilst its topology remains the same. Therefore there is a separate topology model, and a feature can be independently associated with topology. The GML approach to topology is discussed in document "OWS (OGC Web Services) 3 GML Topology Investigation" (http://portal.opengeospatial.org/files/?artifact_id=14337). The document contains - Geometry and topology, which shows an approach similar to that of ISO 10303-42.

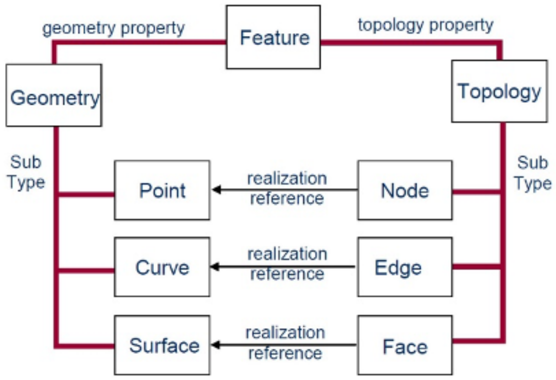

Figure 6 - Geometry and topology in GML

A major different between geometry in GML and geometry in ISO 10303-42, is that the geometric objects in GML, such as points, curves and surfaces, exist in physical space rather than in the space of real pairs or triples, according to dimension, with the Euclidean metric.

4.1.4 Documentation

The models are represented initial UML, from which the XML schemas that make up the Geography Markup Language (GML) are derived. Ontologies in OWL are also being derived.
The architecture of the standards is shown in Figure 7.

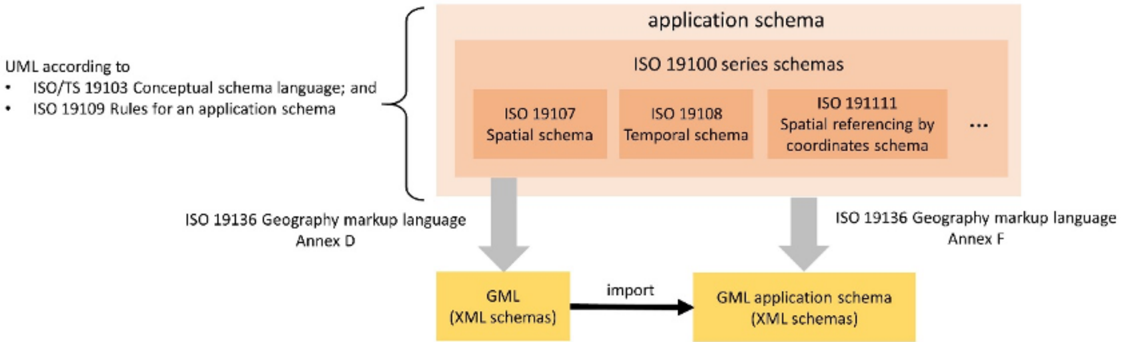

Figure 7 - Architecture of OGC standards

The GML standard is publicly available on https://www.ogc.org/standards/gml
The GML schemas can be downloaded from http://schemas.opengis.net/gml/3.2.1/

NOTE The architecture provides extensibility at both the UML and XML schema levels. As a result, there is some complexity. Some relationships are defined partially in the GML schemas and then left to the application schemas to make precise. This is analogous to the “management resources” in ISO 10303.

4.1.5 Maintenance and usage

Both the OGC and ISO TC 211 are active organizations, supporting a family of standards for geospatial information with regular revisions.

The OGC standards are ubiquitous for geospatial information.

4.2 PipelineML

https://pipelineml.org/

4.2.1 Defining organization

This standard was developed by the OGC PipelineML Standards Working Group.

4.2.2 Objectives and scope

The OGC overview says:

> The OGC PipelineML Conceptual and Encoding Model Standard defines concepts supporting the interoperable interchange of data pertaining to oil and gas pipeline systems. PipelineML supports the common exchange of oil and gas pipeline information. This initial release of the PipelineML Core addresses two critical business use cases that are specific to the pipeline industry: new construction surveys and pipeline rehabilitation. This standard defines the individual pipeline components with support for lightweight aggregation.
>
> Additional aggregation requirements such as right-of-way and land management will utilize the OGC LandInfra standards with utility extensions in the future. Future extensions to PipelineML Core will include (non-limitative): cathodic protection, facility and safety. PipelineML was advanced by an international team of contributors from the US, Canada, Belgium, Norway, Netherlands, UK, Germany, Australia, Brazil, and Korea.

4.2.3 Structure of the model

PipelineML is an application schema for GML. The objects in the PipelineML model are shown in Figure 8.

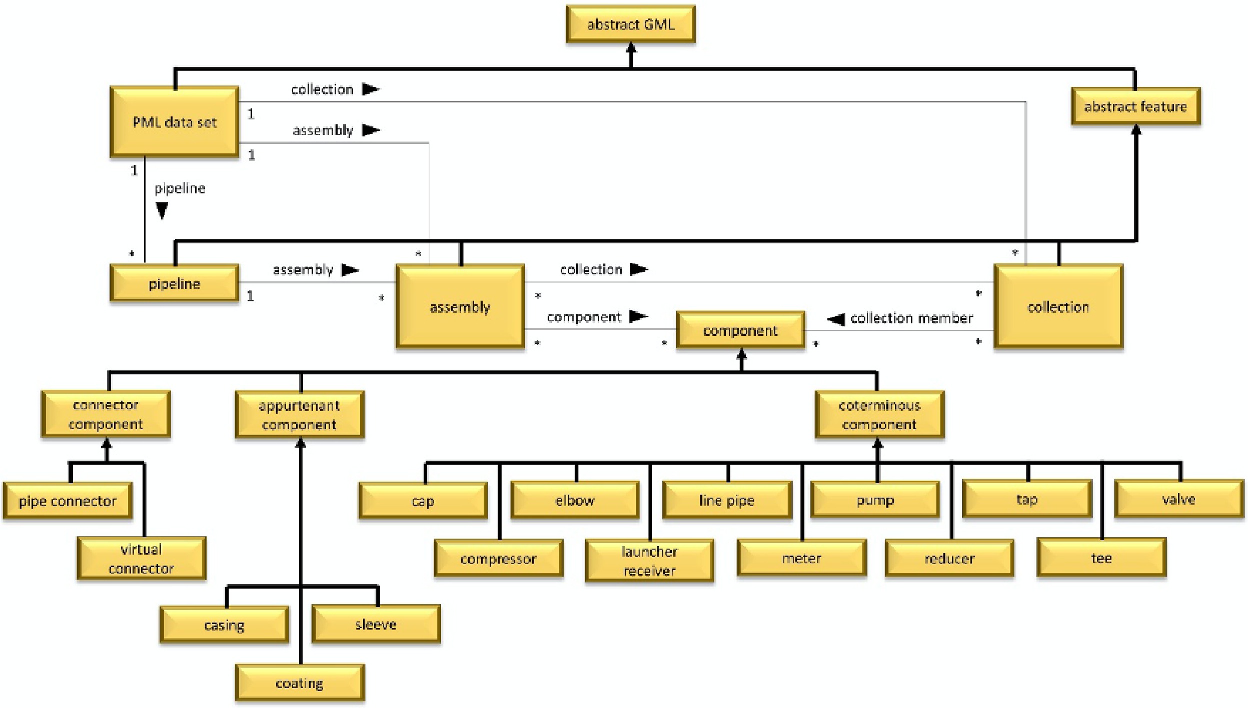

Figure 8 - Objects in PipelineML

Comments on Figure 8:

1. This is a straightforward implementation of the OGC architecture shown in Figure 7.
2. The subclasses of **component** have appropriate properties, and each has a reference to GML geometry. However the components have no topology, so the topology of the pipeline has to be deduced from the geometry.

4.2.4 Documentation

The PipelineML is documented according to the guidelines established for OGC standards, as shown in Figure 7.

4.2.5 Maintenance and usage

PipelineML was published in August 2019. The standard seems to be a natural companion to process industry standards, such as MIMOSA CCOM and ISO 15926, but there is no evidence of such usage.

4.3 Geoscience information

http://geosciml.org/

http://earthresourceml.org/

4.3.1 Defining organization

GeoSciML (Geological Sciences Markup Language) and EarthResourceML (Earth Resources Markup Language) are standards produced by the Commission for the application and management of Geoscience Information (CGI) under the International Union of Geological Sciences (IUGS).

4.3.2 Objectives and scope

The GeoSciML home page says:

> GeoSciML is a data model and data transfer standard for geological data - from basic map data to complex relational geological databases.

The EarthResourceML home page says:

> The model describes the geological features of mineral occurrences, their commodities, mineral resources and reserves. It is also able to describe mines and mining activities, and the production of concentrates, refined products, and waste materials.

4.3.3 Structure of the model

GeoSciML is a well-documented GML application. There is even a postersized UML diagram - https://portal.opengeospatial.org/files/?artifact_id=72895. The dependencies on OGC standards are shown in Figure 9 are taken from the GeoSciML web site.

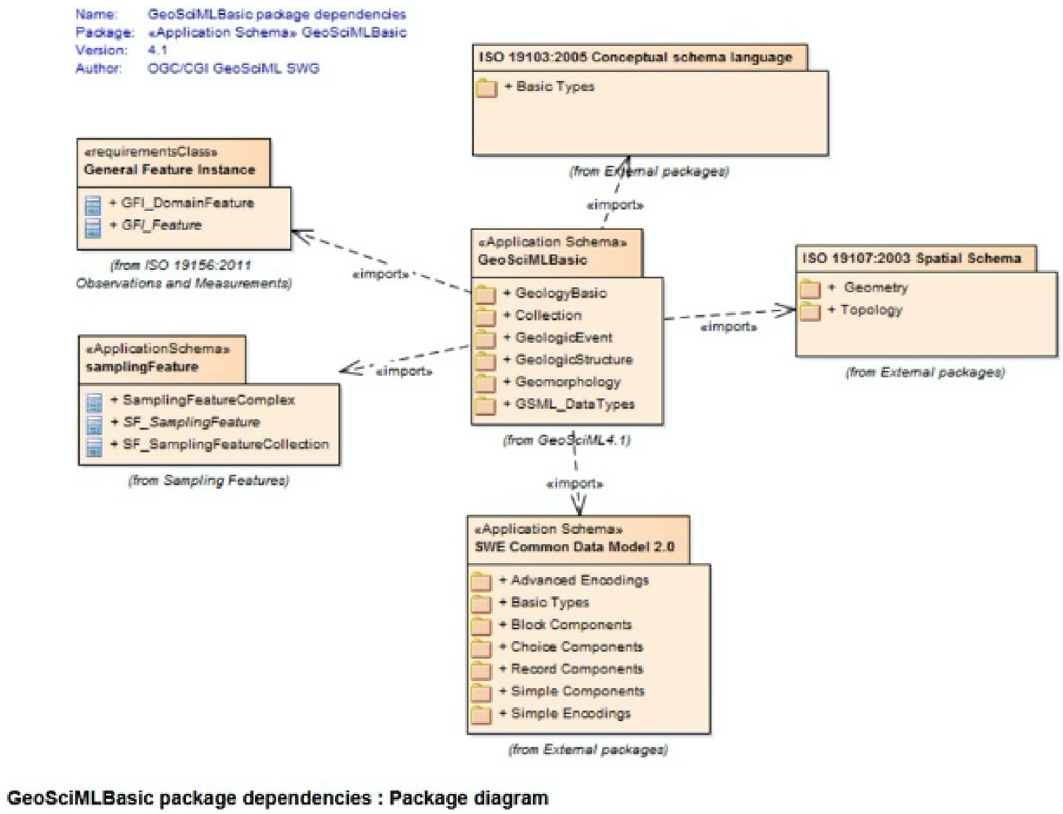

Figure 9 - GeoSciML schemas

The SWE Common Data Model referred to in Figure 6, is the Sensor Web Enablement (SWE) Common Data Model Encoding Standard, which is defined by the OGC for low level sensor data - see https://www.ogc.org/standards/swecommon

EarthResourceML is an extension of GeoSciML, in the same style. It is documented with simple and easily understood diagrams, such as Figure 10.

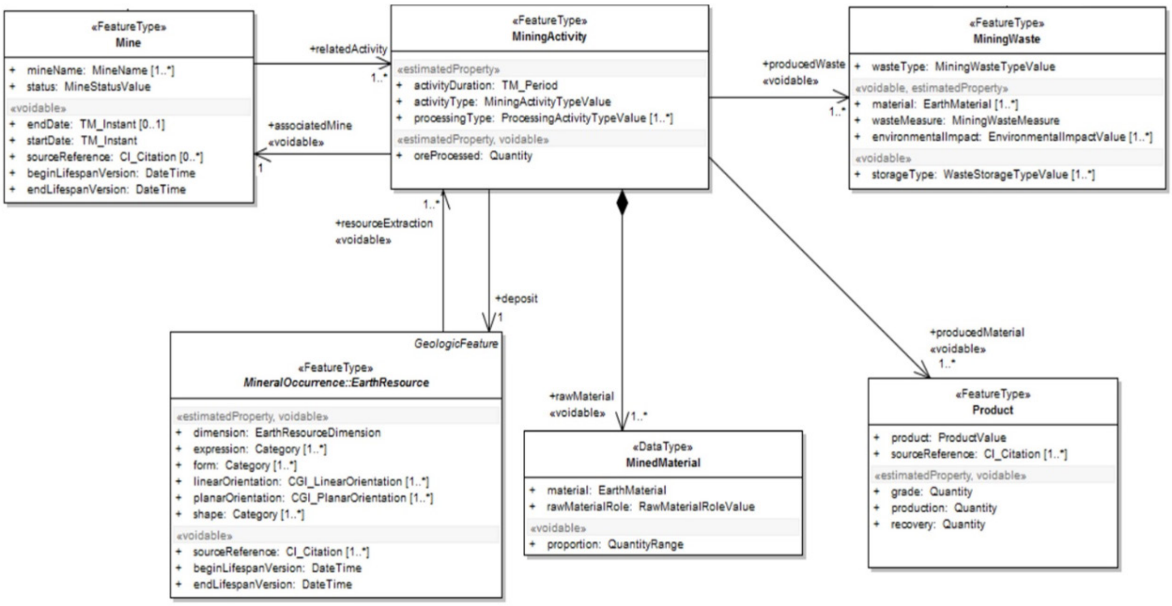

Figure 10 - EarthResourceML schema for a mine

4.3.4 Documentation

The GeoSciML and EarthResourceML are documented according to the guidelines established for OGC standards, as shown in Figure 7.

4.3.5 Maintenance and usage

The CGI is an active organisation.
The latest [in August 2020] release of GeoSciML was in May 2015 and of EarthResourceML in October 2018.

The CGI standards are ubiquitous for geoscience information.

5 Smart cities

5.1 Introduction

This clause considers the overlap between buildings and geospatial information including roads and railways.

NOTE
The ASAM OpenRoad standard is also relevant to "smart cities", but because this standard is concerned with the simulation of vehicle behaviour it is considered in clause 7.

The OGC document "Built environment data standards and their integration an analysis of IFC, CityGML and LandInfra" https://portal.ogc.org/files/?artifact_id=92634 was issued in March 2020.
It has a summary as follows:

> Demand for digital representations of built environments is accelerating and can only be satisfied through greater software interoperability and data integration. The objective of the Integrated Digital Built Environment (IDBE) joint working group is to address this challenge by bringing together experts from the Open Geospatial Consortium and buildingSMART to coordinate the development of the relevant data standards. This document is an output from IDBE in which we describe the state of three of the most prominent built environment standards – CityGML, IFC and LandInfra – and describe some of the problems that hinder their integration; finally, we propose actions points for overcoming these problems.

The document makes proposals as follows:

> The following are proposed as action points for achieving better interoperability and integration:
>
> 1. Articulate clearly a set of illustrative use cases in plain, succinct language that ensures they are digestible by a broad audience, basing them on material in existing technical use case documentation. These use cases should include details of the software applications that are commonly used for integration or working with integrated data, including their input requirements and internal representations.
> 2. Derive and make publicly available a shared vocabulary or definition dictionary from terms that are already used in the standards, or a shared resource for identifying synonyms.
> 3. Author a best practice document that recommends the use of three-dimensional georeferencing that is expressed at an appropriate level of precision, defines the level of confidence or accuracy and states the data provenance.
> 4. Devise a system of common unique identifiers for real-world, physical objects that remain constant and exclusive to the objects either in perpetuity or for as long as the objects exist.
> 5. Agree on a collaborative mechanism for opportunistic harmonisation of conceptual representation at thematic overlaps so far as this does not inhibit enrichment and refinement of the schemas as required within their respective domains

NOTE
The action points are bulleted in the original, but have been numbered here so that they can be referred to.

Comments on the action points are as follows:

1. The creation of a national digital twin is a key use case, which brings together other domain specific use cases.
2. A shared vocabulary is crucial. The vocabulary will have levels, with a top level which generic to all engineering, a level below specific to civil engineering, and levels below that which are partitioned according to discipline and sector. At the very top, the "Core vocabulary for industrial data" developed by ISO TC 184/SC 4 may be useful.
3. Three dimensional georeferencing with predictable levels of accuracy and with provenance is needed because much infrastructure is below ground level.
4. Unique identifiers are needed for real world objects. The "or for as long as the object exists" qualification is unhelpful, because it may be necessary to refer to an object after it has gone.
5. Harmonisation of the schemas may not be the best way to go. Instead there should be:

   - Reference data defining types or classes which can be used with all schemas. This is linked to the development of a shared vocabulary - action point 2.
   - Identifiers of individual real world object which can be used with all schemas - action point 4.
   - A common approach to georeferencing - action point 3.

   The development of an ontology for the national digital twin will provide links between the schemas, because an object in the ontology may have a representation in one or more of the schemas. These representations may be different because of different objectives and scope.

5.2 City Geography ML

http://www.citygml.org/

5.2.1 Defining organization

This standard was developed by the OGC CityGML Standards Working Group.

5.2.2 Objectives and scope

The "Motivation" clause of the document says:

> CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different applications.
>
> It is implemented as an application schema of the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange and encoding issued by the Open Geospatial Consortium (OGC) and the ISO TC 211.

CityGML has modules as follows:

- Appearance;
- Bridge;
- Building;
- CityFurniture;
- CityObjectGroup;
- Generics;
- LandUse;
- Relief;
- Transportation;
- Tunnel;
- Vegetation;
- WaterBody.

CityGML defines Level Of Detail (LOD) as follows:

LOD0: a two and a half dimensional Digital Terrain Model over which an aerial image or a map may be draped. Buildings may be represented in LOD0 by footprint or roof edge polygons.

LOD1: the well-known blocks model comprising prismatic buildings with flat roof structures.

LOD2: a building has differentiated roof structures and thematically differentiated boundary surfaces.

LOD3: denotes architectural models with detailed wall and roof structures potentially including doors and windows.

LOD4: completes a LOD3 model by adding interior structures for buildings. For example, buildings in LOD4 are composed of rooms, interior doors, stairs, and furniture.

In all LODs appearance information such as high-resolution textures can be mapped onto the structures.

5.2.3 Structure of the model

The top of the CityGML model is shown in Figure 11.

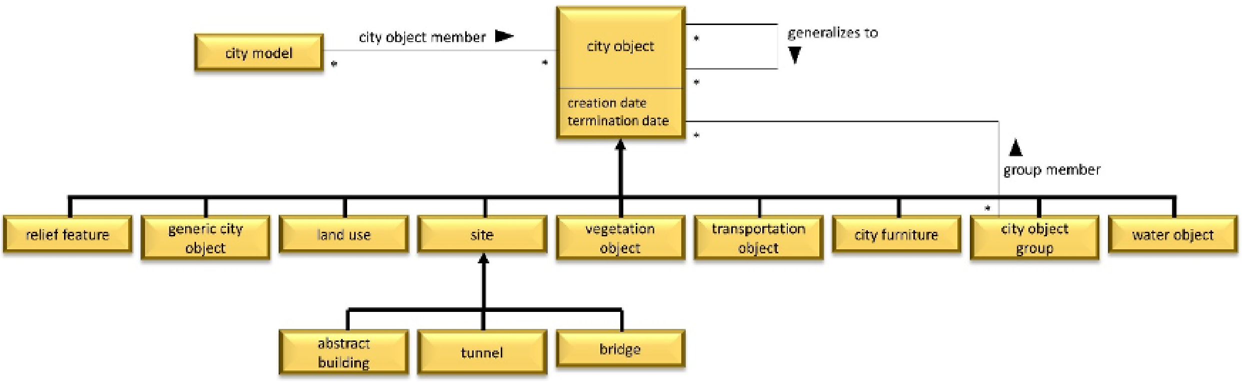

Figure 11 - Top of the CityGML model

Comments on Figure 11:

1. Change is modelled only by a creation and termination of a **city object.**
2. A **city object group** seems to be very similar to a **city model**, with the exception that one **city model** cannot be part of another.
3. The **generalizes to** relationship is not immediately clear. This may be to do with level of detail.

The model for a building in the CityGML model is shown in Figure 12.

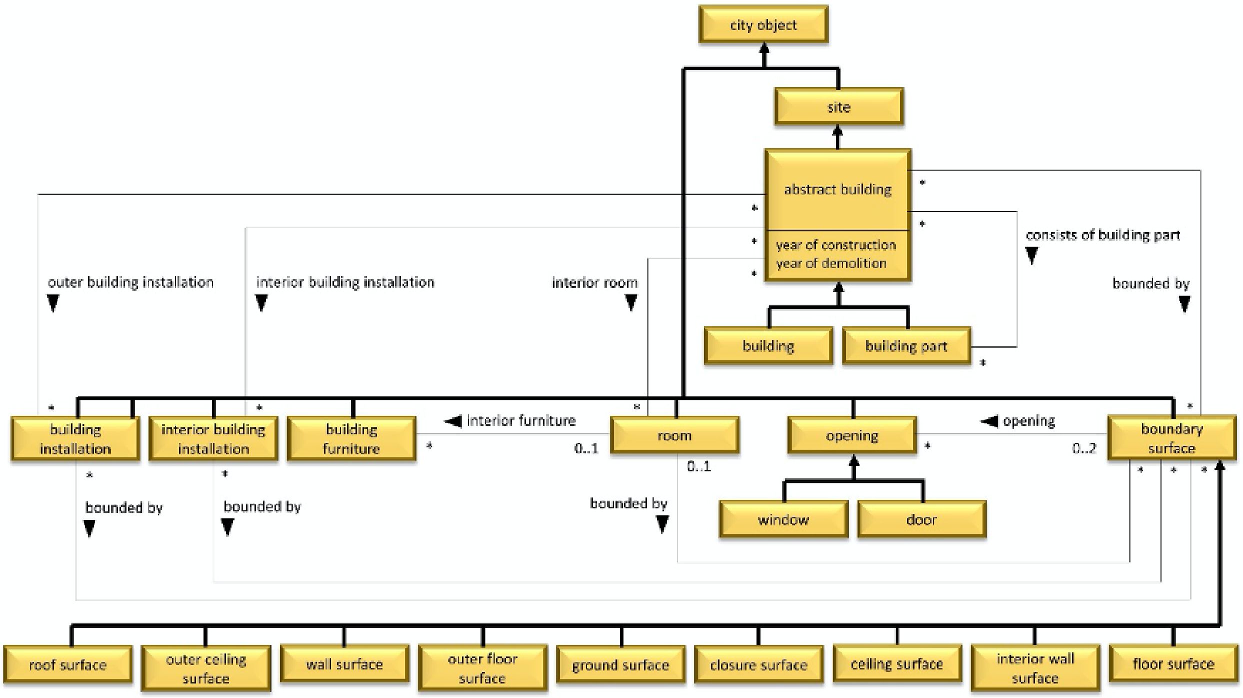

Figure 12 - Building in the CityGML model

Comments on Figure 12:

1. It is not clear how the years of construction and demolition for a **building** relate to the creation and termination dates of a **city object**.
2. The distinction between a **building part** and a **building installation** seems vague.
3. The model is clearly intended principally to support visualisation. Hence a wall is regarded as two surfaces which can be displayed, rather than material between two surfaces which has structural significance.

5.2.4 Documentation

The CityGML model is documented according to the guidelines established for OGC standards, as shown in Figure 7.

5.2.5 Maintenance and usage

The citygml.org website is [in August 2020] "under reconstruction". The OGC website says that version 2 of CityGML was released in 2012, and version 3 is "to be released soon".

The level of industrial usage is unknown.

5.3 Land and Infrastructure Conceptual Model Standard (LandInfra)

http://docs.opengeospatial.org/is/15-111r1/15-111r1.html

5.3.1 Defining organization

This standard was developed by the OGC.

5.3.2 Objectives and scope

The abstract for the model documentation says:

> "This OGC Land and Infrastructure Conceptual Model Standard presents the implementation-independent concepts supporting land and civil engineering infrastructure facilities. Conceptual model subject areas include facilities, projects, alignment, road, rail, survey, land features, land division, and wet infrastructure (storm drainage, wastewater, and water distribution systems). The initial release of this standard includes all of these subject areas except wet infrastructure, which is anticipated to be released as a future extension"

The Terms and definitions clause contains numerous terms and definitions relevant to land and infrastructure, each with a reference to a source.

The UML model has packages as follows:

LandInfra: LandInfra is the core Requirements Class and is the only mandatory Requirements Class. This class contains information about the Land and Infrastructure dataset that can contain information about facilities, land features, land division, documents, survey marks, surveys, sets, and feature associations. LandInfra also contains the definition of types common across other Requirements Classes, such as the Status CodeList.

Facility: Facilities include collections of buildings and civil engineering works and their associated siteworks. The Facilities Requirements Class includes the breakdown of facilities into discipline specific facility parts and introduces the notion of elements which make up these parts. The Facilities Requirements Class only provides general support for facilities themselves, allowing subsequent Requirements Classes to focus on specific types of the parts that make up facilities, such as road and railway. This Requirements Class is optional in order to allow for the condition where all of the LandInfra dataset information is not facility related, such as one containing only survey or land division information.

Project: A project is an activity related to the improvement of a facility, including design and/or construction. This class may be for the creation, modification, or elimination of the entire facility or a part of the facility. The Project Requirements Class includes information about projects and their decomposition into project parts. In order to allow for the condition where none of the LandInfra dataset information is project related, this Requirements Class is optional.

Alignment: An alignment is a positioning element which provides a Linear Referencing System for locating physical elements. The Alignment Requirements Class specifies how an alignment is defined and used.

Road: The Road Requirements Class supports those use cases in which a designer wishes to exchange the output of the design with someone who is likely to use it for purposes other than completing the road design. Consequently, the Road Requirements

Class includes several alternative ways for representing a design such as with 3D RoadElements, 3D StringLines (aka profile views, longitudinal breaklines, long sections), and 3D surfaces and layers, as well as collections of these.

RoadCrossSection: The RoadCrossSection Requirements Class extends the Road Requirements Class by adding the 2D CrossSection alternative way of representing a design, as well as collections of these.

RoadDesign (future work): The RoadDesign Requirements Class will support designer to designer information interchange, such as would exist when a designer other than the original designer takes over the design process to complete the design. It is anticipated that the (future proposed) RoadDesign Requirements Class will cover design information in support of those use cases which involve the exchange of design information between designers. It therefore would include DesignTemplates and SuperelevationEvents.

Railway: The Railway Requirements Class supports those use cases where a designer wishes to exchange the output of the railway design with someone who is likely to use if for purposes other than further design. Consequently, the Railway Requirements Class covers design output such as 3D railway elements and track geometry including superelevation (cant).

Survey: The Survey Requirements Class is the main survey class and provides a framework for information about observations, processes and their results collected during survey work. The content of this package is similar to the OGC Sensor Model Language (SensorML). The main reason not to use the SensorML standard for this topic is to allow the observation and processes structured in a compact way similar to the LandXML format. Due to the high number of classes the Survey Package was split into different parts, Equipment, Observations and SurveyResults.

Equipment: In the Equipment Requirements class all information about the processes and the sensors is available that had been used for the determination of an observation.

Observations: Observations Requirements class is the package containing all information about the raw observations and the measurements observed during survey work. The raw observations are needed to enable later reprocessing or reporting of resulting properties of the observed feature of interest.

Survey Results: The SurveyResults Requirements Class contains the observed property of a feature of interest. Using sampling features from the Observation & Measurements (O&M) standard, the dependencies between the observation acts and the results are realized.

LandFeature: Features of the land, such as naturally occurring water features and vegetation are specified in the LandFeature Requirements Class as land features. Also included are models of the land surface and subsurface layers. Improvements to the land such as the construction of an embankment or the planting of landscape material are considered to be part of Site Facilities in the Facility Requirements Class.

LandDivision: Land can be divided up into land divisions. These can either be public (political, judicial, or executive) or private in nature. The former are administrative divisions and the latter are interests in land. Both of these are specified in the LandDivision Requirements Class, though condominium interests in land are specified in a separate, Condominium Requirements Class.

Condominium: A condominium denotes concurrent ownership of real property that has been divided into private and common portions. The Condominium Requirements Class includes information about condominium units, buildings and scheme.

5.3.3 Structure of the model

The top of the LandInfra model is shown in Figure 13.

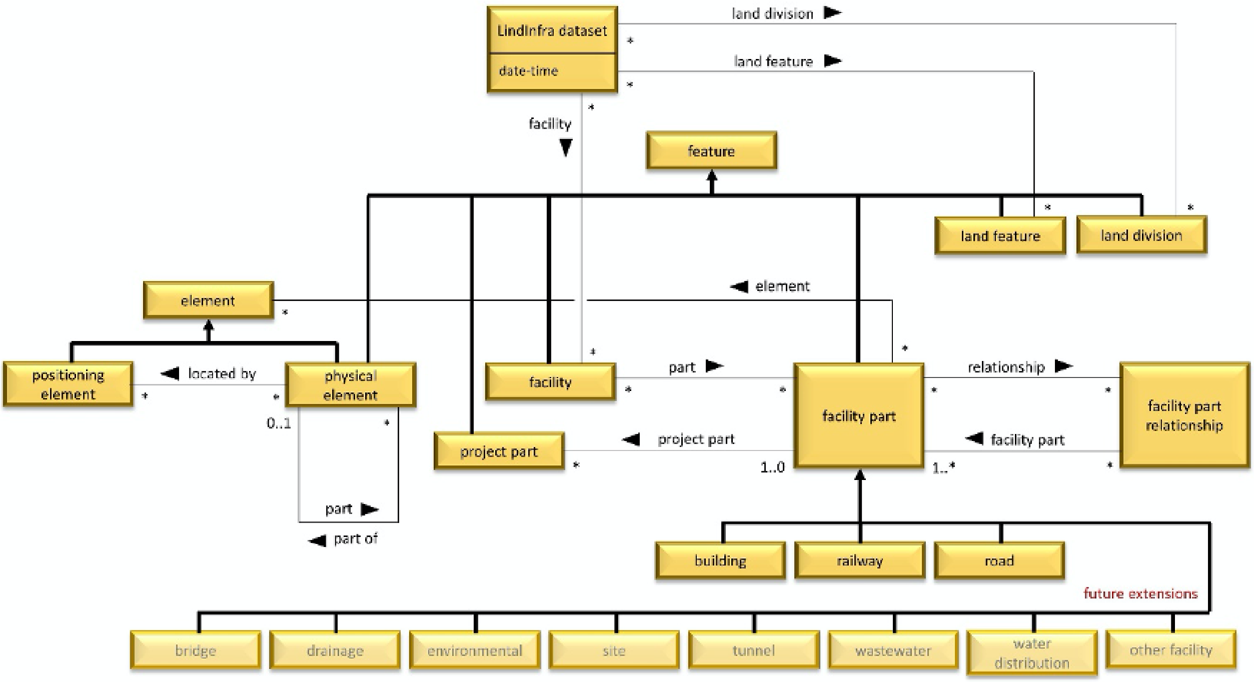

Figure 13 - Top of the LandInfra model

Comments on Figure 13:

1. There is a date-time stamp on a **LandInfra dataset**, but date and time are not recorded elsewhere. The description of the data model says: “date and time that the dataset was created and therefore the point-in-time for which the data is valid”.
2. The description of the model says: “**Facility parts** are roughly equivalent to IfcSpatialElement (e.g., building, road). These provide containment for IfcElements (e.g., windows, curb and gutter).”

3. The description of the model for **physical element** says: "For bSI, IfcElement has subtypes including IfcBuildingElement, IfcElementComponent, and IfcElementAssembly."
4. In the CityGML model, the distinction between a **building part** and a **building installation** seems vague. The same distinction is made here between **facility part** and **physical element**.
5. There are business rules in the model which seem arbitrary. For example, a **facility part** is related to a **project part**, but not a **project** as a whole. Why is a **project** not related either to a **facility** or to a **facility part**?

The LandInfra model extension for a **railway** is shown in Figure 14.

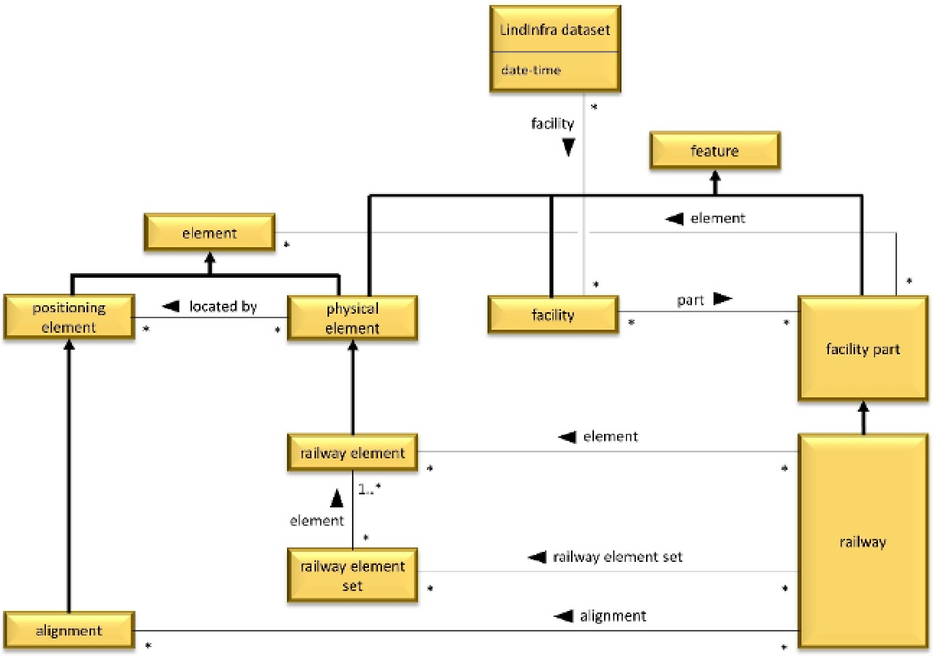

Figure 14 - LandInfra model for railway

Comments on Figure 14:

1. This model extension seems to add little to Figure 13 which is beyond the scope of reference data. The class **railway element set** is structuring which is not specific to **railway**.
2. The type of a **railway element** is specified by reference data. It can be ballast, switch, sleeper, rail, etc.

The LandInfra model has an extension for point cloud observations, along with the image that can be used for colourisation of the surface. This is of interest because point clouds are also within the scope of ISO 10303-42. The model is shown in Figure 15.

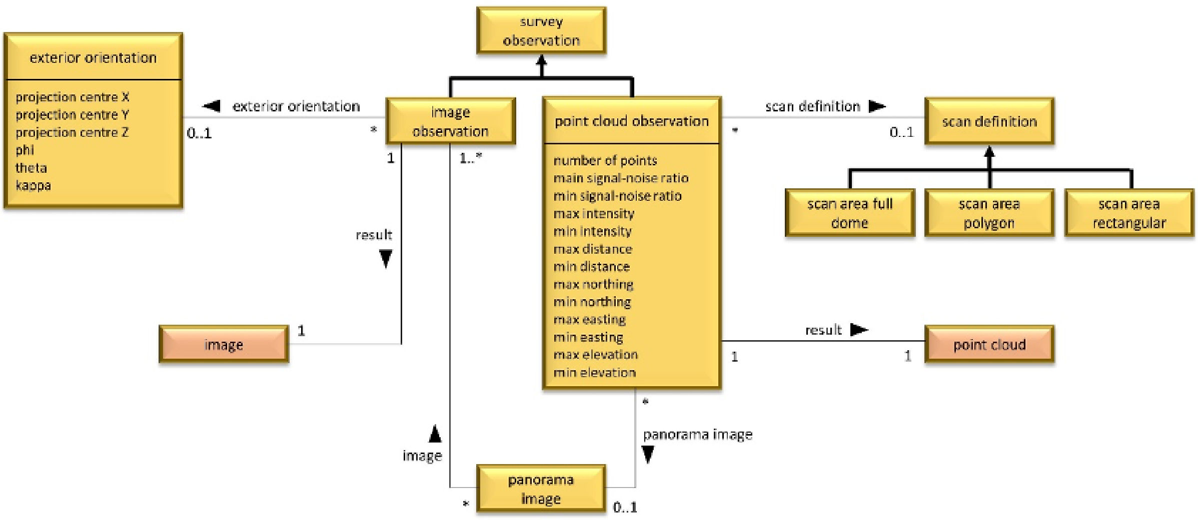

Figure 15 - LandInfra model for point cloud

Comments on Figure 15:

1. The point cloud numeric results are held in an external file with an efficient format for structured data.
2. The **scan definition** and its subclasses are not defined in the LandInfra model.

5.3.4 Documentation

The LandInfra model is documented according to the guidelines established for OGC standards, as shown in Figure 7.

5.3.5 Maintenance and usage

The LandInfra model was published in December 2016.

The level of industrial usage is unknown.

5.4 INSPIRE (Infrastructure for Spatial Information in the European Community)

https://inspire.ec.europa.eu/

5.4.1 Defining organization

Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 established an Infrastructure for Spatial Information in the European Community (INSPIRE)

The Directive came into force on 15 May 2007 and has been implemented in stages, with full implementation required within the EU by 2021.

The INSPIRE website describes the "INSPIRE Coordination Team" as follows:

> The INSPIRE coordination team consists of staff of the European Commission from DG Environment and the Joint Research Centre (JRC) and staff of the European Environmental Agency (EEA). Its role is to coordinate the implementation and further evolution of INSPIRE and to coordinate with other EU policies.
>
> DG Environment acts as an overall legislative and policy co-ordinator for INSPIRE. Given the primary focus of INSPIRE on environmental policy, and based on liaison with the EEA, DG Environment specifies environmental thematic policy requirements for INSPIRE as a framework for the implementation programme. DG Environment is chairing the INSPIRE maintenance and implementation group.
>
> The Joint Research Centre acts as the overall technical co-ordinator of INSPIRE. The JRC ensures the viability and evolution of the technical infrastructure for INSPIRE and guarantees the liaison with the European and international research community. JRC also initiates and monitors the work with international standardisation bodies for the purposes of INSPIRE and is responsible for the technical coordination with other relevant international initiatives. The JRC is chairing the technical sub-group of the INSPIRE maintenance and implementation group (MIG-T).

In 2013, the European Environmental Agency (EEA) increased its involvement in the EU level coordination, by taking on tasks related to monitoring and reporting, and data and service sharing under INSPIRE as part of the SEIS and INSPIRE activities. The EEA also uses its networking experiences through the well-established European Environment Information and Observation Network (Eionet) to strengthen the integration of INSPIRE with other EU level initiatives, including reporting and information dissemination under the environmental acquis.

5.4.2 Objectives and scope

The "About INSPIRE" page on the website says:

> The INSPIRE Directive aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. This European Spatial Data Infrastructure will enable the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policy-making across boundaries.

Article 4 of the directive says:

This Directive shall cover spatial data sets which fulfil the following conditions:

a) they relate to an area where a Member State has and/or exercises jurisdictional rights;

b) they are in electronic format;

c) they are held by or on behalf of any of the following:

   i. a public authority, having been produced or received by a public authority, or being managed or updated by that authority and falling within the scope of its public tasks;

   ii. a third party to whom the network has been made available in accordance with Article 12;

d) they relate to one or more of the themes listed in Annex I, II or III.

[Annex I includes mapping, land registries, hydrology and transport systems; Annex II includes topography, land cover and geology; Annex III includes buildings, soil, land use, agricultural and industrial facilities, minerals, and environmental monitoring and risks.]

The INSPIRE website says the following:

> Technical Guidance documents define how Member States might implement the Implementing Rules described in a Commission Regulation. Technical Guidance documents may include non-binding technical requirements that must be satisfied if a Member State chooses to conform to the Technical Guidance. Implementing this technical guidance will maximise the interoperability of INSPIRE services.

and contains Figure 16.

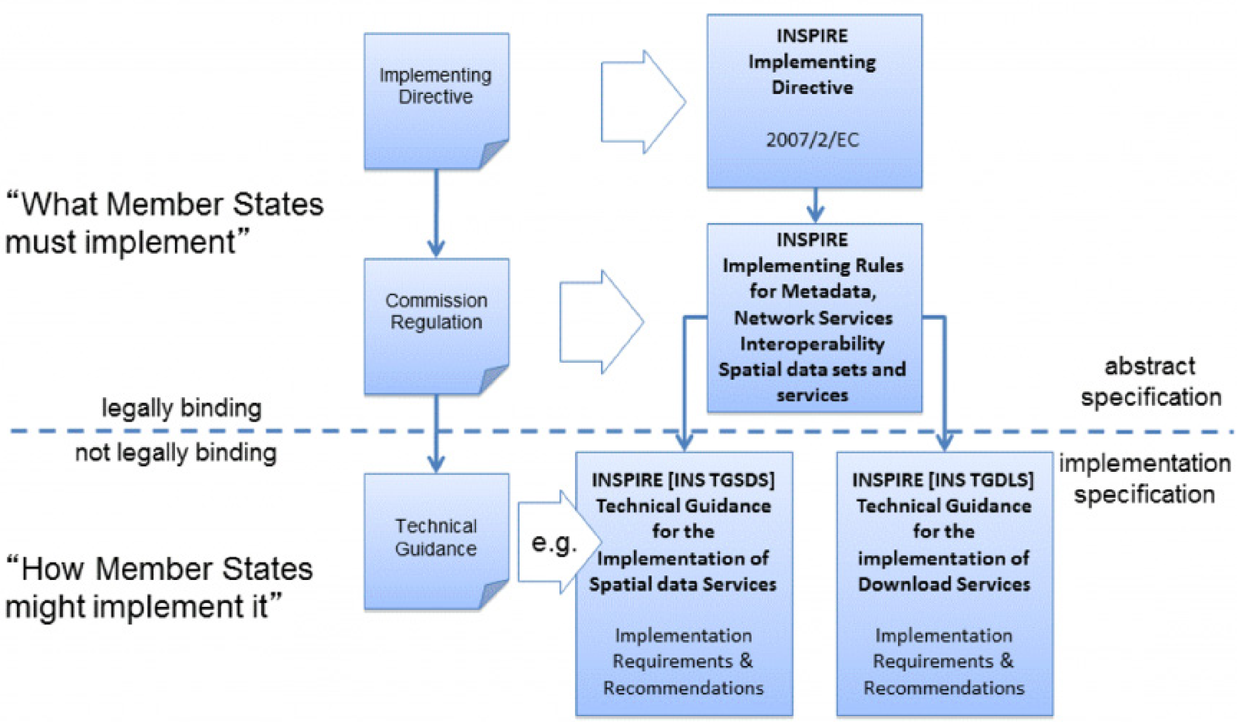

Figure 16 - Relationship between INSPIRE implementing rules and technical guidance

"Data specification - Technical guidelines" are defined for the different "themes" listed in the Annexes to the INSPIRE directive. The data specifications conform to ISO 19131 "Data product specifications". The development approach is governed by the following:

Definition of Annex Themes and Scope which describes in greater detail the spatial data themes defined in the Directive

Generic Conceptual Model which defines base technologies for identification, use of reference data libraries, and spatial information

Methodology for the Development of Data Specifications which describes how to arrive from user requirements to a data specification.

Guidelines for the Encoding of Spatial Data defines how geographic information can be encoded.

> For each data specification, the Interoperability of Spatial Data Sets and Services - General Executive Summary says:
>
> > Even though it does not specify a mandatory encoding rule it [Guidelines for the encoding of spatial data] sets GML (ISO 19136) as the default encoding for INSPIRE.

Guidelines for the use of Observations & Measurements which describes how ISO 19156 "Observations and Measurements" is used within INSPIRE.

The data schemas can be accessed at https://inspire.ec.europa.eu/data-specifications/2892

The GML schemas that provide and implementation can be accessed at https://inspire.ec.europa.eu/documents/gml-application-schemas-april-2010

5.4.3 Structure of the model

5.4.3.1 Transport networks

https://inspire.ec.europa.eu/id/document/tg/tn

Transport Networks is a theme in Annex I of the INSPIRE directive. (It is considered here as an example.)

A railway transport network (say) is implemented by a hierarchy of XML schemas as follows:

railway transport network

common transport elements

network

GML (defined by OGC/ISO 19136)

All the schemas "above" GML are GML application schemas following the rules given in Annex E of ISO 19136.

The principal classes in the hierarchy from GML **abstract feature** to the railway schema are shown in Figure 17.

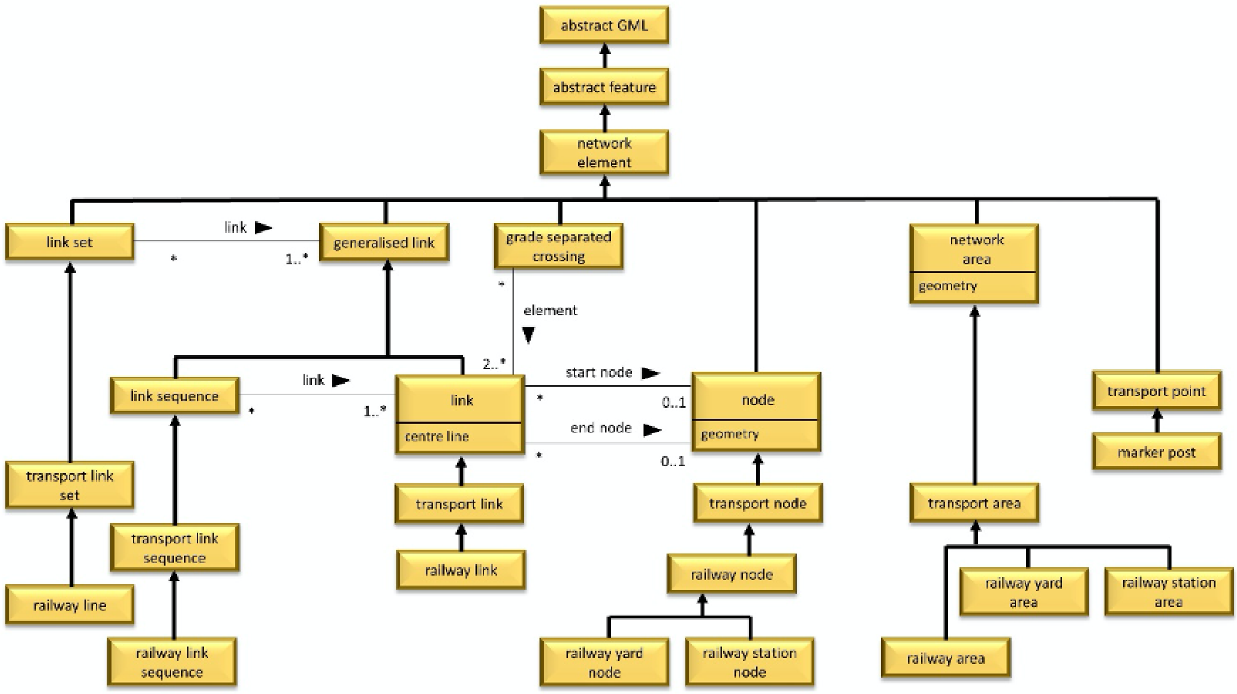

Figure 17 - Railway transport network

5.4.3.2 INSPIRE Feature Concept Dictionary (IFCD)

https://inspire.ec.europa.eu/featureconcept

The INSPIRE Feature Concept Dictionary web page says:

> The INSPIRE Feature Concept Dictionary (IFCD) acts as a common feature concept dictionary for all INSPIRE data specifications. The common feature concept dictionary contains terms and definitions required for specifying thematic spatial object types and it is main role is in particular to support the harmonisation effort and to identify conflicts between the specifications of the spatial object types in the different themes.

372 "concepts" are defined. Mostly these are subclasses of **abstract feature**, but some are properties and some are document types.

5.4.4 Documentation

The INSPIRE models are documented according to the guidelines established for OGC standards, as shown in Figure 7. However there are additional implementation guidelines because compliance is required by EU directive.

5.4.5 Maintenance and usage

The model is actively maintained by the INSPIRE Coordination Team.

Compliance will be mandatory within the EU from 2021.

5.5 iCity Transportation Planning Suite of Ontologies

https://enterpriseintegrationlab.github.io/icity/iCityOntologyReport_1.2.pdf

5.5.1 Defining organization

University of Toronto, Transportation Research Institute

5.5.2 Objectives and scope

The Ontario report is a combination of ontologies taken, or adapted, from different sources to cover a broad scope. The Ontario report does not have a single Foundation Data Model to which the ontologies are fitted. Instead, there is a set of "foundation ontologies", as follows:

- Location
- Activity
- Recurring Event
- Resource
- Parthood
- Units of Measure
- Observations
- Time
- Change

5.5.3 Structure of the model

The location ontology taken from OGC has the entity **Feature**. The change ontology taken from Katsumi and Fox [http://ceur-ws.org/Vol-2043/paper-05.pdf] has the entities **TimeVaryingConcept** and **Manifestation**. The activity ontology taken from PSL has the entities **Activity** and **State**.

There is no diagram that relates these entities, although there are examples showing them used together.

> NOTE
> The 4D approach to change can be related to ISO 15926-2. Hence a TimeVaryingConcept is a whole life individual, and a Manifestation is more or less a temporal part of an individual.

The ontology for recurring events is interesting. This is something important, which is not often addressed. It is partially addressed in ISO 15926-13 for recurring work periods. The ontology in the Ontario report is simplified because it only considers completely regular recurrences. In practice an event may occur every day, except Sundays and bank holidays.

Based on the foundation ontologies are application ontologies, as follows:

- Contact
- Person
- Household
- Organization
- Building
- Vehicle
- Transportation System
- Travel
- Parking
- Public Transit
- Land Use
- Trip
- Trip Costs
- Urban System

In these ontologies, the allocation of relationships to whole life individuals seems arbitrary. A **Household** can have different people at different times that are part of it, but cannot occupy a different **DwellingUnit** at different times. Also a **DwellingUnit** has the same postal address throughout its life.

The Transportation System and related application ontologies are perhaps less complete and detailed than ASAM Open-Drive.

The report states:

> Future work should clarify the distinction between the adoption of the 4-dimensionalist approach to capture change and the ontological commitment to the 4-dimensionalist philosophy. There are many implications in defining a class as a Perdurant (Occurant) or an Endurant (Continuant). Future work should consider alignment of the iCity Ontology to an Upper Ontology such as DOLCE or BFO in order to make these commitments explicit.

5.5.4 Documentation

The report is well written, with UML-like diagrams and good examples. Recasting the examples with respect to the adopted Top Level Ontology will be useful documentation and a measure of progress on the National Digital Twin.

5.5.5 Maintenance and usage

The report is a one-off academic study, and no direct industrial usage is expected.

6 Industrial data

6.1 Introduction

https://committee.iso.org/home/tc184sc4

ISO TC 184/SC 4 develops standards for "industrial data". Two major families of standards have been developed as follows:

- ISO 10303 "Product data representation and exchange" which covers the design and manufacturing of mechanical parts and circuit boards, and the maintenance of equipment through its life;

- ISO 15926 "Integration of life-cycle data for process plants including oil and gas production facilities" which covers the design, construction, operation and maintenance of process plant.

The scope of the standards is illustrated by Figure 18 reproduced from the website.

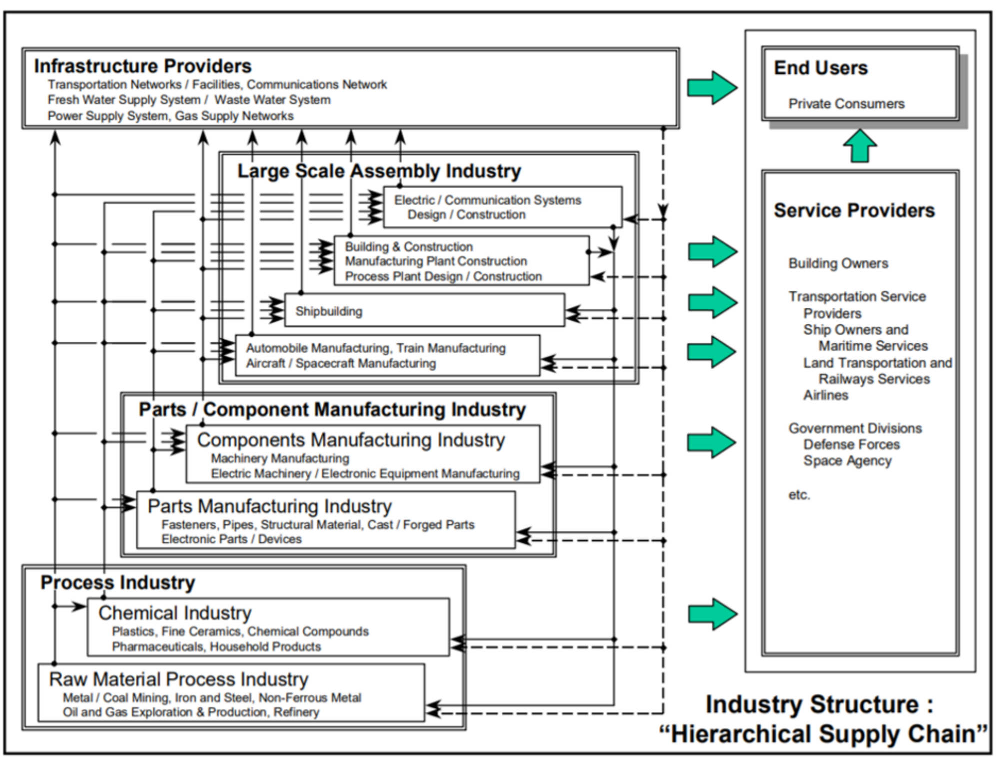

Figure 18 - Scope of ISO TC 184/SC 4 standards

The scope is large and there is a correspondingly complicated architecture to support it. This architecture is not well documented as the OGC architecture or its implementation with INSPIRE.

ISO TC 184/SC 4 currently has 770 published standards (mostly within the ISO 10303 series) and 31 under development. This complexity is unsupportable, and work is going on at present to rationalise the architecture.

Th ISO 15926 series of standards is discussed along with other process industry standards in clause 8 of this document.

6.2 ISO 10303 (STEP) Application Protocols

6.2.1 Defining organization

ISO TC 184/SC 4 "Industrial data" with support from industry organizations such as the Prostep ivip Association and PDES Inc..

6.2.2 Objectives and scope

A STEP Application Protocol (AP) is equivalent to an "application schema" within the OGC environment. There are two STEP APs (or families of APs) with wide industrial use:

ISO 10303-242 "Managed model-based 3D engineering"

> http://www.ap242.org/
>
> This is widely used within the automotive and aerospace industries for storing and exchanging engineering design information.
>
> The companion AP 209 "Multi-disciplinary analysis and design" (http://www.ap209.org/) supports the FEA and CFD analyses carried out during the design process.
>
> These APs are used within the aerospace "Long Term Archiving and Retrieval" (LOTAR) consortium (http://lotar.prostep-ivip.org/).

ISO 10303-239 "Product Life Cycle Support" (PLCS)

> http://www.ap239.org/
>
> This is widely used within the aerospace and defence communities for maintaining equipment and systems through their life.

6.2.3 Structure of the model

At the top of ISO 10303 is a very sparse structure devoted principally to version control shown in Figure 19.

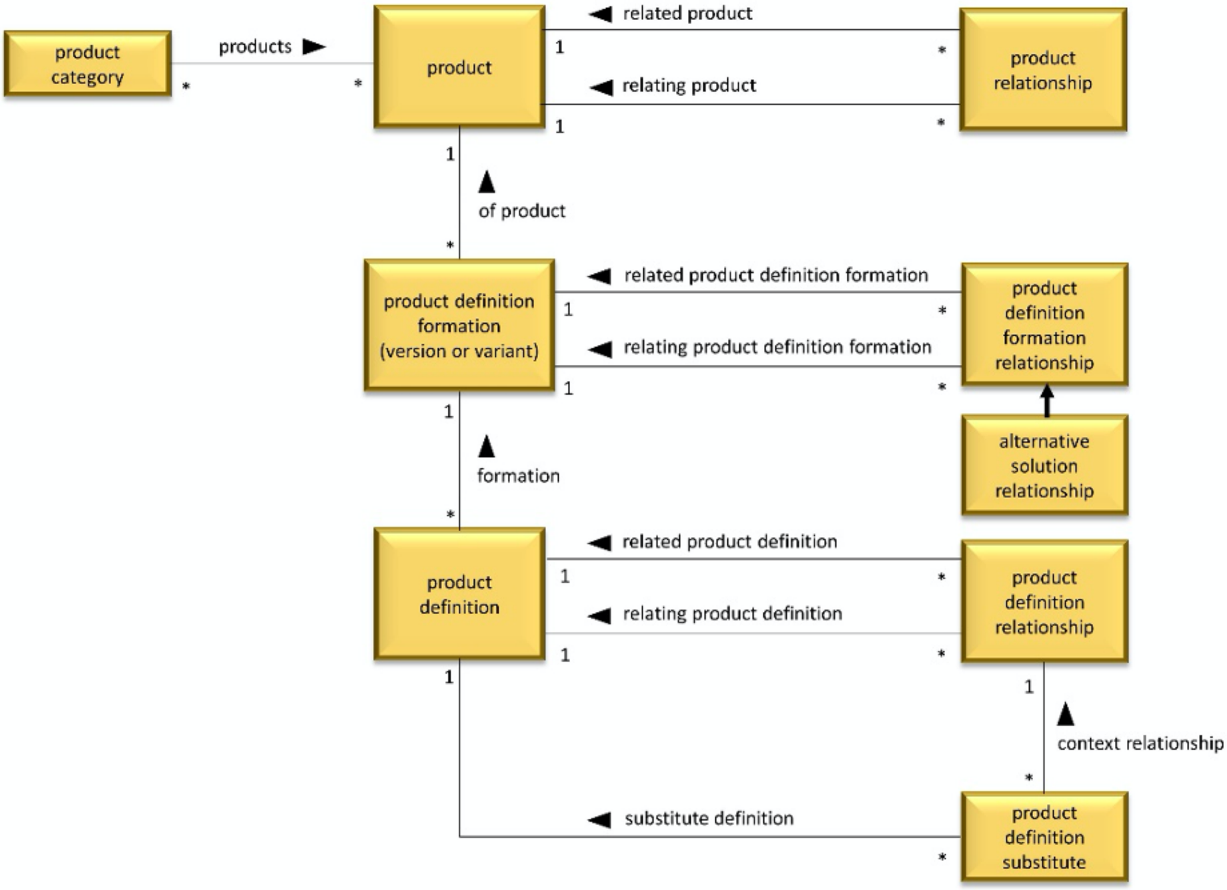

Figure 19 - STEP product structure backbone

The STEP backbone has been extended in the different APs to support the complexity of mechanical assemblies and systems. The class product is also at the top of the IFC data model, which was initially developed within ISO TC 184/SC 4. However the “bells and whistles” for version control and assembly structures were not seen to be relevant to buildings.

6.2.4 Documentation

STEP APs are documented via the STEP Module and Resource Library (SMRL). This is a publishing environment, where the source is XML and HTML views are generated automatically.

STEP is complicated, and therefore is difficult for a domain expert to understand, in spite of the sophistication of the publishing environment.

6.2.5 Maintenance and usage

The STEP APs are actively maintained. The latest [in August 2020] revision of AP 242 was published in April 2020.

The STEP APs are widely used in the automotive and aerospace industries, and in military lifecycle support.

6.3 Ontology for geometry and topology

6.3.1 Defining organization

ISO TC 184/SC 4/WG 12/T 1 "Industrial data - data modelling - geometry and topology"

6.3.2 Objectives and scope

At the heart of STEP is the model for geometry and topology - ISO 10303-42. STEP and the OGC standards are similar in this respect. Within OGC, a **feature** is linked to points, curves and surfaces on the surface of the Earth. In STEP, a **product** is linked to points, curves, surfaces and solids within a 3D CAD space.

The STEP geometry and topology model precedes those of the building IFCs and OGC, and both appear to have been based upon it initially. However, the models have diverged to support different requirements.

ISO TC 184/SC 4/WG 12/T 1, which is responsible for STEP geometry and topology, is carrying out a feasibility study on an ontology for geometry and topology which can bring the different geometry and topology models back together. The team also includes experts on the more modern geometry standards which have been developed to support visualisation, such as Siemens JT (https://www.plm.automation.siemens.com/global/en/products/plm-components/jt.html).

6.3.3 Structure of the model

The team will deliver its report to the November 2020 meeting of ISO TC 184/SC 4. No outline model has yet been published, but the work is included here because of its long-term importance for the National Digital Twin.

6.3.4 Documentation

Initial work has been documented in UML and OWL.

6.3.5 Maintenance and usage

It is intended that the ontology will be maintained alongside ISO 10303-42.

6.4 Core Industrial data set of terms

6.4.1 Defining organization

ISO TC 184/SC 4/AHG 1 "Industrial data - vocabulary"

6.4.2 Objectives and scope

Different teams with ISO TC 184/SC 4 extend their top-level ontologies or data models with domain-specific reference data. A good example of this is the classes and properties defined within ISO/TS 15926-4 (see clause 8.5). It is recognised that domain specific reference data libraries can be relevant to more than one top level ontology or data model. For example, aeroplanes, ships motor cars and process plants all contain pipes, pumps and valves in mechanical systems, and motors and switches in electrical systems.

A difficulty is that the developers of a reference data library often place the classes and properties that they define with respect to a particular top ontology or data model, and thereby limit the use of the reference data library. A solution to this is the creation of an intermediate level - a core vocabulary which consists of precise and understandable industrial data terms which can:

- be specialised for different domains by teams of domain experts, who do not need to be concerned with the top ontologies or data models;
- be mapped to different top ontologies or data models.

This enables the reference data can be used with different top ontologies or data models in different applications. The approach is illustrated in Figure 20.

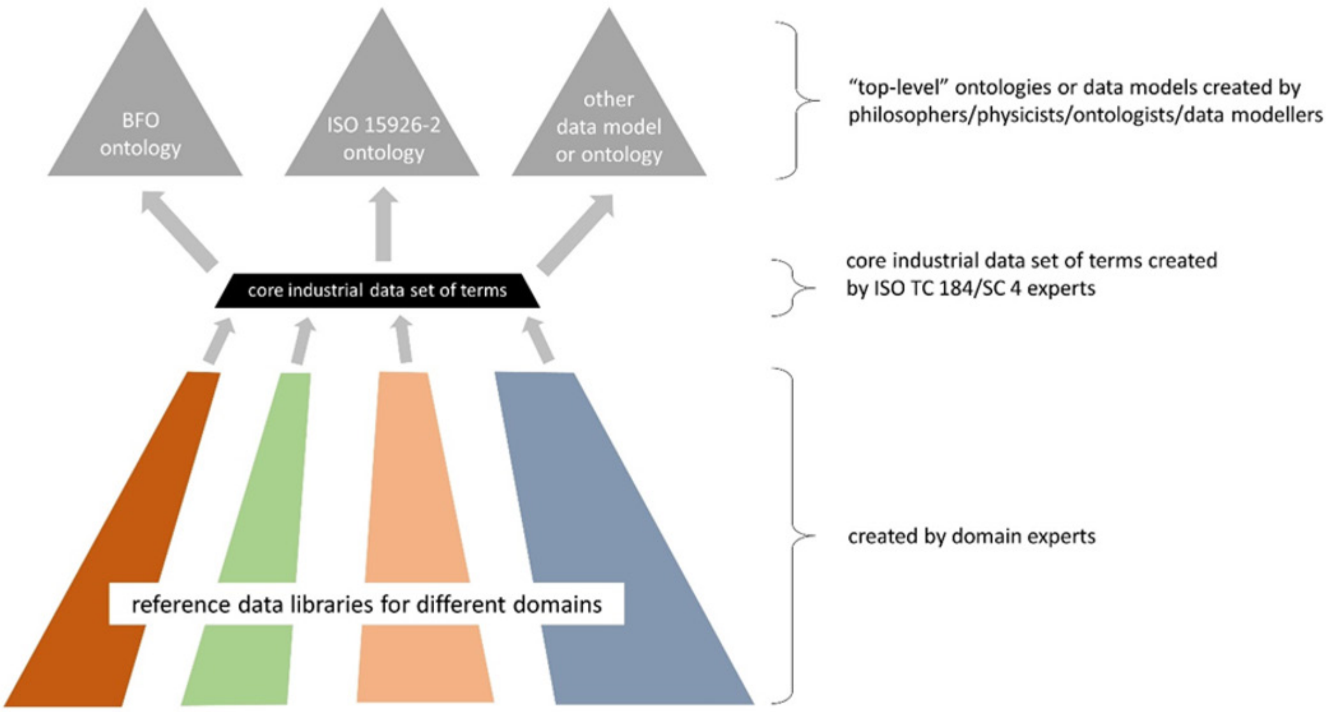

Figure 20 - Role of the Core Industrial data set of terms

The core vocabulary group within ISO TC 184/SC 4 contains representatives from the teams developing the different standards within SC 4, and also from the ISO/IEC Common Data Dictionary (CDD - https://cdd.iec.ch/). The core vocabulary is seen as analogous to the Dublin Core for document metadata, and consists of about 80 terms.

6.4.3 Structure of the model

The team will deliver its report to the November 2020 meeting of ISO TC 184/SC 4. No outline model has yet been published, but the work is included here because of its long-term importance for the National Digital Twin.

6.4.4 Documentation

Initial work has been documented as a "paper" document. Representations in EXCEL and SKOS are planned.

6.4.5 Maintenance and usage

It is intended that the vocabulary will be maintained as an ISO standard.

6.5 Modeling and Simulation information in a collaborative Systems Engineering Context (MoSSEC)

http://www.mossec.org/

6.5.1 Defining organization

ISO TC 184/SC 4 “Industrial data” with support from the industry MoSSEC consortium, which includes the manufacturers Airbus, Collins Aerospace, Boeing, and BAE Systems, and the software suppliers Eurostep, Dassault Systèmes, MSC Software, and Siemens.

The Modeling and Simulation information in a collaborative Systems Engineering Context (MoSSEC) project began outside ISO, but its deliverable is now a STEP AP (ISO 10303-243).

6.5.2 Objectives and scope

The overview of the MoSSEC project says:

> The MoSSEC standard enables a proper exchange and sharing of modelling and simulation data with traceability to its systems engineering & PDM context.
>
> This collaborative context data can be summarised as “who”, “what”, “where”, “when”, “how”, “why”.

6.5.3 Structure of the model

MoSSEC adds the object **study** to the STEP framework. This is an activity which investigates a “concept” and produces **study reports**, which are **documents**.

6.5.4 Documentation

The MoSSEC AP will be documented within the SMRL environment.

6.5.5 Maintenance and usage

ISO 10303-243 was approved as a Committee Draft in June 2018, and is intended [in August 2020] to be published in 2020.

7 Metrology and simulation

7.1 Quality Information Framework (QIF)

https://qifstandards.org

7.1.1 Defining organization

Digital Metrology Standards Consortium (DMSC) defines the Quality Information Framework (QIF) standard. The QIF has been adopted as an ANSI standard

7.1.2 Objectives and scope

The "what is QIF?" webpage says:

> QIF (Quality Information Framework) is an American National Standard supporting Digital Thread concepts in engineering applications ranging from product design through manufacturing to quality inspection. Based on XML, the QIF standard contains a Library of XML Schema ensuring both data integrity and data interoperability in Model Based Enterprise implementation.

The QIF covers quality information including measurement plans, results, part geometry and product manufacturing information, measurement templates, resources, and statistical analysis. The scope of QIF is shown in Figure 21.

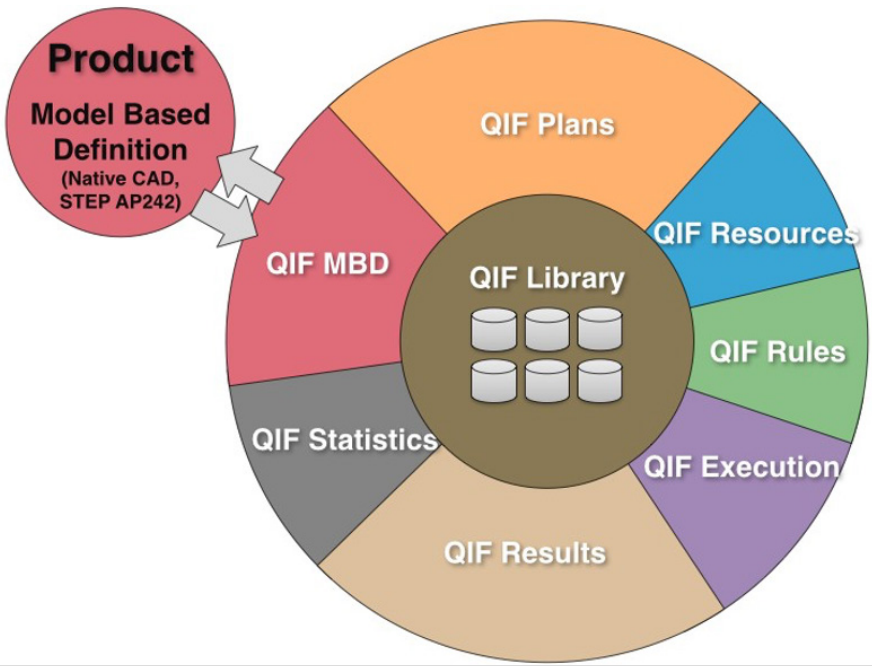

Figure 21 - Scope of the QIF

7.1.3 Structure of the model

A simplification of the top structure is shown in Figure 22.

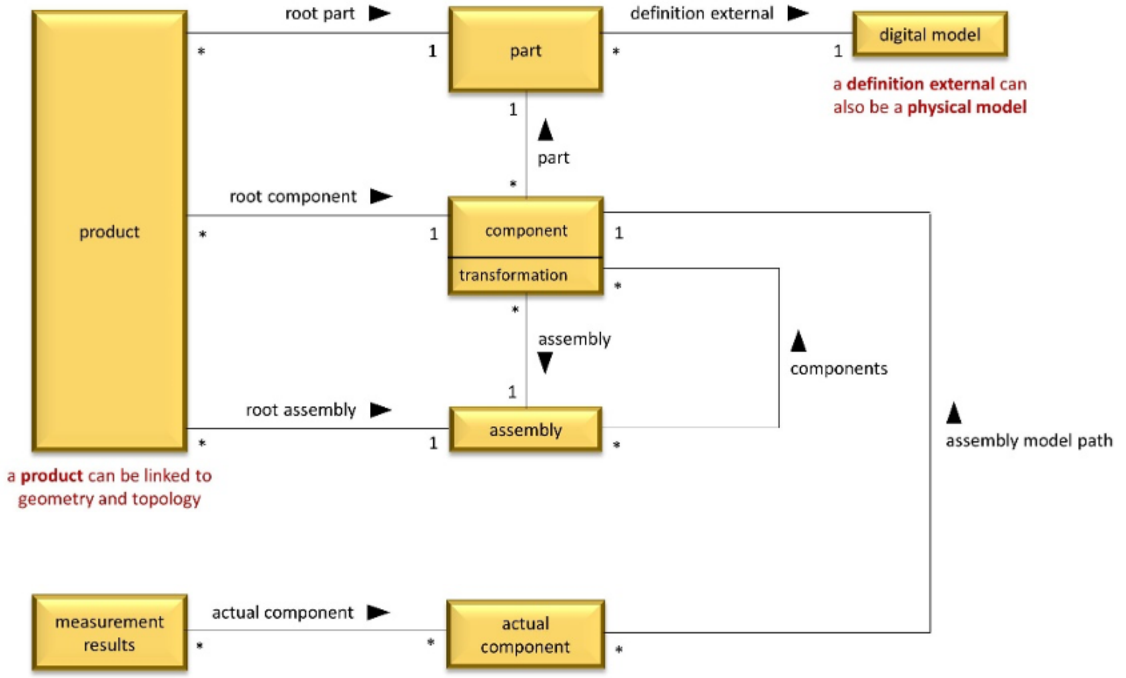

Figure 22 - The top of the QIF model

Comments on Figure 22:

1. The QIF approach to the definition of an assembly is similar to that of ISO 10303, but differs in detail and uses different terminology.
2. The documentation of the QIF envisages that a definition of a part can be provided by a **digital model** according to ISO 10303-242. It is curious that the definition of an assembly is not provided in the same way.
3. ISO 10303-239 also considers both actual products and product designs. The way in which the actual and design are linked is not the same in the QIF.

The QIF contains XML schemas for geometry and topology. These are similar to the EXPRESS schemas in ISO 10303-42, but different in detail.

7.1.4 Documentation

The QIF standard exists as an explanatory 563 page PDF document, and a set of XML schemas. No visualisation of the data architecture in UML or similar is provided.

Both ISO 10303-242 and the QIF are large and complicated. Working the two together must be a challenge for IT specialists.

7.1.5 Maintenance and usage

The QIF is actively maintained by a consortium of industrial users supported by NIST. The latest [in August 2020] edition of the QIF was published in December 2018.

Use of the QIF for metrology data is widespread.

7.2 OpenDrive

https://www.asam.net/standards/detail/opendrive/

7.2.1 Defining organization

OpenDrive is defined by ASAM (Association for Standardization of Automation and Measuring Systems) e.V., which is a non-profit organization that promotes standardization for tool chains in automotive development and testing.

ASAM e.V. is based in Germany.

7.2.2 Objectives and scope

The introduction to the OpenDrive standard says:

> ASAM OpenDRIVE defines a file format for the precise analytical description of road networks. Unlike other file formats typically used for navigation systems, ASAM Open-DRIVE's main use is in the area of simulation applications, which require exact road geometry descriptions, including surface properties, markings, signposting and logical properties such as lane types and directions. Road data may be manually created from road network editors, conversion of map data, or originate from converted scans of real-world roads.

The OpenDrive standard also covers railway networks. OpenDrive is similar to many other data models that are created for analysis applications, however it has been included here because it is closely related to infrastructure description.

7.2.3 Structure of the model

The OpenDrive standard supports road geometry, as do the GIS applications, but with additional details about lane camber. The standard supports information about road surfaces to support vehicle dynamics simulation.

An interesting feature of the OpenDrive model is that it can hold detailed information about a road junction, as shown in Figure 23.

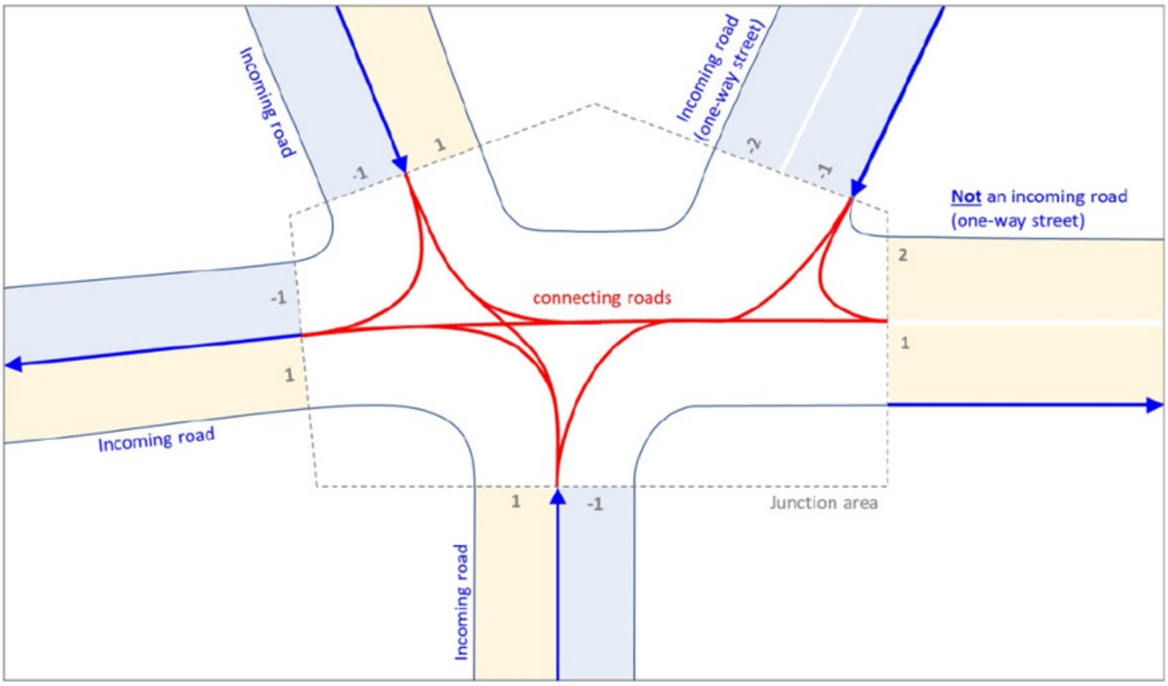

Figure 23 - OpenDrive paths through a road junction

Comments on Figure 23:

1. The “connecting roads” are the allowed paths through the junction.
2. Additional details can be provided about lanes and how they are marked out and connect, about tram lines, and about junction controls.

7.2.4 Documentation

The OpenDrive standard is well documented, with explanations using UML and implementations using XML schema.

7.2.5 Maintenance and usage

The OpenDrive standard is actively maintained. The latest [in August 2020] edition of OpenDrive was published in March 2020.

Use of the OpenDrive for vehicle dynamics simulation is widespread.

7.3 Intelligent transport systems - Terminology

https://github.com/ISO-TC204/iso14812

7.3.1 Defining organization

ISO/WD-TS 14812 "Intelligent transport systems - Terminology" is being defined by ISO TC 204 "Intelligent transport systems".

7.3.2 Objectives and scope

No objectives or scope have been published by ISO, but the current deliverable is more than merely a terminology. Instead it is a UML model that has classes with natural language definitions. Where possible, the definitions are taken from other ISO standards.

There is detailed modelling of:

- vehicle automation, and Driver Automation Systems (ADS);
- roadways, road networks and junctions;

There is also a high-level model of Intelligent Transport Systems (ITS).

7.3.3 Structure of the model

The detailed modelling is represented in UML, and is easy to understand. As an example the models for vehicle component and vehicle automation are shown in Figure 24 and Figure 25.

The top-level model for intelligent transport systems distinguishes between functional and physical views. The model contains the entities physical object, functional object and process. However the model is not easy to relate to the process industry system models in ISO 15926, MIMOSA CCOM or EPRI CIM. Neither is the terminology of ISO/IEC/IEEE 15288 "System life cycle processes" used.

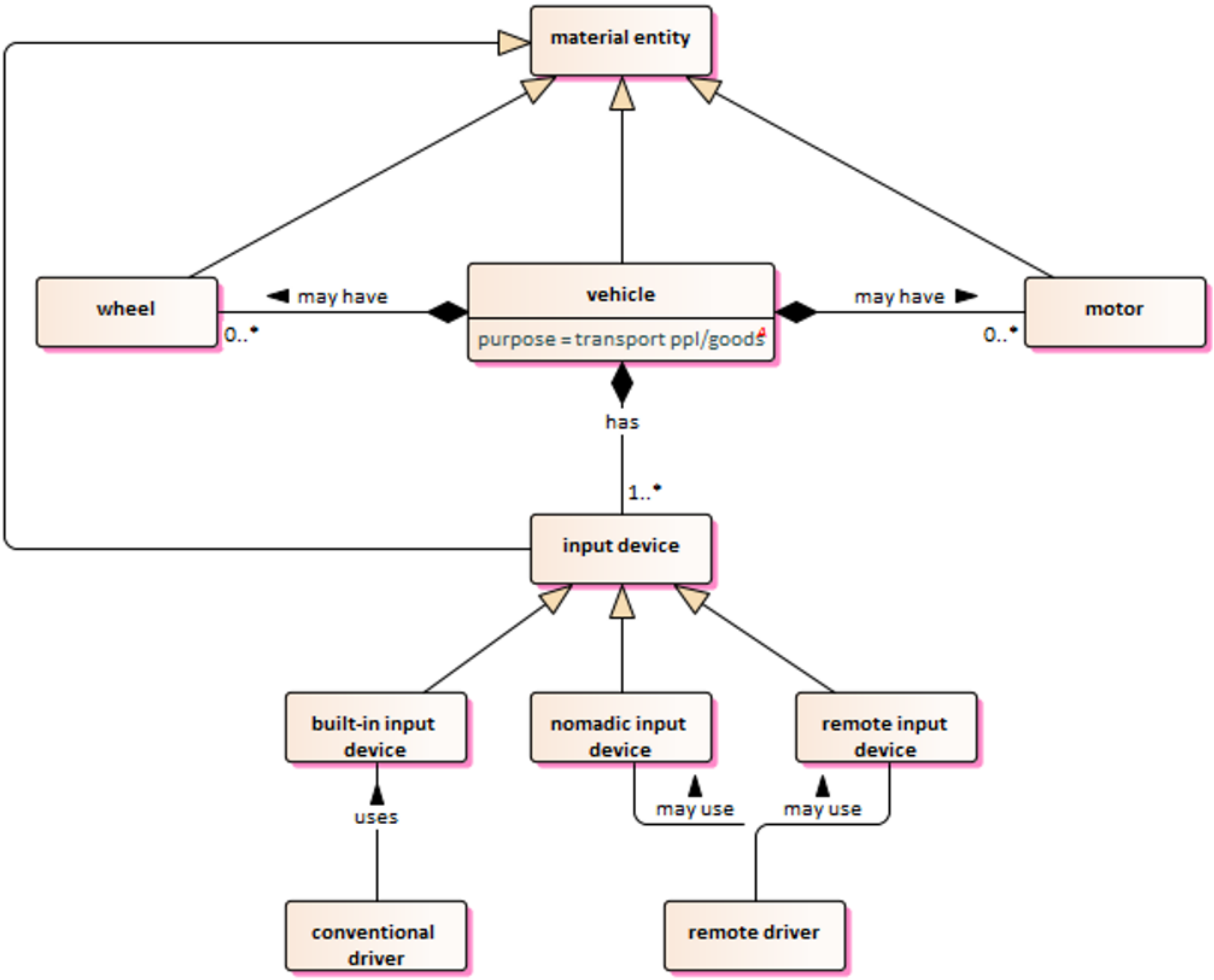

Figure 24 - ISO 14812 model for vehicle components

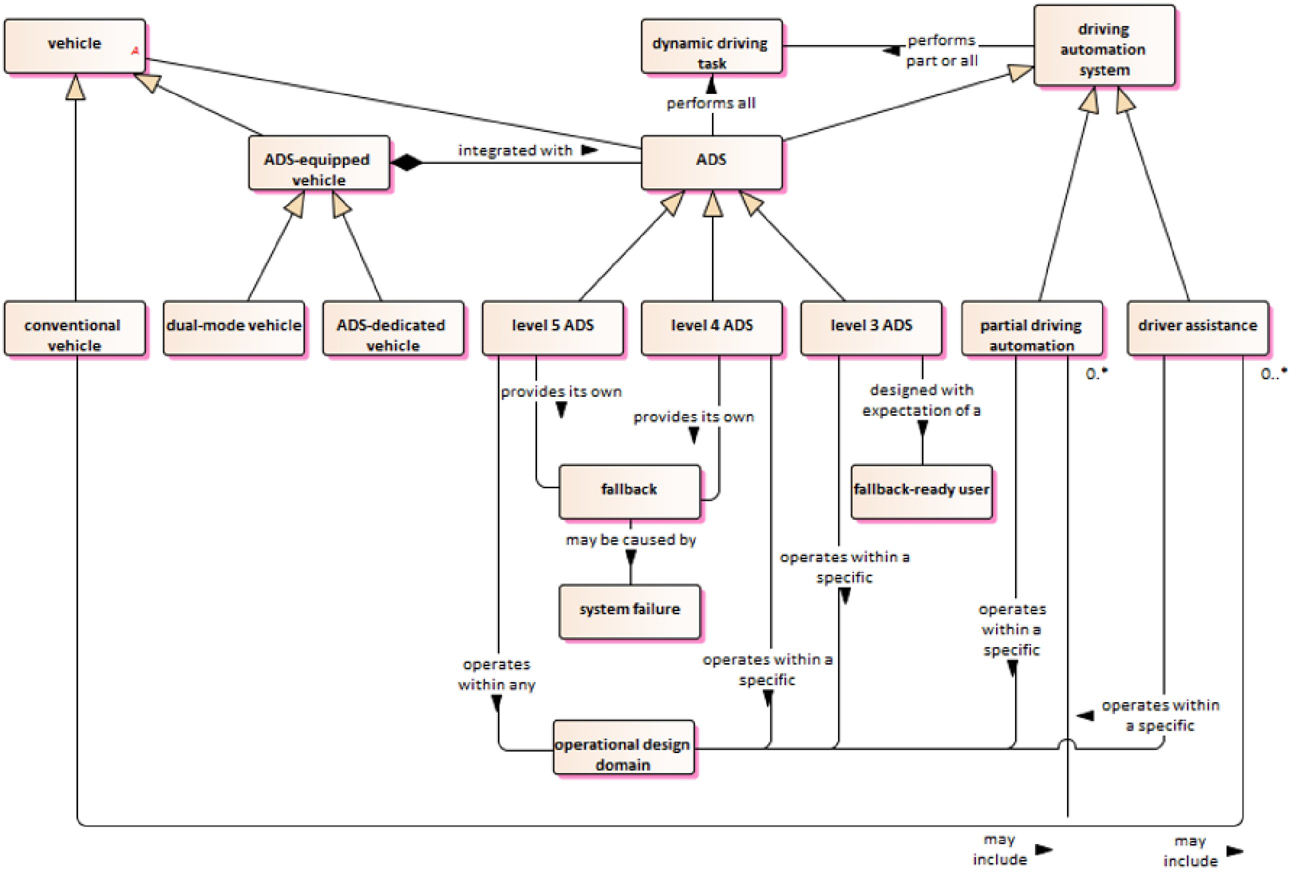

Figure 25 - ISO 14812 model for vehicle automation

7.3.4 Documentation

The UML model was generated using the Enterprise Architect software, and is available as an Enterprise Architect native file or as an HTML view. The HTML view is adequate for review.

7.3.5 Maintenance and usage

The latest [in August 2020] version of the UML model is April 2020.

The standard is still under development, so there is no industrial usage.

7.4 ISO/IEC JTC 1 AHG 11 “Ad Hoc Group on the Digital Twin”

7.4.1 Defining organization

ISO/IEC JTC 1 AHG 11 “Ad Hoc Group on the Digital Twin” was formed in 2018 and produced the report “Data Architecture of the Digital Twin” (document ISO/IEC JTC 1 AHG 11 N0007) in July 2019.

7.4.2 Objectives and scope

The Scope clause of the report says:

> This Ad Hoc Group is charged with:
>
> - Defining the Digital Twin in order to establish common terminology across ISO/TC 184
> - Drafting a proposed architecture concept of the Digital Twin
> - Assessing the ISO/TC 184 portfolio of standards against the data architecture
> - Propose an organizational structure to carry the work forward (Task Force, Working Group, etc.)
> - Making recommendations to TC 184 based on the group’s work.

The report does this, and notes the role of the ISO 23247 series of standards being developed under ISO TC 184/SC 4.

7.4.3 Structure of the model

N/A

7.4.4 Documentation

N/A

7.4.5 Maintenance and usage

N/A

7.5 ISO/TC 184/WG 15 “Digital manufacturing”

7.5.1 Defining organization

ISO/TC 184/WG 15 “Digital manufacturing”

7.5.2 Objectives and scope

This working group has four standards under development, which are currently [in August 2020] at the DIS (Draft International Standard) stage:

ISO 23247-1 “Digital Twin framework for manufacturing — Overview and general principles”

ISO 23247-2 “Digital Twin framework for manufacturing — Reference architecture”

ISO 23247-3 “Digital Twin framework for manufacturing — Digital representation of manufacturing elements”

ISO 23247-4 “Digital Twin framework for manufacturing — Information Exchange”

These standards are at a high level and do not contain data models or reference data libraries.

7.5.3 Structure of the model

N/A

7.5.4 Documentation

N/A

7.5.5 Maintenance and usage

N/A

7.6 Digital twin consortium

https://www.digitaltwinconsortium.org

7.6.1 Defining organization

The website says:

> Digital Twin Consortium is The Authority in Digital Twin. It coalesces industry, government and academia to drive consistency in vocabulary, architecture, security and interoperability of digital twin technology. It advances the use of digital twin technology from aerospace to natural resources.
>
> Digital Twin Consortium is a global ecosystem of users who are accelerating the digital twin market and demonstrating the value of digital twin technology. Members set de facto technical guidelines and taxonomies, publish reference frameworks, develop requirements for new standards and share use cases to maximize the benefits of digital twins.
>
> Digital Twin Consortium is open to any business, organization or entity with an interest in digital twins. Its global membership is committed to using digital twins throughout their operations and supply chains and capturing best practices and standards requirements for themselves and their clients.

The consortium has the same address as OMG.

8 Process plant and electrical utility data

8.1 Introduction

A key feature of the process plant and electrical utility data models is the distinction between:

- a system element, which is a role played by a piece of equipment within a system and which can have many different pieces of equipment installed to play the role during its life; and
- a piece of equipment which can be installed as many different system elements during its life.

The industrial data models, described in clause 5.4.4, recognise that the same type of component can be in different places within an assembly design. This is referred to in ISO 10303 as an "occurrence" of a component within a design.

However, the process plant and electrical utility data models go further and recognised during the life of an actual system components can be replaced, and that it is necessary to record the history of these replacements. The history provides two audit trail views:

- for a system element - what equipment has been installed there over time;
- for a piece of equipment - for what system elements has it been installed over time.

Although the engineering requirement is straightforward, different terminologies have been developed to describe it. It has become almost traditional to illustrate the terminologies using the vehicle - wheel example shown in Figure 26.

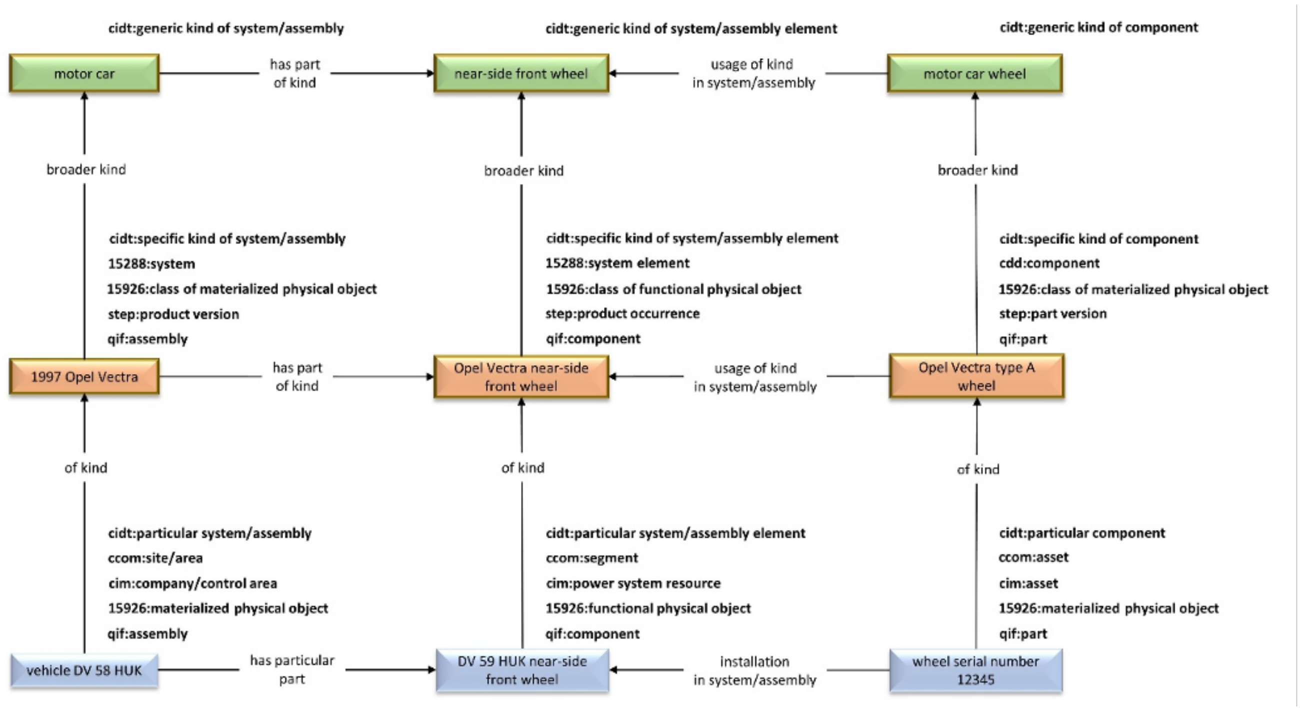

Figure 26 - Vehicle - wheel example

Comments on Figure 26:

1. In this example, a wheel is an "asset" which can be installed for a period of time to play a role within the "system" that is the vehicle.
2. The terms are prefixed by their source as follows:

   cidt: Core Industrial Data set of Terms (see clause 6.4)
   15288: ISO/IEC 15288 "System life cycle processes"
   cdd: ISO/IEC Common Data Dictionary (see clause 9.3)
   step: ISO 10303 "Product data representation and exchange" (see clause 6.2)
   qif: Quality Information Framework (see clause 7)
   ccom: MIMOSA CCOM (see clause 8.2)
   cim: EPRI CIM (see clause 8.3)
   15925: ISO 15926 "Integration of life-cycle data for process plants" (see clause 6.2)

3. Neither MIMOSA CCOM nor EPRI CIM are intended as data models for vehicle maintenance, but nonetheless the example serves to illustrate the terminology.
4. A vehicle is an assembly as well as a system - many assemblies are both. An electrical transmission system is not usually regarded as an assembly, because the position and orientation of the system elements is largely unimportant. A substation could be regarded as an assembly, but a transformer is certainly an assembly.

8.2 MIMOSA Common Concept Object Model (CCOM)

https://www.mimosa.org/mimosa-ccom/

8.2.1 Defining organization

8.2.1.1 MIMOSA

MIMOSA (formerly Machinery Information Management Open System Alliance) is a trade association that defines open standards for physical asset management.

MIMOSA is involved in the development of ISO 18101 "Automation systems and integration - Oil and gas interoperability" (see https://www.iso.org/standard/68521.html) within ISO TC 184/WG 6. The standard gives guidelines for the collaborative use of different standards. The guidelines have been validated using the Oil and Gas Interoperability (OGI) pilot.

Standards used in the OGI pilot include:

- ANSI/ISA 88 (Batch control) and ANSI/ISA 95 (Enterprise-control system integration)
- MIMOSA CCOM (see clause 8.2)
- OPC Unified Architecture (UA)
- OAGi Business Object Document (BOD) message architecture
- ISO 15926-4 (see clause 8.4)

Only the MIMOSA CCOM and ISO 15926-4 standards are relevant to this report. The other standards are concerned with the data communications and processing.

8.2.1.2 Open O&M

http://www.openoandm.org/

MIMOSA is the host organisation for the Open Operations and Maintenance Initiative, which is concerned with real time and near real time SCADA data. The participating organizations are:

- ISA (International Society of Automation) https://www.isa.org/
- MESA (Manufacturing Enterprise Solutions Association) http://www.mesa.org/
- MIMOSA
- OAGi (Open Applications Group Inc.) https://oagi.org/
- OPC (Open Platform Communications) Foundation https://opcfoundation.org/

8.2.2 Objectives and scope

The introduction to MIMOSA CCOM says:

> MIMOSA CCOM serves as an information model for the exchange of asset information. Its core mission is to facilitate standards-based interoperability between systems: providing an XML model to allow systems to electronically exchange data.

CCOM itself is a single XML schema. Packaged with CCOM are message schemas which support flows of information into and out of a CCOM repository using the OAGi BOD architecture.

8.2.3 Structure of the model

The top level of CCOM is shown in Figure 27.

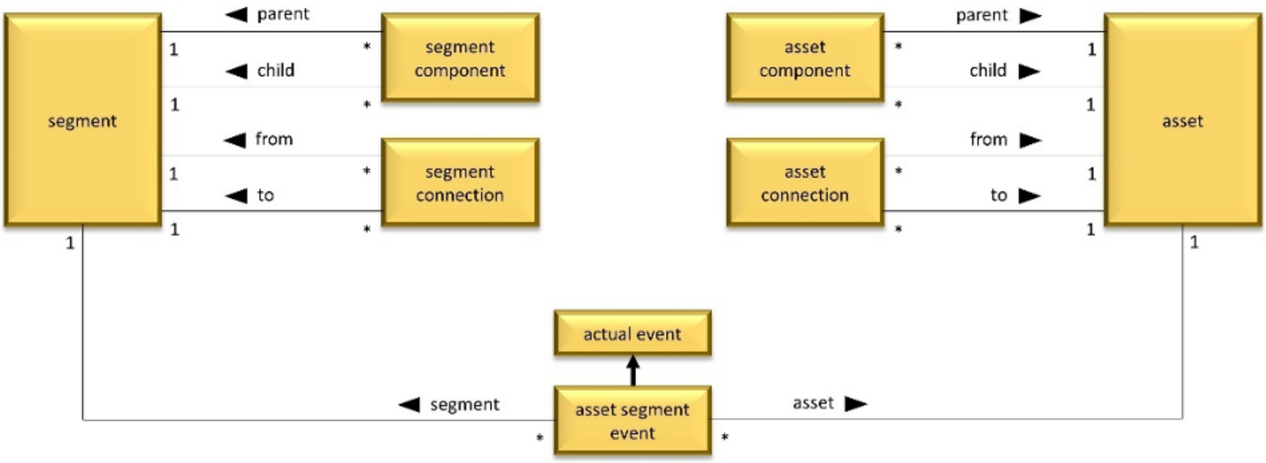

Figure 27 - MIMOSA CCOM top level

Comments on Figure 27:

1. A **segment** is a part of a process plant that performs a function. In the Core Industrial Data Set of Terms and in ISO/IEC 15288 "System life cycle processes" it is called a "system element". In ISO 15926-2 it is called a "functional physical object". In the process industry it is often called a "tagged item".
2. An **asset** is a moveable material object that can be installed within a process plant as a **segment**. In the Core Industrial Data Set of Terms it is called a "component". In ISO 15926-2 it is called a "materialized physical object".
3. An **asset segment event** is the installation of an **asset** as a **segment**. This object is time stamped so that the history of where an **asset** has been used or of what has been installed as a **segment** can be obtained from the stored data.
4. An **asset owner event** is similar in structure to an **asset segment event**. This enables a history of the ownership of an **asset** to be obtained from the stored data.

The MIMOSA CCOM model is important because it recognises that the system elements within a process plant change over time. Building and geographic data models are largely static.

8.2.4 Documentation

MIMOSA CCOM is a well-documented XML schema.

8.2.5 Maintenance and usage

MIMOSA-CCOM is actively maintained. The latest revision [in August 2020] was in March 2020.

MIMOSA-CCOM has wide industrial use in operations and maintenance systems.

8.3 EPRI Common Information Model (CIM)

8.3.1 Defining organization

The CIM is maintained by IEC TC 57/WG 13 and published as:

IEC 61970-301 "Energy management system application program interface (EMS-API) - Common information model (CIM) base";

IEC 61970-301 "Energy management system application program interface (EMS-API) - Common information model (CIM) dynamics".

The US Electrical Power Research Institute (EPRI) developed the Common Information Model (CIM) as part of its Control Center Application Program Interface (CCAPI) project to provide a common definition for power system components for use in the Energy Management System (EMS) Application Programming Interface (API).

8.3.2 Objectives and scope

The CIM is a large UML model containing more than 600 classes which covers the electrical transmission and distribution domain. Subsets of the CIM called "profiles" are defined for particular applications, which include:

IEC 61970-452 "CIM static transmission network model profiles";

IEC 61970-453 "Diagram layout profile";

IEC 61970-456 "Solved power system state profiles".

A profile is a view on the CIM that specifies exactly how the CIM shall be implemented for a particular application. The CIM is a generic model, which can represent the same information in different ways. The CIM also does not specify which attributes are mandatory, and which are optional.

A profile can then be implemented as a "contextual model", either in RDF/XML or in XML derived directly from the UML. The approaches are standardised as:

IEC 61970-501 "Common Information Model Resource Description Framework (CIM RDF) schema";

IEC 61970-552 "CIMXML Model exchange format".

The CIM as a whole can also be implemented as a SQL database. The Common Information Model Primer published by EPRI (https://www.epri.com/research/products/000000003002006001) contains the following diagram shown as Figure 28.

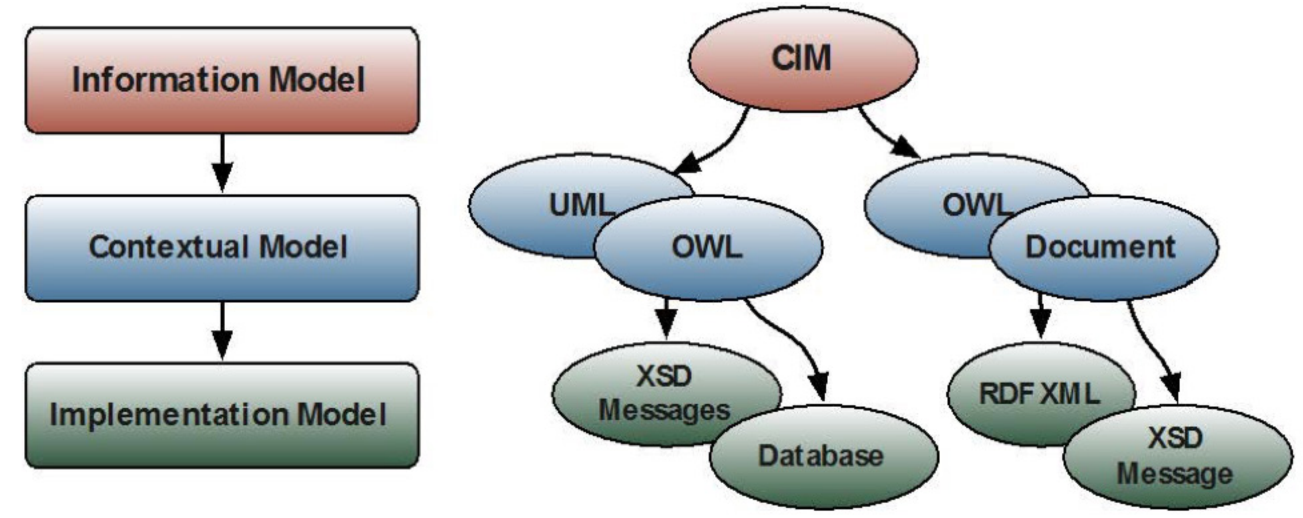

Figure 28 - CIM implementation architecture

8.3.3 Structure of the model

An extract from the CIM top structure is shown in Figure 29.

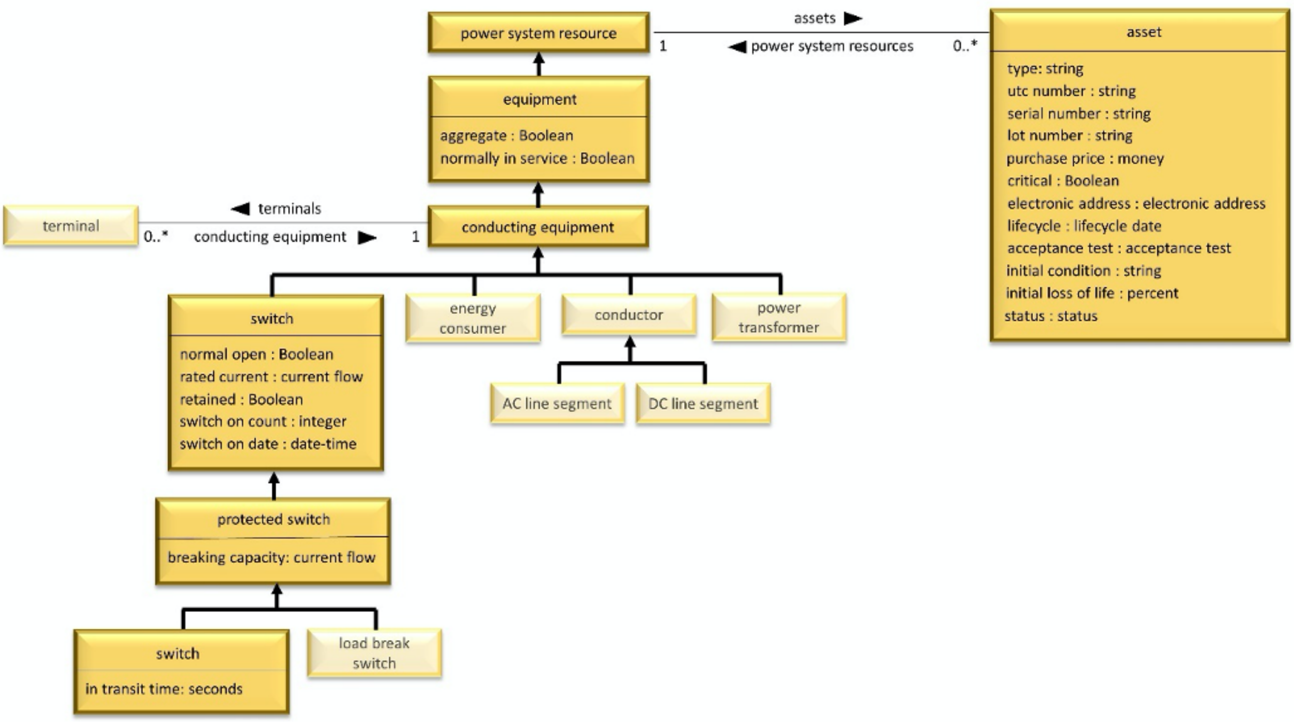

Figure 29 - CIM Power system resource and asset

Comments on Figure 29:

1. The subclasses of **power system resource** show the allowed connection and composition relationships and the valid attributes.
2. The CIM, like CCOM and ISO 15926, makes a distinction between the functional objects within a system (**power system resources**) and the **assets** that are installed as the functional objects. However in CCOM, only asset management information is recorded about an **asset**, and not its engineering properties. Also the CCOM model does not record the history of asset installations, but merely the **asset** that is installed "now".

8.3.4 Documentation

The EPRI CIM is well documented in UML.

8.3.5 Maintenance and usage

The EPRI-CIM is actively maintained by IEC TC 57. The latest edition of IEC 61970-301 [in August 2020] was published in June 2020.

The EPRI-CIM has wide industrial use transmission and distribution systems.

8.4 ISO 15926 Data model

https://www.iso.org/standard/29557.html

8.4.1 Defining organization

The ISO 15926 series of standards is maintained by ISO TC 184/SC 4/WG 3.

The initial development of ISO 15926 had involvement from the oil and gas industry, particularly in Norway, the Netherlands and the UK, and from the nuclear industry, particularly in France. Today, there is also involvement from the oil and gas and nuclear industries in Japan, Korea and China.

Initial the standard was intended to be a part of ISO 10303 (STEP), but it became clear that the ISO 10303 architecture did not have the flexibility to support either the large scope or the need to keep a record of changes through time. Therefore ISO 15926 was developed as a companion standard. Both ISO 15926 and ISO 10303 are developed within ISO TC 184/SC 4 "Industrial data".

8.4.2 Objectives and scope

ISO 15926 was developed to support the storage and sharing of process plant data throughout the life cycle of a process plant, from design, through construction, commissioning, operation and maintenance, to final decommissioning and site clearance.

8.4.3 Structure of the model

The core of the ISO 15926 series of standards is ISO 15926-2 "Data model". This is a top-level ontology which is described in detail in the Top-Level Ontology Baseline report. The structure of the ISO 15926 data model is similar to that of MIMOSA CCOM, but with a formal inheritance structure. The ISO 15926 equivalent to Figure 27, is Figure 30.

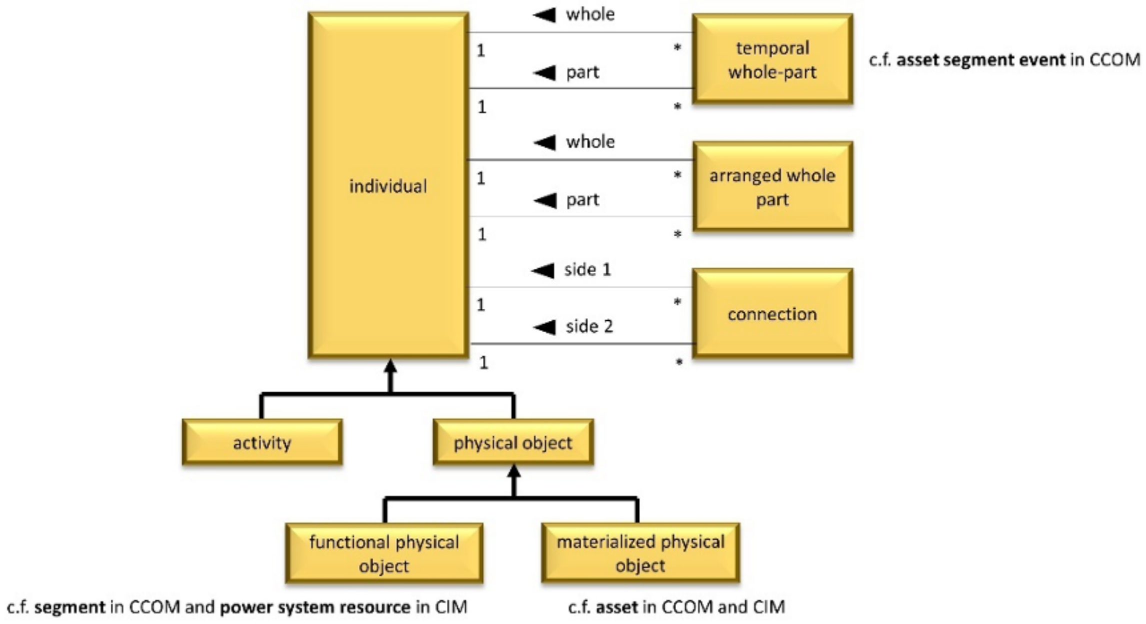

Figure 30 - ISO 15926 top level

Comments on Figure 30:

1. The relationship **temporal whole part** can relate a **functional physical object** to a **materialized physical object** that is installed. During the temporal part of a **functional physical object** during the period of an installation is also a temporal part of the installed **materialized physical object**.
2. The data model does not have subclasses of physical object with explicit relationships and attributes comparable to those in the CIM shown in Figure 29. Instead, this information is provided by reference data libraries.

8.4.4 Documentation

The ISO 15926-2 data model is published by ISO as a PDF document with EXPRESS-G diagrams, good definitions and examples.

[A pre-standardisation HTML representation was created for review. Currently this is not on the web, which is a problem to be addressed. DL]

8.4.5 Maintenance and usage

The ISO 15926-2 data model is not actively maintained, and has not been revised since published in 2003.

A revision of the data model to comply with ISO/IEC 21838-1 "Information technology — Top-level ontologies (TLO) — Part 1: Requirements" is being discussed.

There have been many industrial systems derived from ISO 15926-2, but little direct implementation of either its EXPRESS schema or of the OWL vocabulary derived from it and standardised as ISO 15926-12.

8.5 ISO 15926 Reference Data Library (RDL)

https://standards.iso.org/iso/15926/-4/reference-data-library/

8.5.1 Defining organization

The ISO 15926 series of standards is maintained by ISO TC 184/SC 4/WG 3.

8.5.2 Objectives and scope

The ISO 15926 "Initial Reference Data Library (RDL)" contains 11,000 classes relevant to process plants. This initial RDL is intended to be extended by company and project specific RDLs.

8.5.3 Structure of the model

The RDL is divided into modules as follows:

- activity
- connection material
- electrical
- encoded information (format type)
- control function
- heat transfer
- information (document type)
- instrumentation
- piping
- property
- protection material
- rotating equipment
- solid handling
- static equipment
- transport
- UoM
- valve

8.5.4 Documentation

Currently the reference data library is published as spreadsheets, but representation using OWL and SKOS have been derived from this.

8.5.5 Maintenance and usage

The ISO 15926 reference data library is maintained, but progress is very slow. Since its first publication in 2007, the only new edition [in August 2020] was published in November 2019 to update quantity and unit of measure references to ISO 31-1 and ISO 1000 by references to the ISO 80000 series.

The ISO 15926 reference data library is widely used in industry, and there are numerous proprietary extensions.

8.6 Integrated Asset Planning Lifecycle (ILAP)

8.6.1 Defining organization

The ILAP standard was defined by EPIM (E&P Management Association) in Norway. This is now part of Norske Olje & gass.

The standard is published as ISO 15926-13.

8.6.2 Objectives and scope

The Norske Olje & gass website says:

> ISO 15926-13:2018 specifies the terminology for asset planning for process plants, including oil and gas production facilities. In addition, it specifies an XML schema for exchange of data used for asset planning.
>
> ILAP interfaces translate the schedules from commercial planning tools to the standard format, readable to other planning tools also equipped with an ILAP interface. By installing the ILAP adapter, the files can be imported and exported to the different tools. The exchange format is based on ISO 15926-13.
>
> At present, ILAP interfaces are available for the following commercial planning tools:
>
> - SAP
> - Safran
> - Primavera
> - Microsoft Excel
> - MS Project

8.6.3 Structure of the model

ISO 15926 is a framework within which applications for particular process industry activities can be developed. The ILAP standard defines implementation levels, as follows:

community level: this is an extension to the ISO 15926-2 data model for lifecycle asset planning, which is defined by reference data in OWL.

This level corresponds to the ANSI SPARC conceptual level.

external level: this is a view of the extended ISO 15926-2 data model, which is limited to the scope of scheduling applications. The view is defined in OWL. An exchange file is defined by an XML schema, which is automatically derived from the OWL.

This level corresponds to the ANSI SPARC external level with user views.

The relationship between the levels and the generic, conceptual ontology defined in ISO 15926-2 is shown in Figure 31.

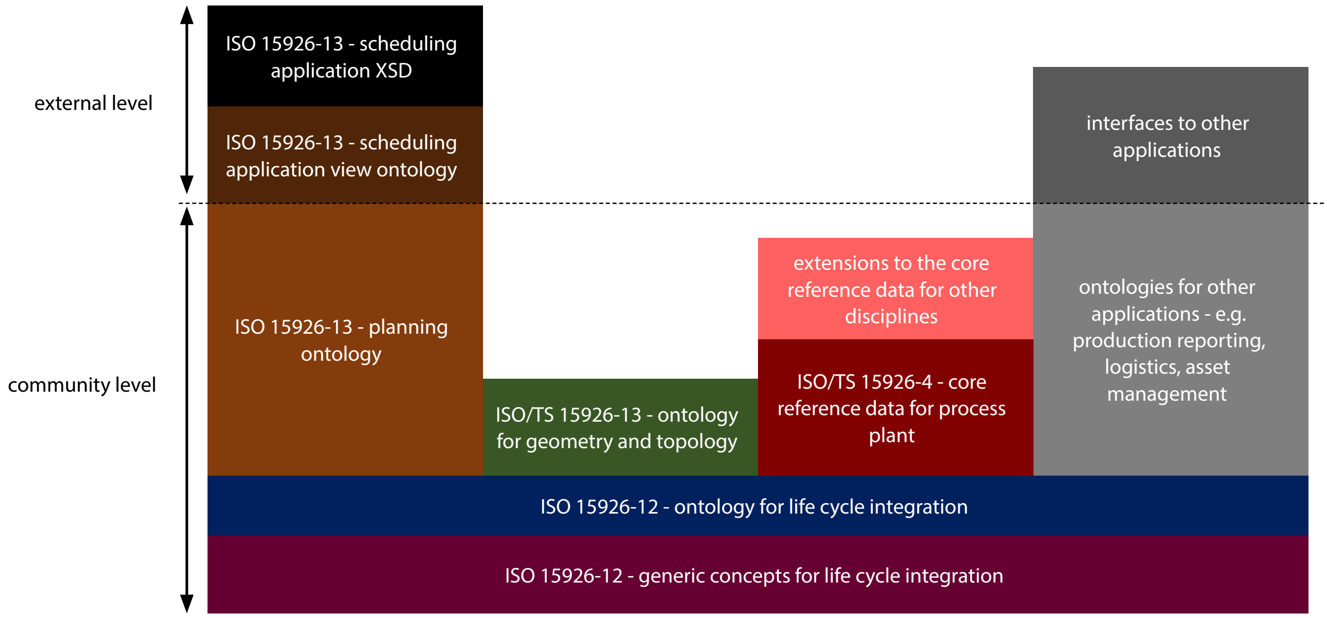

Figure 31 - ISO 15926 implementation architecture

Comments on Figure 31:

1. ISO/TS 15962-12 is a representation of the ISO 15926-2 data model in OWL Full. This ontology has an OWL-DL subset.
2. The "scheduling application view ontology" is a simplification of the ISO 15926-2 data model for the purpose of exchange between scheduling applications. The view is defined in OWL and presented in UML.
3. The scheduling application XSD is created by algorithm from the scheduling application view ontology.

8.6.4 Documentation

The ILAP standard is documented in UML.

8.6.5 Maintenance and usage

A new edition of the ILAP standard is currently [in August 2020] being developed, although a ISO project has not yet begun.

The ILAP standard is used by industry for planning data.

9 General purpose product dictionaries and classification schemes

9.1 Introduction

Clause 9 covers general purpose product dictionaries and classification schemes. The building classification scheme uniclass-2015 is discussed in clause 3.2, and the ISO 15926 reference data library for process plants is discussed in clause 8.5.

9.2 eCl@ss

https://www.eclass.eu/en

9.2.1 Defining organization

The eCl@ss dictionary is maintained by the eCl@ss Association. This was founded in 2000 by 12 large German companies. The eCl@ss association now has more than 150 members, which include businesses, associations and public institutions.

9.2.2 Objectives and scope

The introduction to eCl@ss says that it:

[...] standardizes procurement, storage, production, and distribution activities in and between companies - across sectors, countries and languages.

9.2.3 Structure of the model

eCl@ss has 45,000 product classes and 19,000 properties. These are divided into subject areas as follows:

Development (Service)
Logistics (Service)
Maintenance (Service)
Food, beverage, tobacco
Machine, device (for special applications)
Equipment for mining, metallurgical plant, rolling mill and foundry
Information, communication and media technology
Packing material
Plant equipment, tool
Construction technology
Machine element, fixing, mounting
Office product, facility and technology, paper
General service
Energy, extraction product, secondary raw material and residue
Electric engineering, automation, process control engineering
Vehicle (complete vehicle)
Home economics, Home technology
Auxiliary supply, additive, cleaning agent
Polymer
Laboratory material, Laboratory technology
Installation (complete)
Medical Device
Semi-finished product
Machine, apparatus
Industrial piping
Inorganic Chemical
Organic Chemical
Occupational safety, accident prevention
Marketing
In-vitro diagnostic
Optics
Automotive engineering, vehicle component
Human and veterinary drug, pesticide as well as active ingredient
Clothing and textile
Body care, personal hygiene
Sport, playing, leisure
Public safety and military technology
Interior furnishing
Fluid power
Interim class (unspecified)

The representation of the classes and properties is according to IEC 61360-1 "Standard data element types with associated classification scheme - Part 1: Definitions - Principles and methods" (https://webstore.iec.ch/publication/28560).

A key strength of the eCl@ass dictionary is that it specifies properties for classes.

9.2.4 Documentation

eCl@ss provides good browsing and querying software for the classes and properties.

9.2.5 Maintenance and usage

The eCl@ss dictionary is actively maintained, and a new release is published every year.

The eCl@ss dictionary is widely used in industry.

9.3 ISO/IEC Common Data Dictionary (CDD)

https://cdd.iec.ch

9.3.1 Defining organization

The ISO/IEC Common Data Dictionry (CDD) is defined by a maintenance agency operated jointly by ISO and IEC.

Formerly the CDD was the IEC standard IEC 61360-4, which has been withdrawn.

9.3.2 Objectives and scope

The introduction to the CDD says:

> The IEC Common Data Dictionary (IEC CDD) is an International Standard (IEC 61360-4 DB) and serves as a common repository of concepts for all industrial/technical domains (electrotechnical and non-electrotechnical; e.g. industry, building, energy, healthcare, ...) based on the methodology and the information model of IEC 61360 series, and provides
>
> - unambiguous identification of classes and properties, and their relations;
>
> - commonly accepted terminology and definitions based on accepted sources such as IEC International Standards, other International Standards, industry standards, or public authorities;
>
> - hierarchies of concepts enabling users to appropriately characterize their products and services;
>
> - relevant conditions and constraints if necessary on possible values of characteristics;
>
> - technical representation of concepts including units and data types and their identification.

[The introduction is no longer quite correct. The IEC CDD is not IEC 61360-4, which has been withdrawn, but defined by a maintenance agency operated jointly by ISO and IEC.]

9.3.3 Structure of the model

The IEC CDD hosts different product classifications (based on international standards) for

- process automation equipment (based on IEC 61987);
- low voltage switchgear and control gear (based on IEC 62683);
- electro-electronic components (provided by IEC TC47);
- optics (based on ISO 23584);
- measuring instruments (based on IEC ISO 13584-501);
- environmental declaration (based on IEC 60721).

The content of the CDD is therefore similar to that of eCl@ss, but with items having a status assigned by the ISO/IEC maintenance agency.

9.3.4 Documentation

The CDD has browsing and querying software for the classes and properties maintained by IEC.

The transfer of hosting of the CDD to eCl@ss is being considered.

9.3.5 Maintenance and usage

The level of maintenance of the CDD is difficult to determine because revision information is published item by item. However the top class **component** has been revised more or less annually with the latest [in August 2020] revision in January 2020.

[It is unclear what “revision” means here. Most likely it is any change to its subclasses. DL]

The CDD dictionary is widely used in industry.

10 Government information model

10.1 UK Information Exchange Standard (IES)

This standard will become publicly available soon, and will probably be hosted by the UK Government Defence Science and Technology Laboratory.

10.1.1 Defining organization

The UK Information Exchange Standard is defined by the UK Government.

10.1.2 Objectives and scope

Under "background" the introduction to the IES says:

> Across the UK Government there are many separate knowledge stores, including multiple stores within each organisation; and this will remain the case for many years. Many of the knowledge stores contain similar information about the real world but, for numerous technical and business reasons, there is no standardised way of representing such content – this is usually because different terminologies, formats and/or schemas are used for each of these stores.
>
> Analysts across the police, defence and national security community need comprehensive access to the information distributed across these many knowledge stores so that they can concentrate their efforts on analysis and exploitation tasks without having to broker between different internal formats and schemas. Being able to exchange and share information effectively and efficiently is therefore imperative and needs to be achieved without the need for collaborating organisations to:
>
> - develop numerous and bespoke bilateral interchange mechanisms;
>
> - make costly and highly disruptive changes to their individual knowledge stores.
>
> The Information Exchange Standard (IES) was developed in order to enable that collaboration.

The scope of the model encompassed many of the activities carried out by government including:

- maintenance of law and order;
- purchasing and finance;
- communication;
- transport;
- maintenance of relationships with other governments.

10.1.3 Structure of the model

The top structure of the IES model is broadly based upon the ISO 15926 and Boro models, both of which are 4D. The nature of the top structure is within the scope of the "Top Level Ontologies" report and is not discussed here.

Of importance here is the broad scope of the IES model, and the way in which it is organised. The IES model contains the following principal types of object:

entity: a tangible thing like a person, a device, location, etc.

state: and entity at moment in time or for a period of time (e.g. a moment in a person's life, a phase of a project, etc.)

event: an activity or incident, involving one of more participating entities, that occurred/ started at a specific point in time - e.g. a meeting or a telephone call.

There are relationships between objects, and particular relationships which describe the way in which entities and states participate in events.

The model is divided into parts within the topics of **entity**, **event** and relationship, as follows:

entity (including **state**):

> **person**: identification, characteristics, nationality, place of birth, religion, etc.
>
> **communications account:** how people and organizations communicate by telephone, e-mail, VOIP etc.
>
> **asset**: something of value that a person or organization may have, such as a vehicle, land, money, a document, rights, a payment artefact (see below)
>
> **amount of money**: money in different currencies
>
> **identity document**: document such as a birth certificate, passport, visa, driving licence and identity card, with information about the issuer and the period of validity

organisation: types of organisation, such as commercial organisations, not-for-profit organisations, government organisations, and their places of registration

vehicle: make, registration number, where registered, where usually parked, etc.

posts and roles: how people relate to organisations

ticket: entertainment and travel tickets, the issuer and in the case of a travel ticket the journey that it is for

communications device: telephone, radio handset, network, cellular base station, etc.

financial account: account identification, account holder, account provider, account type

on-line: information on-line such as a website, social media site, social media post, comment, and cookie, along with information about the publisher, creator and hosting

location: to different levels of precision - mapping coordinates, postal address, cell phone base station, geographic region

document: book or report with author and publisher

data object: data base, schema and data that are held within or according to them

communications identifier range: telephone number range, IP address range, domain name and its registration

communications identifier: individual telephone number, IP address, e-mail address, radio call sign and its registration

payment artefact: bank card, travel card, store card and its issuer

event

assessment: finding out whether something it true, and asserting a degree of confidence

authorisation: gaining approval for an activity, which includes the request, the grant and the warrant document that records the authorisation and the roles played by people and organisations

observation: observing something

agreement: negotiating, ratifying and executing a treaty, trade agreement, non-disclosure agreement, rental agreement. etc. and the roles played by people and organisations

business: opening and closing accounts, and transferring money between accounts

attendance: being at a meeting, and checking-in for travel

communication: exchange of information between parties by telecommunication or attendance at a conference, with information about the medium and communications account

lifecycle: creating, modifying and destroying objects

on-line event: logging on, logging off, and creating content, within information about the device used and the on-line account

criminal: criminal activity such as stalking, forgery, and terrorism, with information about the perpetrator and victim

law enforcement: arrest, prosecution and incarceration, with roles such as witness, arresting officer, prosecutor, and incarcerating organisation

operational: reconnaissance, surveillance and arrest, with roles such as lead investigator and documents such as arrest warrant

political: policy announcements, elections, changes of government and summits, with their participants

trade: offer for sale, withdraw from sale, request quotation, purchase, deliver, transfer money, with information about what is traded, between whom, and how money transfers were made

movement: check-in and travel, with information about the from and to, means of travel, tickets and identify documents used

travel booking: the reservation, booking agent and payment

relationship

familial: parent, sibling, cousin, etc.

interest: likes, dislikes, loves, hates

lifecycle relationships: creator, destroyer, modifier

mutual understanding: party to an agreement, negotiator, signatory, in disagreement

operational: between assets, such as part of and stored in, and between people and assets, such as maintains and owns, and between people and locations, such as works at, socialises at, worships at, stays at

professional: employed by, managed by, contracted to, is teacher of, works with, etc.

social: influenced by, know associate of, friend of, etc.

topological: near to, next to

10.1.4 Documentation

The documentation of the IES is in UML and admirably clear. For each of the topics listed above, there is a separate UML diagram. Objects are shown in more than one diagram because **entities** are involved in **events** and are linked by **relationships**. A typical UML diagram is reproduced as Figure 32.

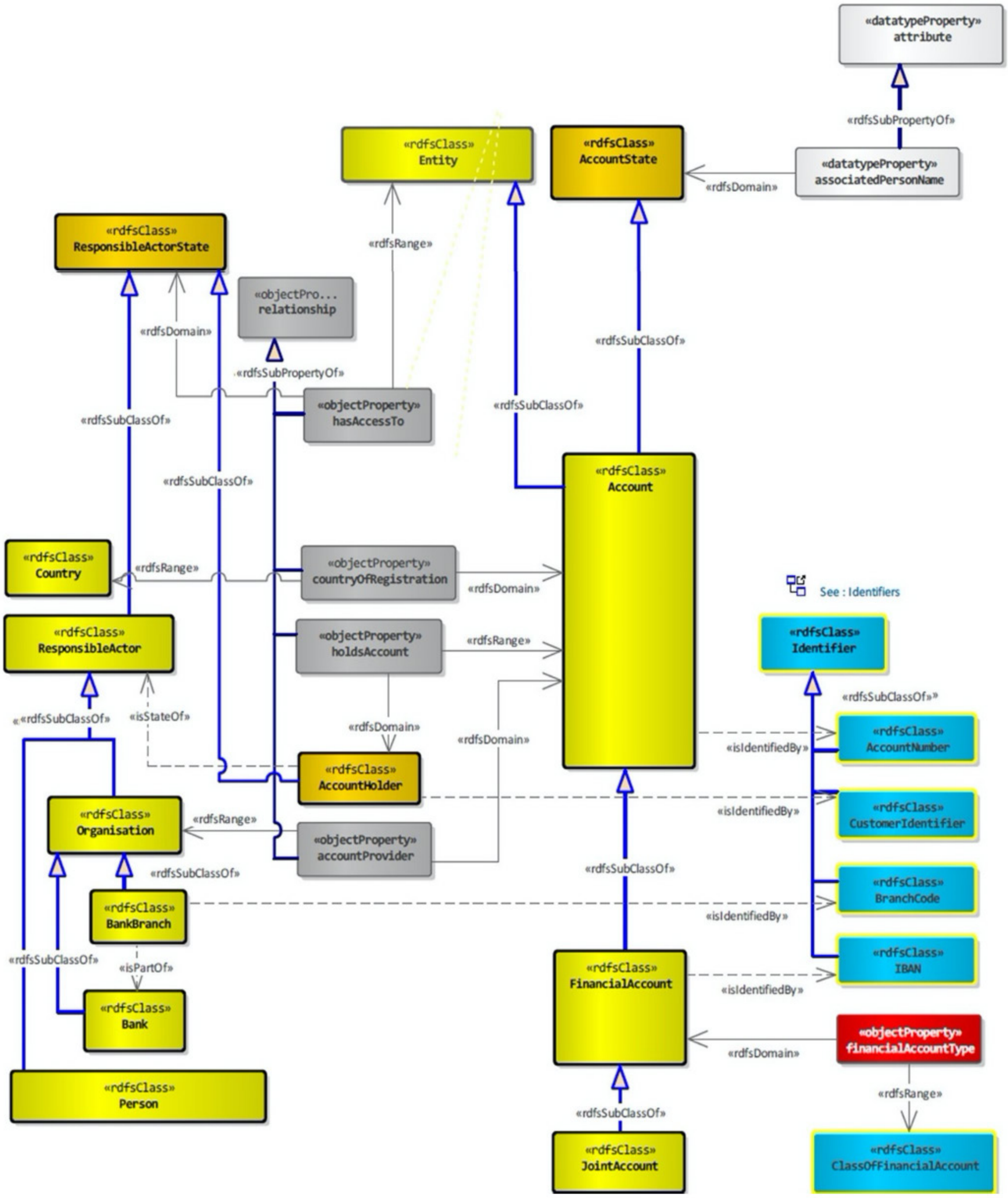

Figure 32 - UML model for a financial account

The UML classes are colour coded for clarity, with entities in yellow, relationships in grey, and information content, such as text strings, in blue. The red link is to members of the powerclass which are a library of account types held as reference data.

An equivalent to the UML model is provided in RDF schema. This enables implementation of the model for government data exchange using TURTLE, N3, XML and JSON.

10.1.5 Maintenance and usage

The IES standard is actively maintained. Version 4.2 was released on 2nd September 2020. Version 1.0 was released on 3rd June 2015, and there has been a succession of revisions since then.

The IES standard is used by Government departments and agencies within the UK for the exchange of data, and particularly by the legal community and Home Office for data concerning warrants. The standard is also used for inter-government exchange by Australia, Canada, NZ, UK, and USA.

Appendix A
A Survey of Industry Data Models and Reference Data Libraries

Summary of Models and Libraries

Data model or reference data library	scope	documentation	representation	maintenance	usage
Building Information Models					
buildingSMART	building	good (EXPRESS)	EXPRESS XML OWL	regular	widespread
NBS Uniclass	building component	no definitions	EXCEL	regular	widespread
Brick - a uniform metadata schema for buildings	building system	fair	OWL	unknown	unknown
Building Topology Ontology	building space	fair	OWL	work in progress	unknown
Graphical Information Systems					
Open Geospatial information	landscape	good (UML)	UML XML OWL	regular	widespread
PipelineML	pipeline	good (UML)	UML XML	unknown	unknown
GeoSciML	geology	good (UML)	UML XML	regular	widespread
EarthResourceML	minerals	good (UML)	UML XML	regular	widespread
Smart cities					
City Geography ML	landscape + building + transport	good (UML)	UML XML	unknown	unknown
Land and Infrastructure Conceptual Model Standard (LandInfra)	landscape + building + transport	good (UML)	UML XML	unknown	unknown
INSPIRE (Infrastructure for Spatial Information in the European Community)	landscape + building + transport	good (UML)	UML XML	regular	widespread
iCity transport planning	transport	good (UML)	UML	research	none
Industrial data					
ISO 10303 (STEP) Application Protocols	manufacture and maintenance	fair (EXPRESS)	EXPRESS XML	regular	widespread
Ontology for geometry and topology	geometry	work in progress	UML OWL	work in progress	none
Core Industrial data set of terms	terminology	work in progress	text	work in progress	none
Modeling and Simulation information in a collaborative Systems Engineering Context (MoSSEC)	simulation	fair (EXPRESS)	EXPRESS XML	work in progress	unknown

Data model or reference data library	scope	documentation	representation	maintenance	usage
Metrology and simulation					
Quality Information Framework (QIF)	manufacture	fair (XML)	XML	regular	widespread
OpenDrive	transport	good (UML)	UML XML	regular	widespread
Intelligent transport systems - Terminology	transport	fair (UML)	UML	work in progress	none
ISO/IEC JTC 1 AHG 11 “Ad Hoc Group on the Digital Twin”	manufacture	N/A	N/A	N/A	N/A
ISO/TC 184/WG 15 “Digital manufacturing”	manufacture	N/A	N/A	N/A	N/A
Digital twin consortium	manufacture	N/A	N/A	N/A	N/A
Process plant and electrical utility data					
MIMOSA Common Concept Object Model (CCOM)	process plant	good (XML)	XML	regular	widespread
EPRI Common Information Model (CIM)	electrical transmission and distribution	good (UML)	UML XML RDF	regular	widespread
ISO 15926 Data model	process plant	good (EXPRESS)	EXPRESS OWL	revision planned	some
ISO 15926 Reference Data Library (RDL)	process plant terminology	good (EXCEL)	EXCEL		widespread
Integrated Asset Planning Lifecycle (ILAP)	planning	good (UML)	XML	revision in progress	widespread
General purpose product dictionaries and classification schemes					
eCl@ss	terminology	good (browser)	EXPRESS (IEC 61360-1)	regular	widespread
ISO/IEC Common Data Dictionary (CDD)	terminology	good (browser)	EXPRESS (IEC 61360-1)	regular	widespread

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About the Construction Innovation Hub

The Construction Innovation Hub brings together world-class expertise from the Manufacturing Technology Centre (MTC), BRE and the Centre for Digital Built Britain (CDBB) to transform the UK construction industry.

With £72 million from UK Research and Innovation's Industrial Strategy Challenge Fund, and working around the four core themes of Value, Manufacturing, Assurance and Digital, we are changing the way buildings and infrastructure are designed, manufactured, integrated and connected within our built environment.

We are a catalyst for change. We are driving collaboration to develop, commercialise and promote digital and manufacturing technologies for the construction sector. We are helping build smarter, greener and more efficient buildings much faster and cheaper than we currently do.

Research is helping us understand how the industry needs to change in terms of skills, product standards, capacity and innovation. This is combined with an academic programme to create the security-minded frameworks and rules that will underpin the future digital built environment and grow exports for UK know-how.

We are working closely with other initiatives as part of the Government's Transforming Construction challenge programme. Through collaboration across the sector, we can provide a better-built environment for future generations.

Further information
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