Semantic-based Building Information Modelling (BIM)

Approaches and related Standarziation Actions

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ANR-15-IDEX-0003

Summary

1 Background

- BIM and main related standards that apply
- Ontology design and rule-based reasoning, and how it compares to (semi-)automatic learning approaches

2 Projects

- Semantic checking of compliance rules
- IFC view extraction,
- MVD adaptation through semantic rules

3 Standards

- buildingSmart International : ifcOWL
- CEN WI 442021 Semantic Modelling and Linking Guide (CEN)
- ISO 21597:2020 Information Container for Data Drop (ISO), ISO 23386:2020 Building information modelling and other digital processes used in construction – Methodology to describe, author and maintain properties in interconnected data dictionaries

Background

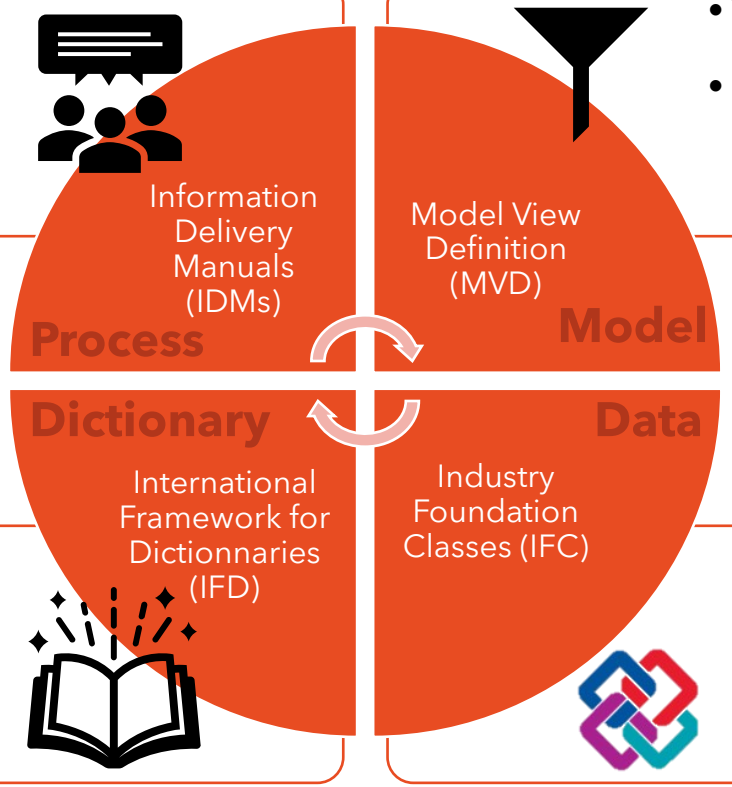
BIM and related standards

Information Delivery Manuals (IDM), Model-View Definition (MVD) and Industrial Foundation Classes (IFC).

buildingSMART BIM Ecosystem

buildingSMART
International home of openBIM

- Methodology to capture and specify processes and information exchanges during the lifecycle of a facility
- Defined through text-based templates
- **ISO 29481-1:2010** "BIM – IDM – Part 1 : Methodology and format"

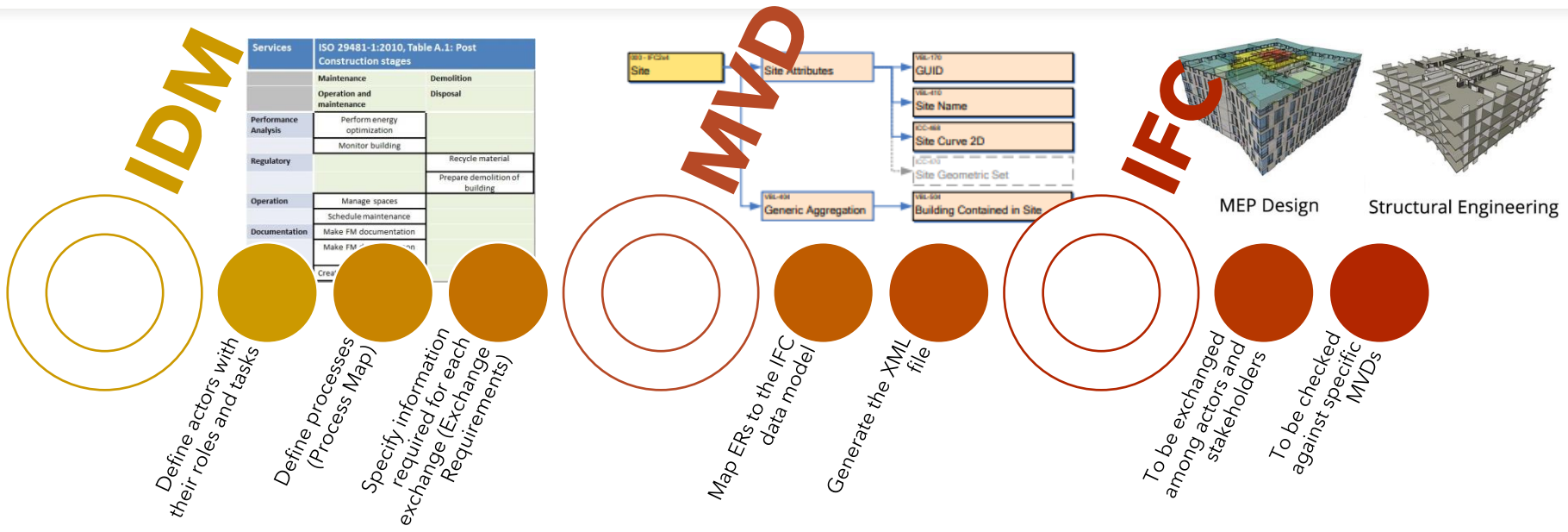


- To enable IFC implementations that satisfy a given set of data exchange requirements
- Defined through diagrams, based on XML

- bSDD online service with objects and their attributes and translations
- **ISO 12006-3 :2007** "Building construction – Organization of information about construction works – Part 3: Framework for object-oriented information"

- Open, international standard for data exchange - **ISO 16739-1:2018**
- Concepts as used in real-world building projects, for all building licecycle phases

How is it working in practice ?



Planning
6 – 12 months

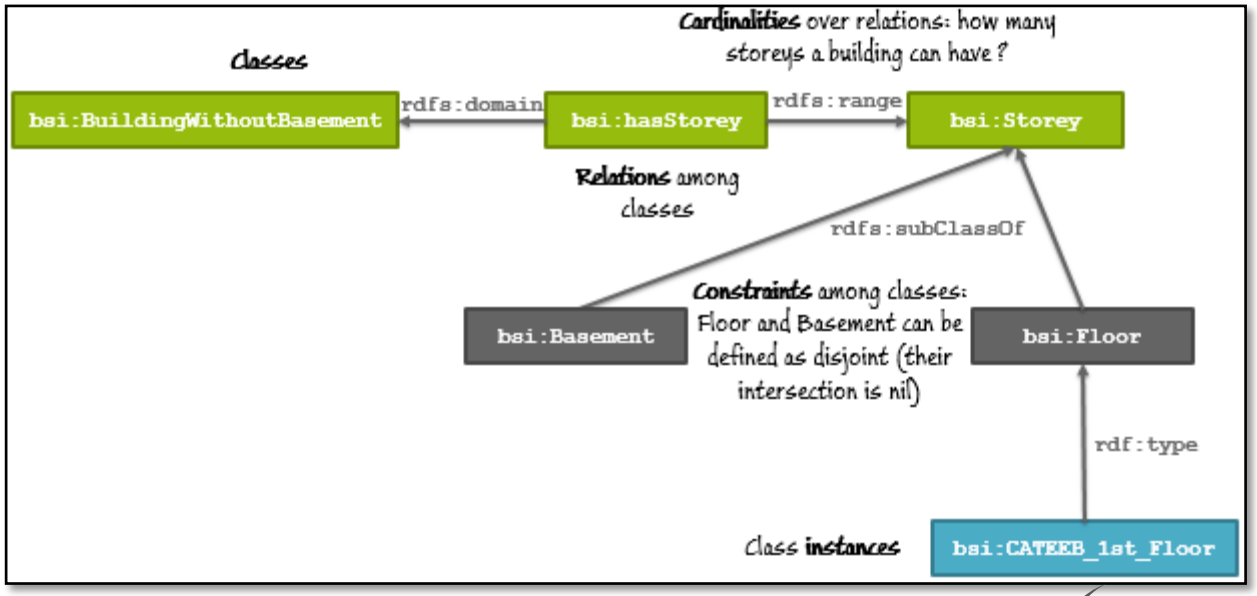
Design
9 – 18 months

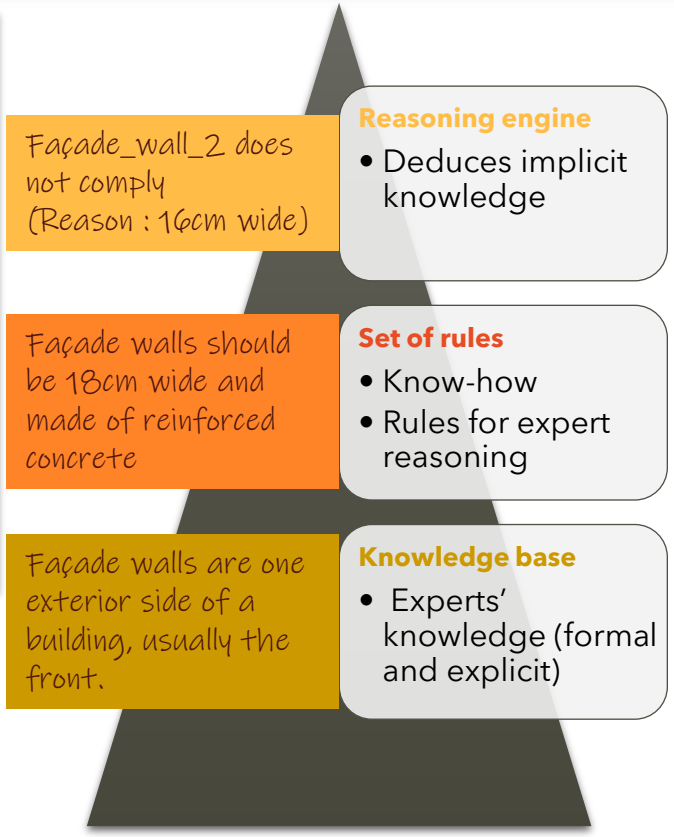
Construction, deployment
9 – 15+ months

Ontologies

Ontology design and rule-based reasoning and how it compares to (semi-)automatic learning approaches

Ontologies or Specifying Actionnable Knowledge





In complex decision-making systems, AI must be **fast and intuitive enough** to be perceived as an advantage by humans. *Deductions are logical and justifiable*. The expressivity handled by the reasoner must match the one of the ontology language.

Rules allow **tracking and constraining** how the expert system "reasons".
Rule languages : SWRL, SHACL, RIF.
Rules must be managed efficiently.

The digital description must be a *conceptualization of the world* with enough detail to **support useful decision-making**.
The level of expressivity of the ontology language used (OWL family) impacts efficiency.

Comparison with learning-based systems

Systems based on **automatic learning** *Machine learning*

- **Unsupervised learning**
  - Partitioning : k means, KNN
  - Dimension reduction : artificial neuronal networks
  - → Automatically identify structure in unlabelled data
- **Reinforcement learning**
  - Genetic algorithms
  - TD Learning, Q Learning
  - → Learning improved by credit/blame assignment
- **Supervised learning**
  - Discrete : classification or categorization
  - Continuous : regression
  - → Find specific relations or structures in the input data that allow effective output of correct data.

Systems based on **reasoning**

- **Programmed learning** — **Expert Systems**

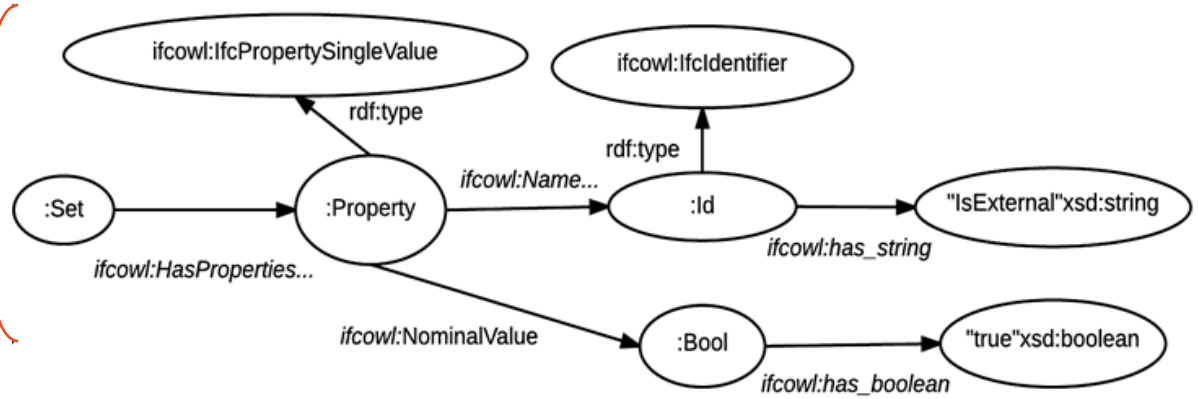
Expertly solving problems in a given domain by drawing inferences from a knowledge base developed from human expertise.

Projects (academic & industrial)

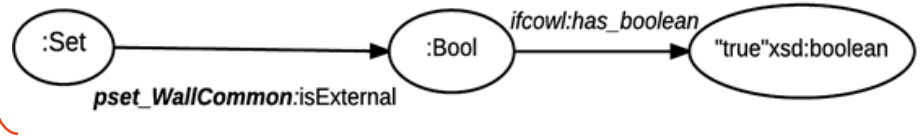
ifcWoD (Web of Data)
Enhancing ifcOWL

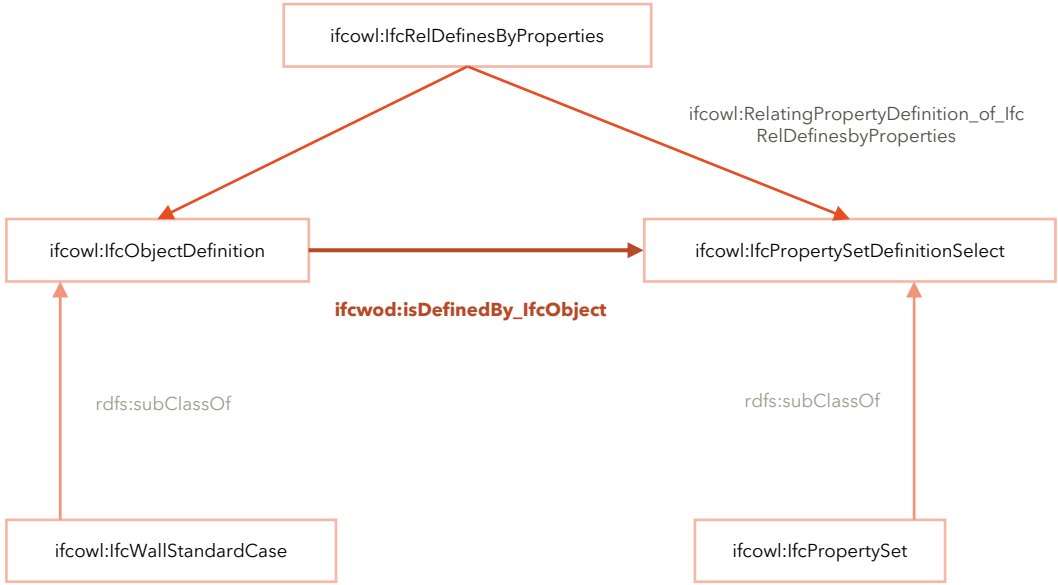
Eléments de l'ontologie	ifcOWL
Axiomes	7216
Axiomes logiques	4455
Classes	802
Propriétés objet	1177
Propriétés de type de données	247
Propriétés inverses	111
Instances	0
Propriétés objet fonctionnelles	942
Domaines de propriétés objet	1073
Portées de propriétés objet	1070
Propriétés type de données fonctionnelles	50
Domaines de propriétés de type de données	260
Portées de propriétés de type de données	247
Expressivité DL	$\mathcal{ALUIF}^{(D)}$

Without **IfcWoD**



With IfcWoD

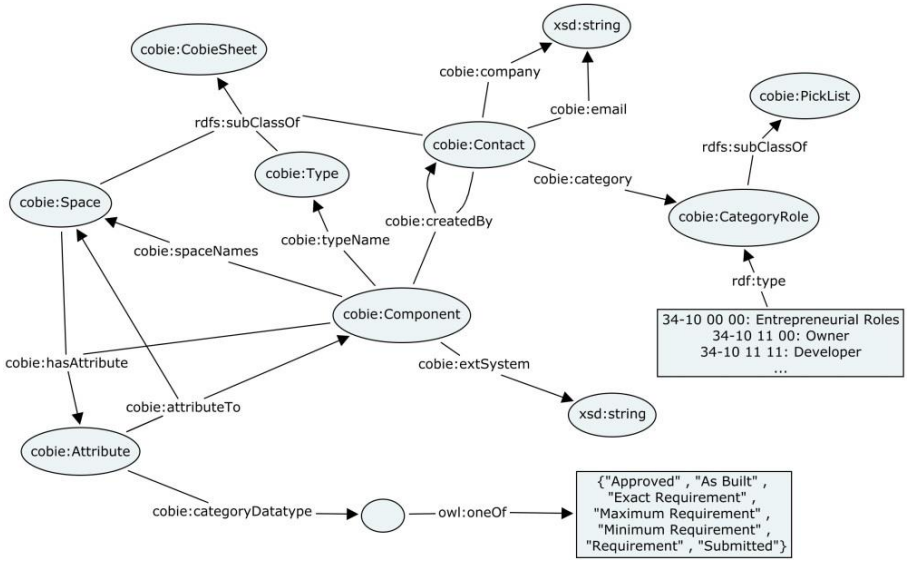




Tarcisio Mendes de Farias, **Ana Roxin**, Christophe Nicolle. **IfcWoD, Semantically Adapting IFC Model Relations into OWL Properties**. *In proceedings of the 32nd CIB W78 Conference on Information Technology in Construction*, Oct 2015, Eindhoven, Netherlands

COBieOWL
From spreadsheet to ontology

Eléments de l'ontologie	COBieOWL
Axiomes	19840
Axiomes logiques	19658
Classes	30
Propriétés objet	32
Propriétés de type de données	125
Propriétés inverses	7
Instances	9416
Propriétés objet fonctionnelles	24
Domaines de propriétés objet	26
Portées de propriétés objet	24
Propriétés type de données fonctionnelles	122
Domaines de propriétés de type de données	124
Portées de propriétés de type de données	123
Expressivité DL	$\mathcal{ALCHIF}^{(D)}$



Tarcisio Mendes de Farias, **Ana Roxin**, Christophe Nicolle. **COBieOWL, an OWL ontology based on COBie standard**. In proceedings of *On the Move to Meaningful Internet Systems*: OTM 2015 Conferences. Lecture Notes in Computer Science 9415, Springer 2015.

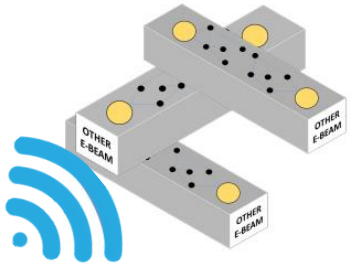
Column	Reference	Horn-like Rule defined based on ifcOWL terms
Email (Contact)	IfcActor.Name	ifcowl:IfcActor(X) ∧ ifcowl:name_IfcRoot (X, Y) ∧ expr:hasString(Y, Z) → **cobieowl:name(X,Z)**
CreatedBy (Contact)	IfcActor.OwnerHistory\ IfcOwnerHistory.OwningUser\ IfcPersonAndOrganization.ThePerson\ IfcPerson.Identification	ifcowl:IfcActor(X) ∧ ifcowl:ownerHistory… (X, Y) ∧ ifcowl:owningUser…(Y,Z) ∧ ifcowl:thePerson…(Z, K) ∧ ifcowl:identification…(K, L) ∧ expr:hasString(L, M) → **cobieowl:createdBy (X, M)**
Company (Contact)	IfcActor.TheActor\ IfcPersonAndOrganization.TheOrganization\ IfcOrganization.Name	ifcowl:IfcActor(X) ∧ ifcowl:theActor… (X, Y) ∧ ifcowl:theOrganization…(Y,Z) ∧ ifcowl:name…(Z, K) ∧ expr:hasString(K, M) → **cobieowl:company (X, M)**
Description (Floor)	IfcBuildingStorey.Description	ifcowl:IfcBuildingStorey(X) ∧ ifcowl:description… (X, Y) ∧ expr:hasString(Y, Z) → **cobieowl:description(X,Z)**
Elevation (Floor)	IfcBuildingStorey.Elevation	ifcowl:IfcBuildingStorey(X) ∧ ifcowl:elevation … (X, Y) ∧ expr:hasDouble(Y, Z) → **cobieowl:elevation(X,Z)**

From sensors to knowledge

How do I extract information about the concrete elements of a building?

Sensors placed in concrete

Knowledge upload



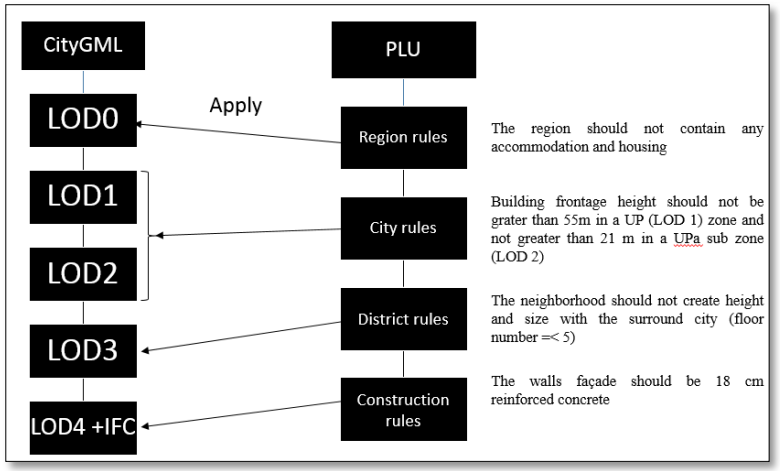
Applications for:

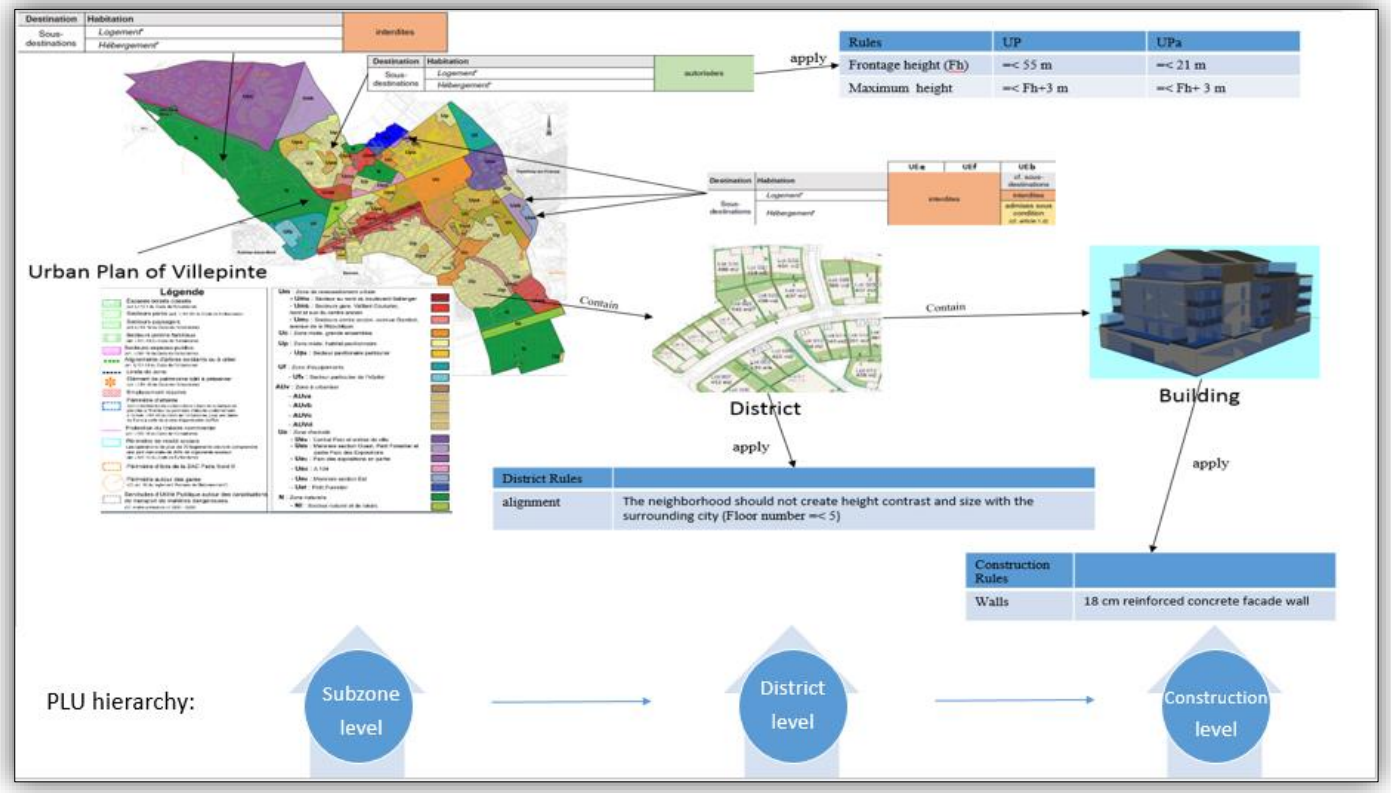
- Concrete production
- Surveillance of building sites
- Structure monitoring

"**Communicating Matter for BIM**"
ANR ongoing project (2017-2021)
N° ANR-17-CE10-0014-03

ANR AGENCE NATIONALE DE LA RECHERCHE

Management of Urban Rules (PLU)





CSTB
le futur en construction

CIFRE PhD with the CSTB (ongoing)

Elio Hbeich, **Ana Roxin**, Nicolas Bus. **Aligning BIM and GIS – CityGML and PLU to achieve compliance checking model**. *18th Int. Conference on INFORMATICS in ECONOMY, May 2019. pp.165-170.*

Adding Expert Knowledge

ifcowl:IfcObject(X1) ∧ ifcowl:IfcRelDefines(X2) ∧ ifcowl:relatedObjects…(X2 , X1) ∧ ifcowl:relatingPropertyDefinition… (X2 , X3) ∧ ifcowl:IfcPropertySet(X3) → **:hasPropertySet**(X1 ,X3)

aei:hasPropertySet(X1 , X2) ∧ ifcowl:hasProperties… (X2 , X3) ∧ ifcowl:IfcProperty(X3) → **:hasProperty(X1** , X3)

aei:hasProperty(X1 , X3) ∧ ifcowl:name_IfcProperty(X3, X4) ∧ expr:hasString(X4 , "IsExternal") ∧ ifcowl:nominalValue… (X3, X5) ∧ expr:hasBoolean(X5 , X6)→ **:isExternal**(X1 , X6)

aei:isExternal(X , true) ∧ ifcowl:IfcWall(X) → :**ExternalWall**(X)

aei:isExternal(X , true) ∧ ifcowl:IfcDoor(X) → :**ExternalDoor**(X)

aei:isExternal(X , true) ∧ ifcowl:IfcWindow(X) → :**ExternalWindow**(X)

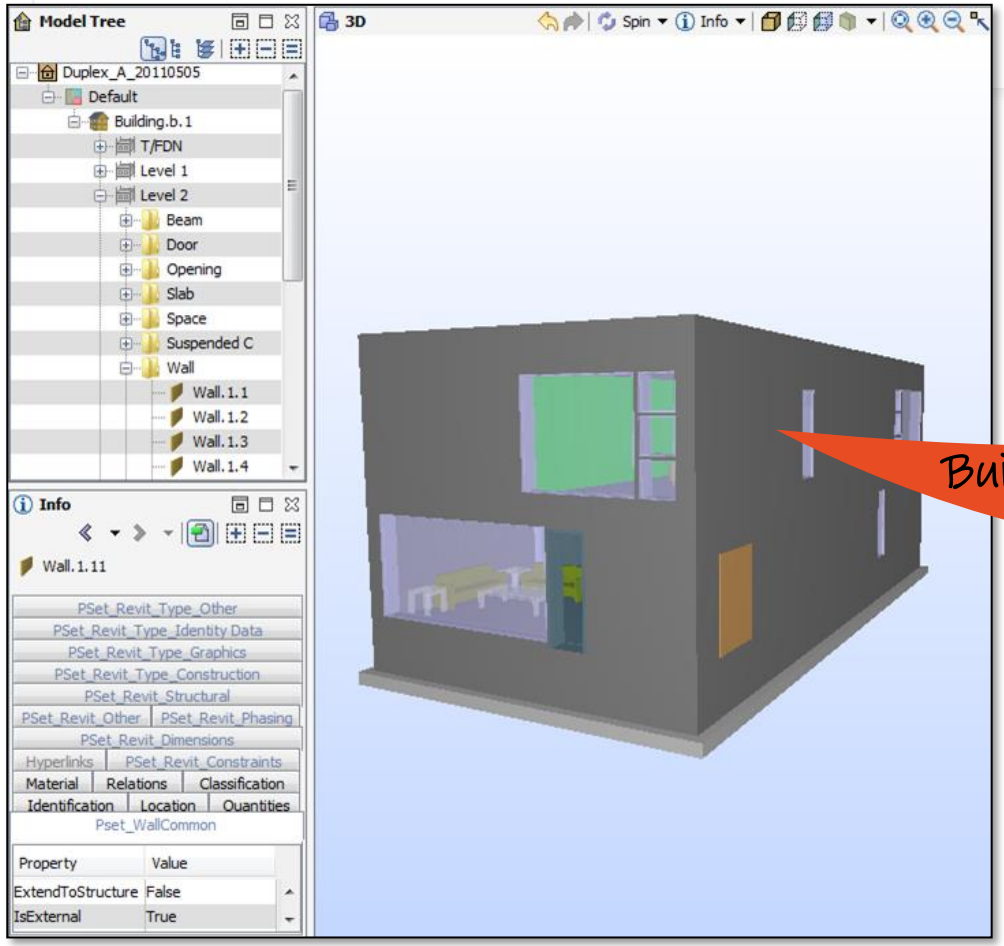
:ExternalDoor(X) → :**BuildingEnvelope**(X)

:ExternalWall(X) → :**BuildingEnvelope**(X)

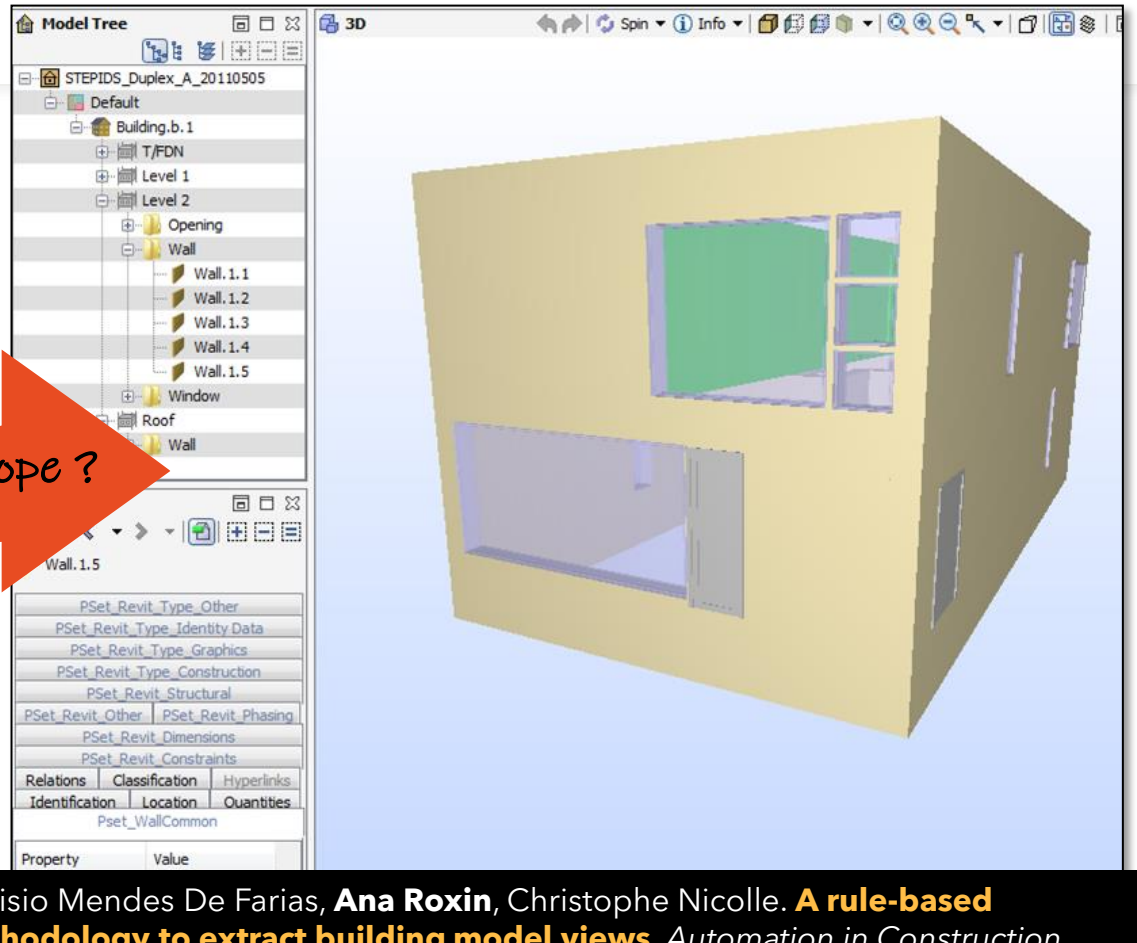
:ExternalWindow(X) → :**BuildingEnvelope**(X)

Presentation @buildingSmart International Standards Summit, Technical Room, Rotterdam, April the 12th 2016 [Available online]

View Extraction

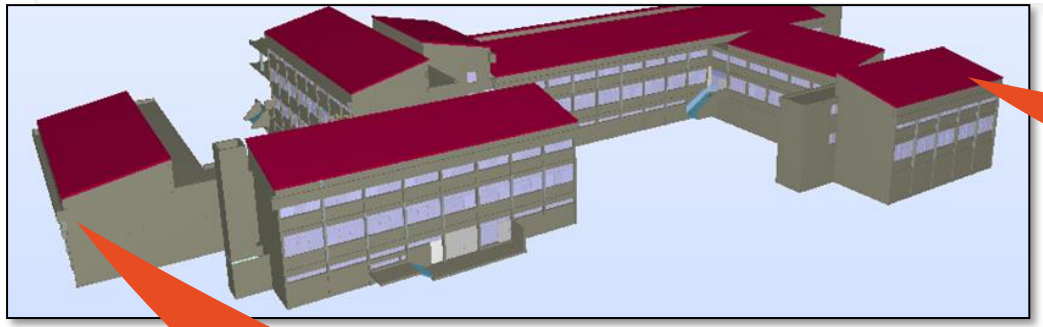


Building envelope ?

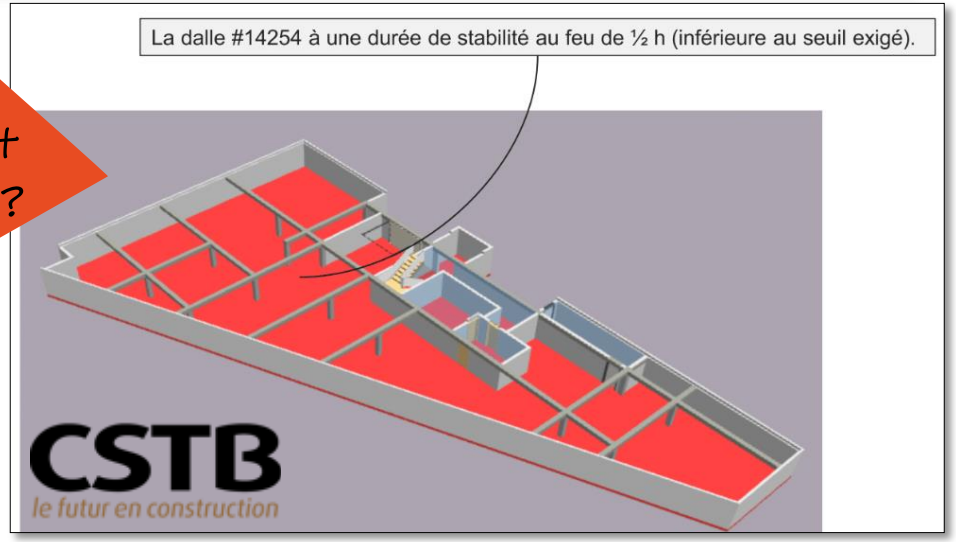


Tarcisio Mendes De Farias, **Ana Roxin**, Christophe Nicolle. **A rule-based methodology to extract building model views**. *Automation in Construction*, Elsevier, 2018, 92, pp.214 - 229. ⟨10.1016/j.autcon.2018.03.035⟩

Compliance Checking



Non-compliant slabs ?



Emergency stairs and issues ?

Nicolas Bus, Muhammad Fahad, Bruno Fies, **Ana Roxin**. **Semantic topological querying for compliance checking**. *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2018*, 2018
Pieter Pauwels, Tarcisio Mendes De Farias, Chi Zhang, **Ana Roxin**, Jakob Beetz, et al. **A performance benchmark over semantic rule checking approaches in construction industry**. *Advanced Engineering Informatics*, Elsevier, 2017, 33, pp.68-88. 10.1016/j.aei.2017.05.001.
Pieter Pauwles, **Ana Roxin**. **Reasoning with Rules**. Presentation @buildingSMART International Standards Summit 2016, Jeju. [Available online]

Semantics in Standards

Existing standards

ifcOWL, ISO 21597-1:2020, ISO/TC 211, etc.

buildingSmart International – ifcOWL

https://technical.buildingsmart.org/standards/ifc/ifc-formats/ifcowl/

IFC EXPRESS/STEP

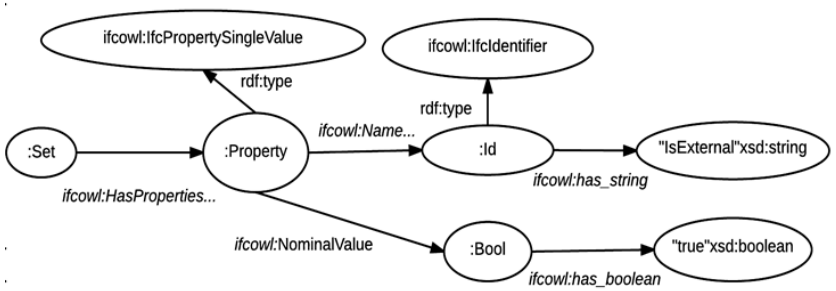
```
VirtualElement
F (IfcElement);
Y;

ENTITY IfcVirtualGridIntersection;
        IntersectingAxes : LIST [2:2] OF UNIQUE IfcGridAxis;
        OffsetDistances : LIST [2:3] OF IfcLengthMeasure;|
END_ENTITY;

ENTITY IfcWall
 SUPERTYPE OF (ONEOF
        (IfcWallStandardCase))
 SUBTYPE OF (IfcBuildingElement);
 WHERE
        WR1 : SIZEOF (QUERY(temp <* SELF\IfcObjectDefinition.HasAssociations |
              'IFC2X3.IFCRELASSOCIATESMATERIAL' IN TYPEOF(temp)
              )) <= 1;
END_ENTITY;
```

The graph structure of ifcOWL allows addressing some limitations of EXPRESS/STEP but not in an optimal way !

ifcOWL (IFC STEP translated into OWL)



Drawbacks for EXPRESS/STEP-based formats:

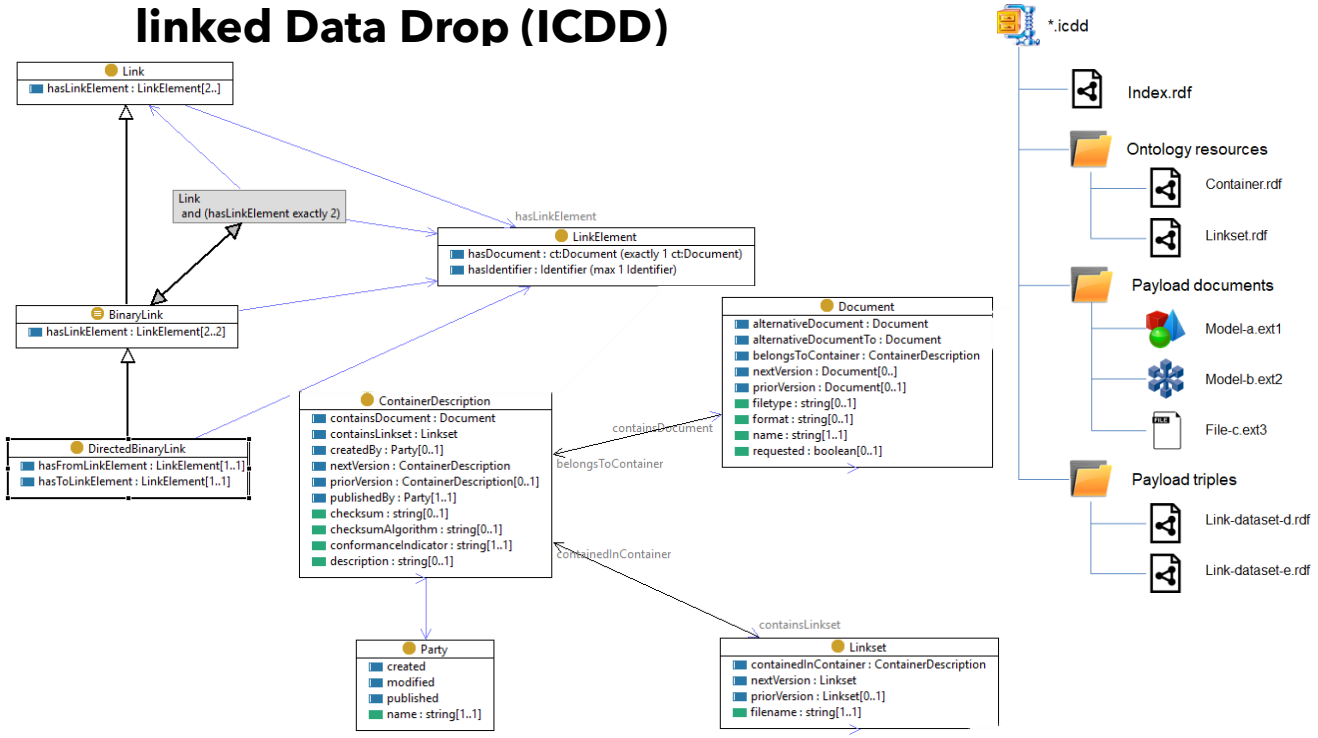
- Queries are software-dependent
- Impossible to combine several IFC files and query the collection
- Difficult to make links to other types of data
- Not adapted for deducing new information

Remaining problems:

- Still difficult understanding of IFC object properties and relationships
- Complex access to the semantics of building data
- Very little links to other vocabularies
- No leverage from constraints dictated by the EXPRESS/STEP file format

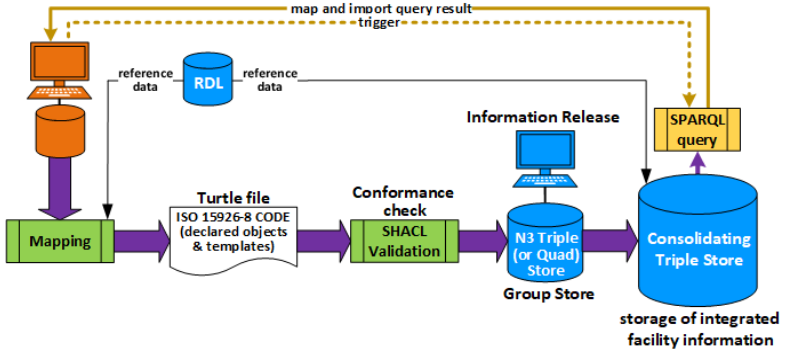
ISO Standards

ISO 21597-1:2020 Information Container for linked Data Drop (ICDD)



ISO 15926 Integration of life-cycle data for process plants, including oil and gas production facilities – http://15926.org/standards/

- ISO 15926 is meant to a) provide global interoperability between all applications, and b) integrate all technical and operational information of a facility during its entire life.
- ISO 15926-8 specifies data exchanges and lifecycle information integration using RDF & OWL.



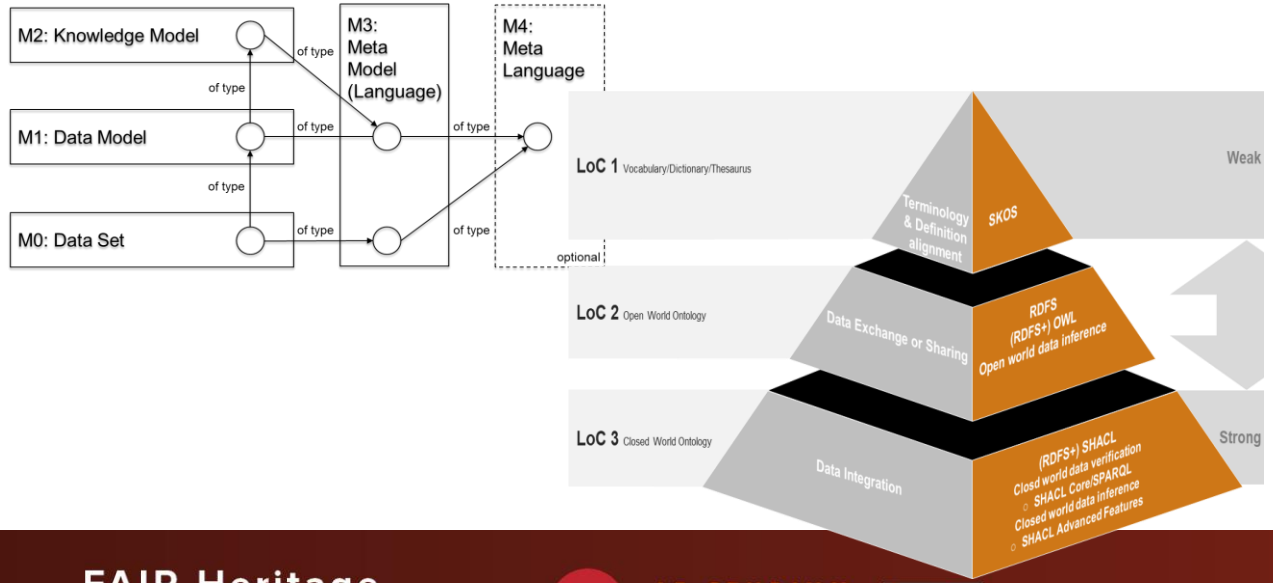
Ongoing standardization

CEN Semantic Modelling and Linking guide, ISO 21597 ICDD Part 2

CEN Initiatives

TC442/WG4 Semantic Modelling & Linking Guide

- The guide defines a Conceptual Meta Model (M3: Meta Model) with four RDF-based language bindings and an M1: Generic Top Level Data model. It recommends an modelling and linking approach, based on the work of Mathias Bonduel on the PROPS ontology.



TC 205/WG 19 Energy Management Ontology (with CENELEC)

- Following the **CEN-CENELEC Mapping Ontologies Workshop** (2018-11-27) pointing out that

  a) interoperability between different systems like knx, 61850, CIM etc. is a major challenge in the Smart Energy applications, and

  b) ontologies support semantic transformation within and / or between domains, semantic transformation all along the product and system life cycle and interoperability

- The goal is to develop a **common standard ontology**, starting from existing data models, addressing use cases defined in the SGAM (Smart Grids Architecture Model)

ISO Initiatives
ISO/DIS 21597-2 ICDD Extended Linkset

Binary links that express comparative relationships ...

Identity	Relates two link elements that are identical but may be represented in different ways.
Conflict	Relates two link elements that conflict with one another in some way.
Alternative	Relates two link elements where one is an alternative to the other.

One-to-many links that express ordering relationships ...

Specialisation	Relates one link element to one or more other link elements that are specialisations or sub-classes.
Aggregation	Relates one link element to one or more other link elements to form an assembly of parts where those parts exist independently.
Membership	Relates one link element to one or more other link elements to form a grouping based on some consistent criteria.

One-to-many links that express dependency relationships ...

Replacement	Relates one link element to one or more other link elements where they are a development of or supersede it in some way.
Elaboration	Relates one link element to one or more other link elements where they provide further explanation, reasoning, derivation, information or usage.
Control	Relates one link element to one or more other link elements over which it exercises some type of control.

```
<owl:Class rdf:ID="HasBasisIn">
    <inverseRelation><owl:Class rdf:ID="IsElaboratedBy"/></inverseRelation>
    <transitive rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true
    </transitive>
    <symmetric rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">false
    </symmetric>
    <rdfs:subClassOf rdf:resource="https://.../Linkset#Directed1toNLink"/>
</owl:Class>
<owl:Class rdf:ID="IsIdenticalTo">
    <transitive rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true
    </transitive>
    <symmetric rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true
    </symmetric>
    <rdfs:subClassOf rdf:resource="https://.../Linkset#DirectedBinaryLink"/>
</owl:Class>
<owl:AnnotationProperty rdf:ID="transitive">
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
</owl:AnnotationProperty>
<owl:AnnotationProperty rdf:ID="symmetric">
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
</owl:AnnotationProperty>
<owl:AnnotationProperty rdf:ID="inverseRelation">
    <rdfs:range rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
</owl:AnnotationProperty>
```

Conclusion

Other approaches

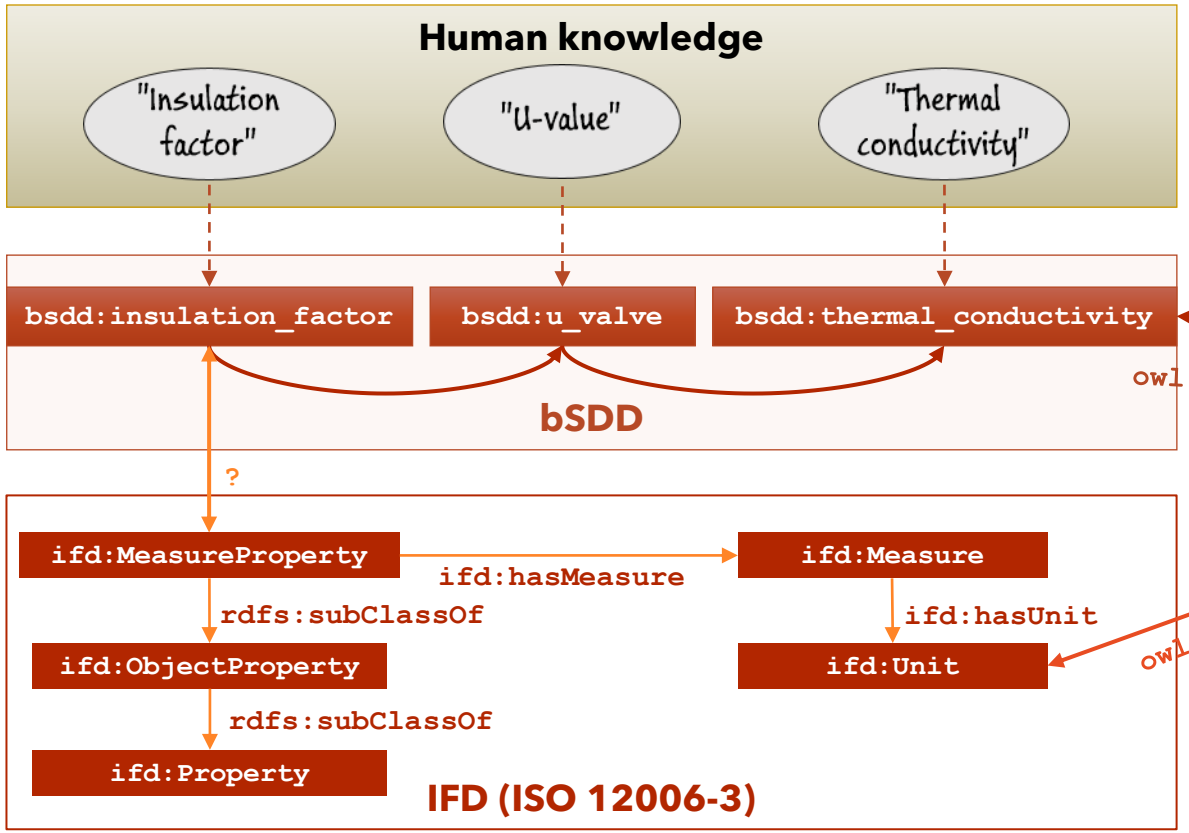
French

- ifcWoD – ifcOWL simplification & adaptation for LD (presented at bSI Rotterdam)
- LD Perspective for BIM (presented at bSI Jeju)
- ifcViews - Extract IFC elements as defined in an MVD (presented at bSI Jeju)
- Linked Data implementation of the Unified Code of Units and Measures (UCUM) (Maxime Lefrançois)
- BIM and GIS semantic interoperability issues for urban checking scenarios (CIB2019 paper)
- eduBIM Workshop series

International

- Simplifying ifcOWL structure (presented at ECPPM2016 with P. Pauwels)
- Querying and reasoning over large scale building datasets – benchmark comparing 3 different implementations
- Semantic Web approaches for expressing MVDs (Whitepaper presented at bSI Barcelona with M. Weise)
- ISO Joint WG between BIM (TC59/SC13) and GIS (TC211) experts for defining NWIPs for BIM/GIS interoperability
- ISO Technical Report on the feasibility of the Geometry Ontology
- The W3C Linked Building Data CG & the LDAC workshop (2020 edition is ongoing, online & free)

The need to go further



Several vocabularies/schemas/models (defined with Semantic Web languages) exist. There is no need to re-define them just **add links** towards them and **verify** they are correctly accessed and interpreted. Only **missing and needed concepts should be defined**.

owl:equivalentProperty

ifcowl

```
ifc:thermalConductivity_IfcThermalMaterialProperties
        a owl:ObjectProperty , owl:FunctionalProperty ;
        rdfs:domain  ifc:IfcThermalMaterialProperties ;
        rdfs:label   "ThermalConductivity" ;
        rdfs:range   ifc:IfcThermalConductivityMeasure .
```

owl:equivalentClass

unit:BtuFootPerSquareFootHourDegreeFahrenheit

qudt:quantityKind

quantity:ThermalConductivity

NASA QUDT Units Ontology

unit: http://www.qudt.org/qudt/owl/1.0.0/unit/
qudt: http://www.qudt.org/qudt/owl/1.0.0/qudt/Properties.html#
quantity: http://www.qudt.org/qudt/owl/1.0.0/quantity/index.html#

Thank you for your attention !

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