# Semi-automated extraction of HVAC topology from imperfect Building Information Models

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Cloud-based Building Information Modelling

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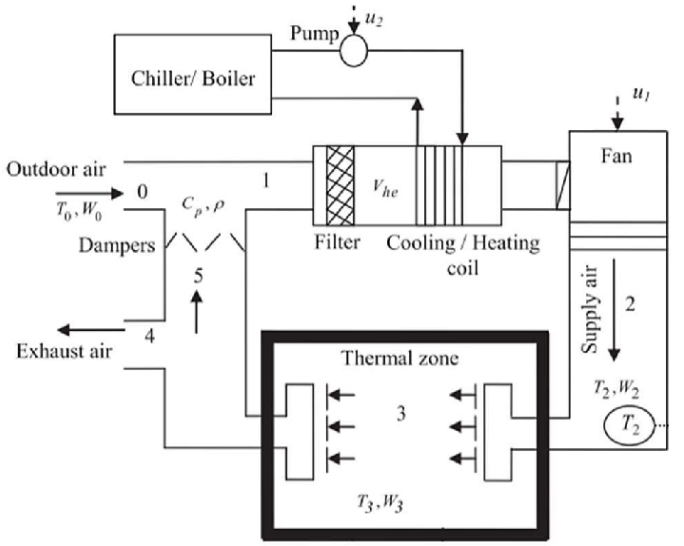
# Importance of HVAC topology

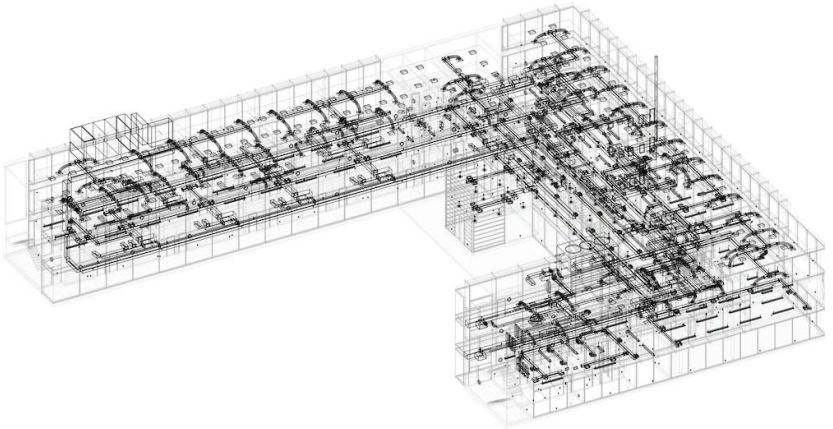
- HVAC Topology describes how various **HVAC components** are **interconnected** and **work in tandem** to provide the desired environmental conditions within a building

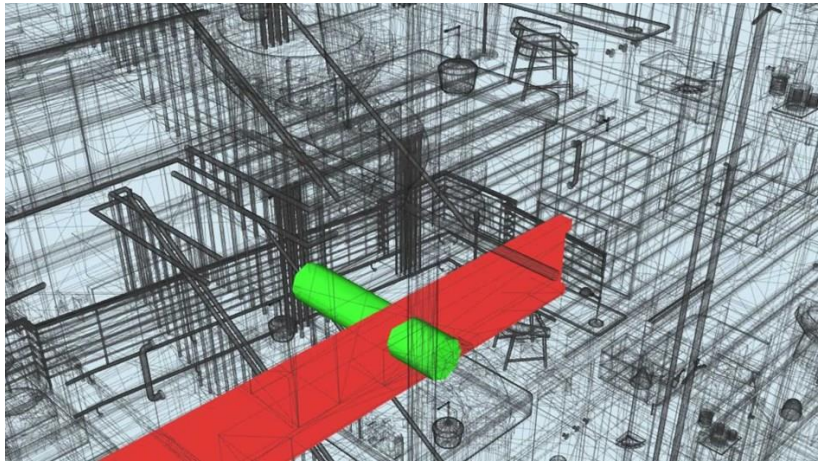



- **HVAC information** can be useful **input** for:
  - Set up Building Energy Models
  - Design Fault Detection and Control applications
  - Support Facility Management tasks

# BIM/IFC as a source of HVAC topology

- **IFC** offers a **digital representation** of the physical and functional characteristics of a building and its constituents
- HVAC topology is being created during **MEP design coordination** of Mechanical, Electrical and Plumbing systems
- Yet, IFC is strongly **focused on geometry** to allow spatial configuration of building constituents, with primary goal to **avoid costly clashes**

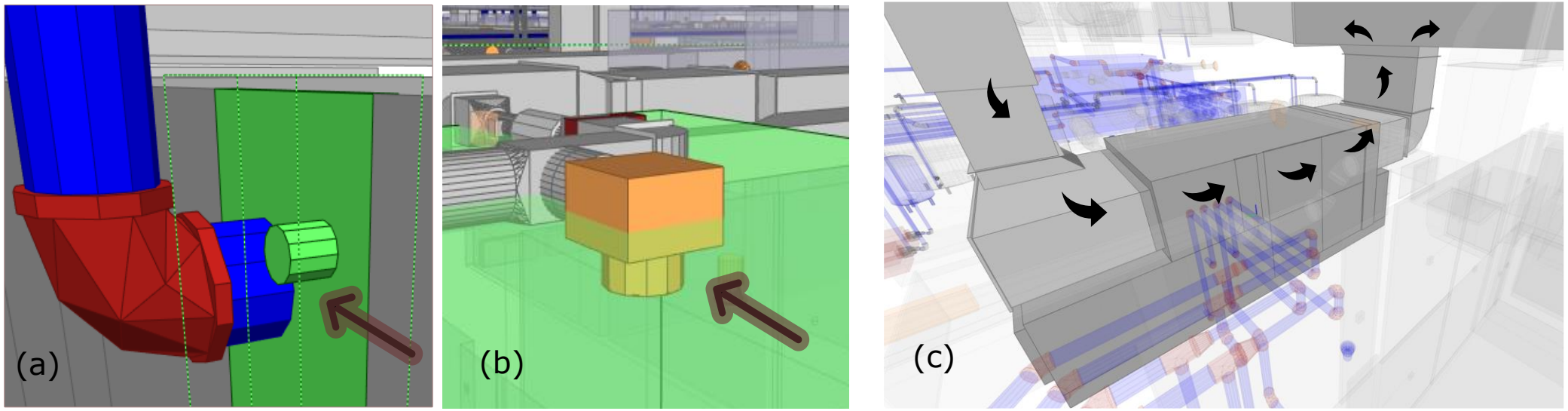




# Modelling Imperfections

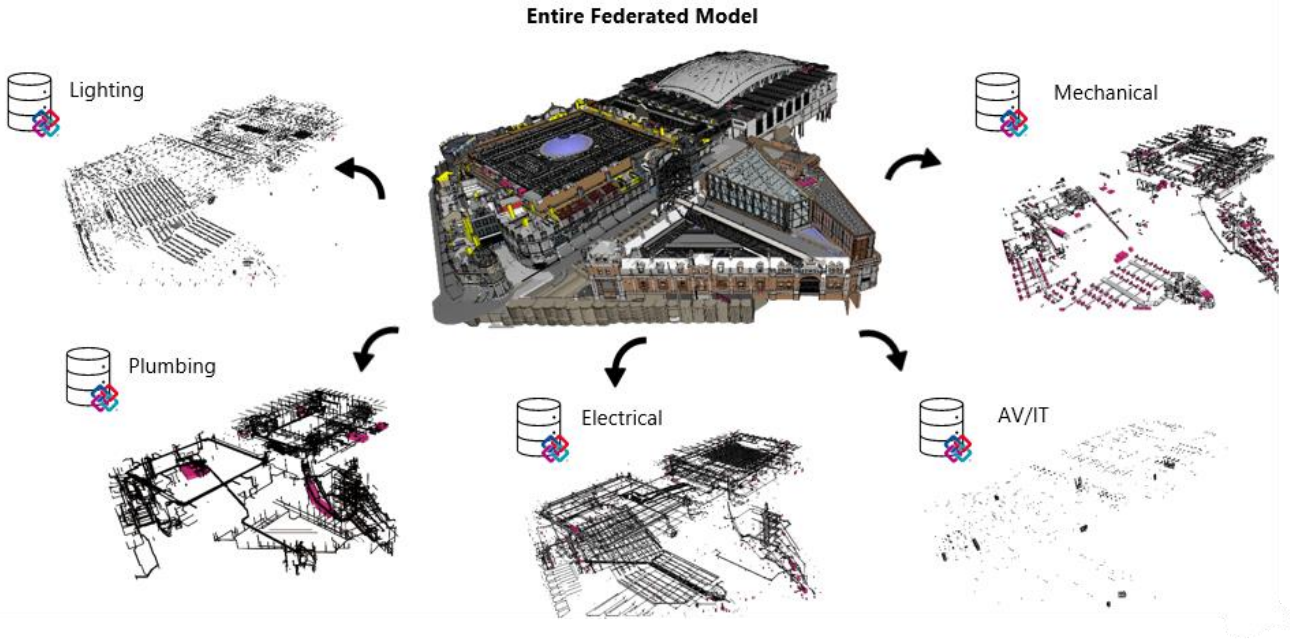
- Modellers **omit operational requirements** that describe how HVAC systems operate

- IFC lack descriptions of how the constituent **equipment** and **spaces function together** due to the **fragmented** nature of **BIM authoring**.




- IFC **insufficient** for **reuse** to set up energy models, data analytics, and other applications

# The New Museum of London (MoL)




- 26,000 $m^2$ re-development project in Central London.
- **24 semantically separated** (siloed) IFC models, produced by different contractors.

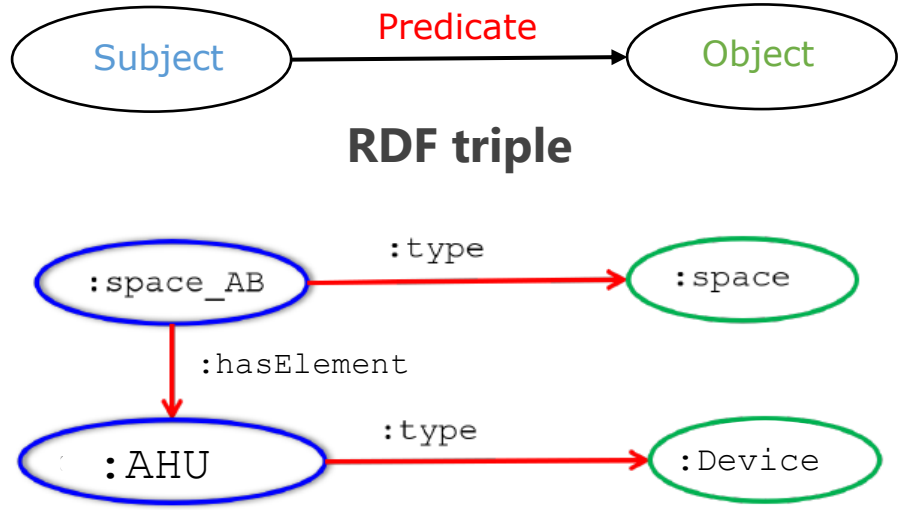
- IFC models remain **unused** **after project delivery**

# BIM/IFC vs Linked Data

- **IFC** adopts a ***"one-size fits all"*** approach
  - Focused on **editable geometries** (design focus) – not required to describe HVAC operation
  - Semantic relationships ***integrated*** with geometry

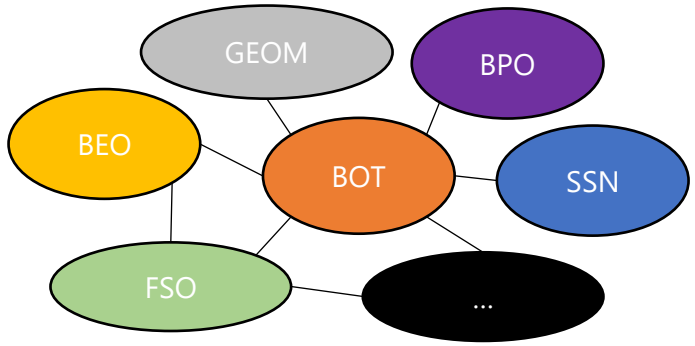
```
#13= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Axis','Model',*,*,*,*,#11,$,.GRAPH_VIEW.,$);
#14= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('FootPrint','Model',*,*,*,*,#11,$,.MODEL_VIEW.,$);
#15= IFCSIUNIT(*,.LENGTHUNIT.,.MILLI.,.METRE.);
#16= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(304.8),#15);
#17= IFCDIMENSIONALEXPONENTS(1,0,0,0,0,0,0);
#18= IFCCONVERSIONBASEDUNIT(#17,.LENGTHUNIT.,'FOOT',#16);
#19= IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#20= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.09290304),#19);
#21= IFCDIMENSIONALEXPONENTS(2,0,0,0,0,0,0);
#22= IFCCONVERSIONBASEDUNIT(#21,.AREAUNIT.,'SQUARE FOOT',#20);
#23= IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#24= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.028316846592),#23);
#25= IFCDIMENSIONALEXPONENTS(3,0,0,0,0,0,0);
#26= IFCCONVERSIONBASEDUNIT(#25,.VOLUMEUNIT.,'CUBIC FOOT',#24);
#27= IFCSIUNIT(*,.MASSUNIT.,.KILO.,.GRAM.);
#28= IFCSIUNIT(*,.TIMEUNIT.,$,.SECOND.);
#29= IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#30= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.0174532925199433),#29);
#31= IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#32= IFCCONVERSIONBASEDUNIT(#31,.PLANEANGLEUNIT.,'DEGREE',#30);
#33= IFCSIUNIT(*,.SOLIDANGLEUNIT.,$,.STERADIAN.);
```

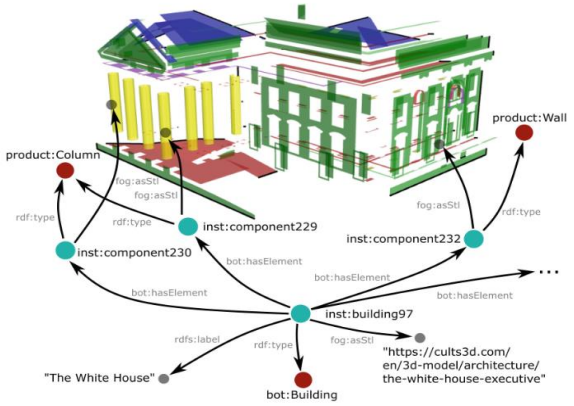
- **Linked Data** offer an alternative **modular** information paradigm:
  - Representing data in **knowledge graphs** (RDF/OWL)
  - Semantic relationships ***separated*** with geometry
  - Cross-domain linking (e.g. analytics/modelling)



# Linked Building Data (LBD)

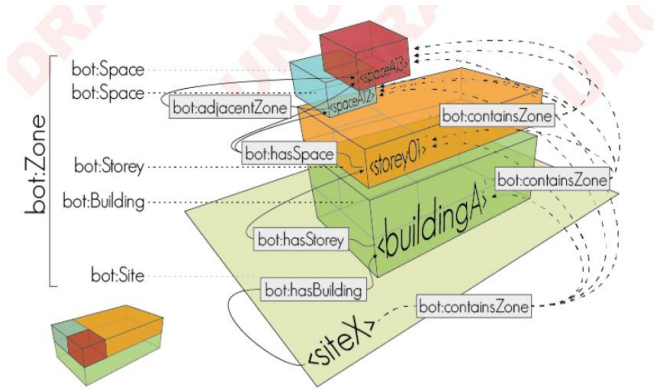
- Efforts to overcome the limitations of ifcowl (large, complex, hard to understand)
- LBD aims to represent **all building data** through a set of **modular domain ontologies**
- **BOT** is a minimal, lightweight ontology is at the **core of LBD**, to be combined with:
  - Geometry (GEOM),
  - Product catalogues (BPO),
  - Flow system (FSO),
  - other…

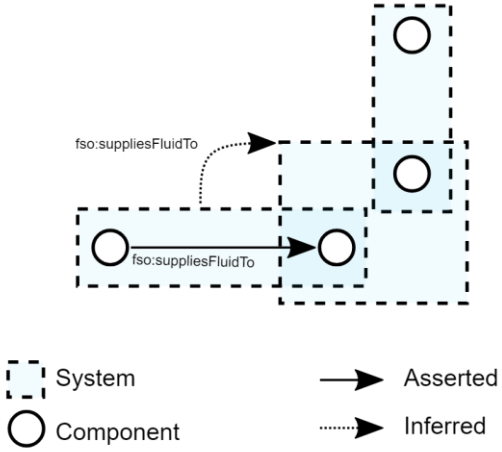


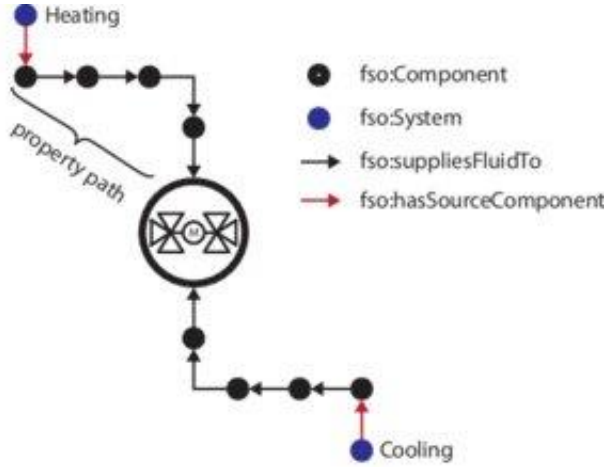




- Focus given on **1-1 mapping** from BIM/IFC

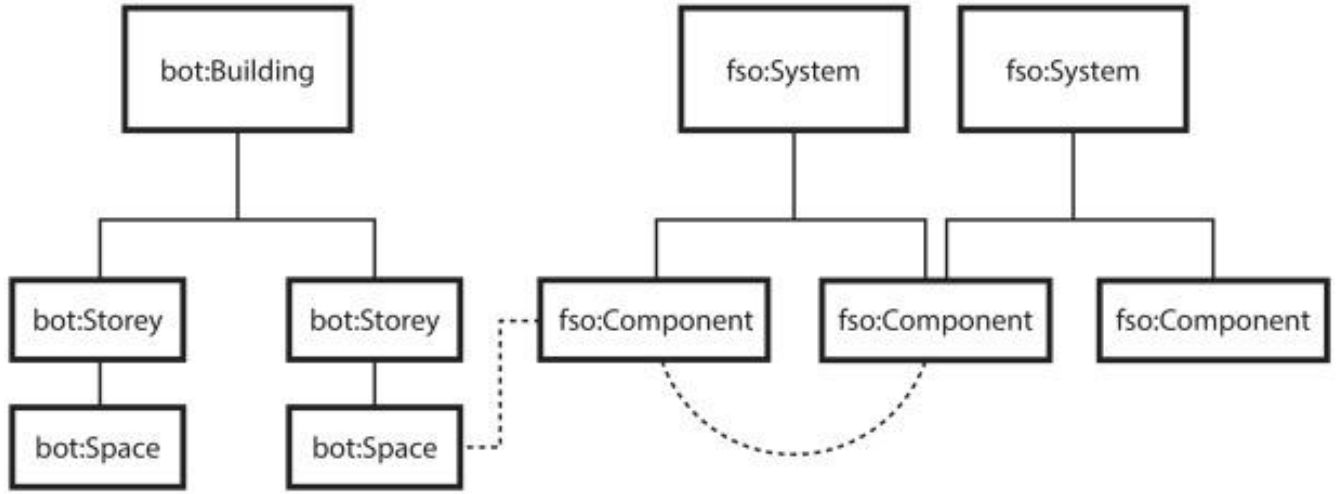
# BOT & FSO for HVAC System Topology



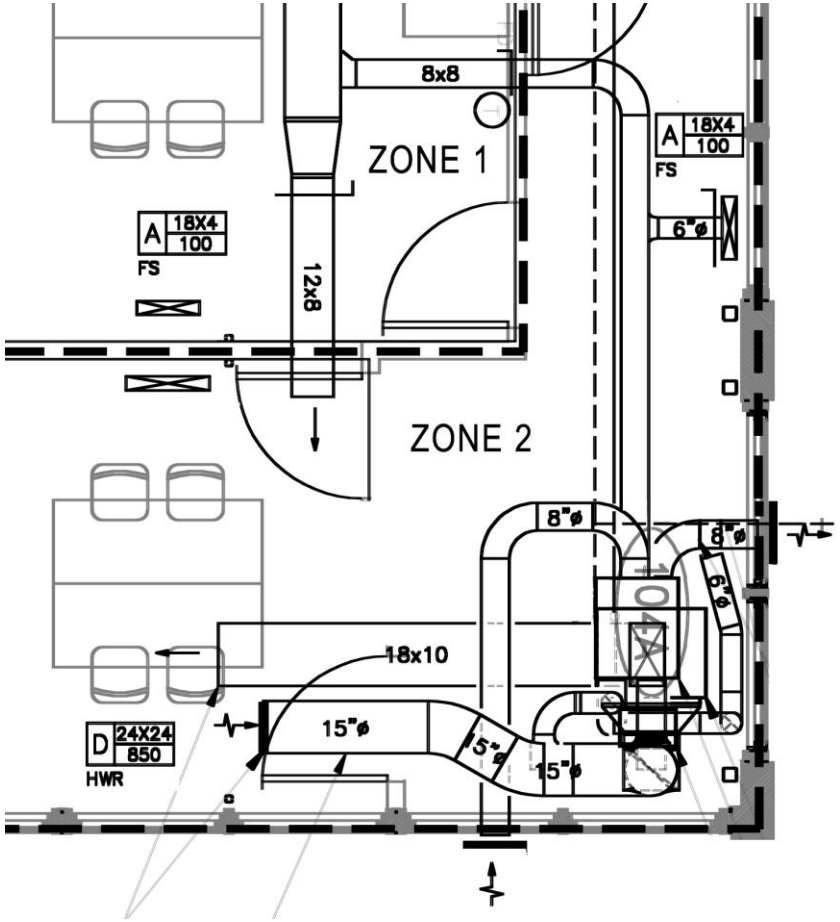




- **BOT**: Basic topological aspects of buildings.
- **FSO**: Systems and components with material or energy flow connections
- Inspired from IFC



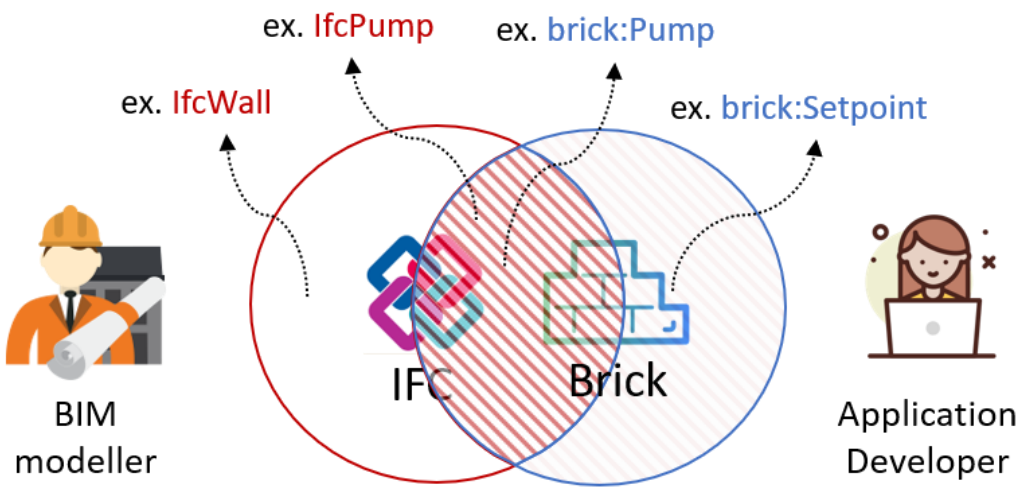
# HVAC topological & logical relationships

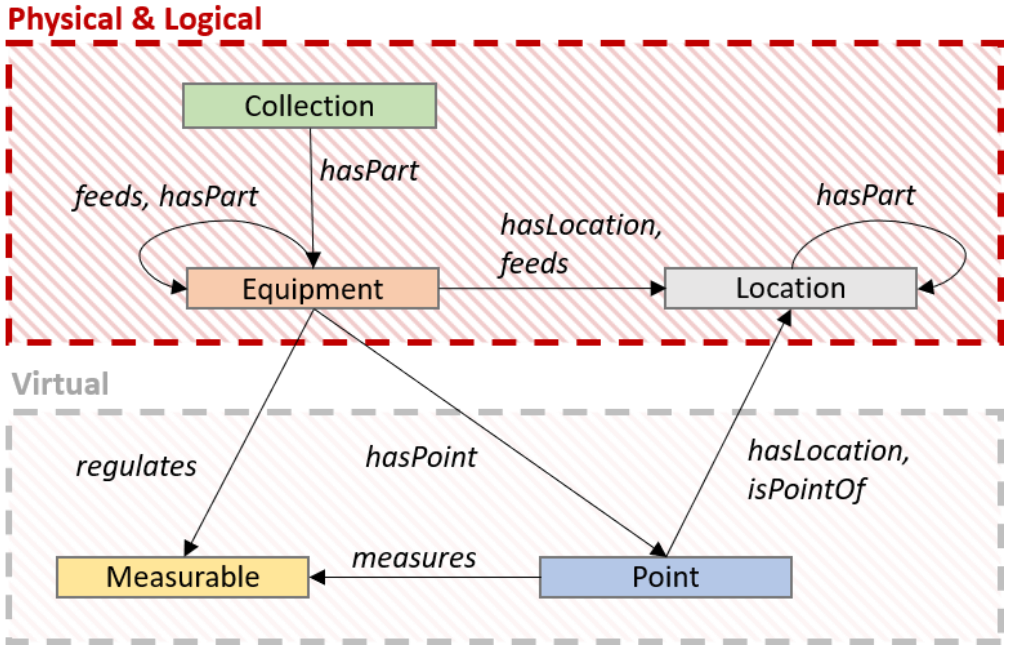
- **Holistic view** of HVAC topology including how HVAC systems "serve" building zones:
  - (1) *Topological* or *Geometry-based* relations capturing **spatial distribution** of HVAC components.
  - (2) *Logical or Upstream/Downstream* **connectivity** between HVAC and spatial components.



# Brick Schema for HVAC operation logic

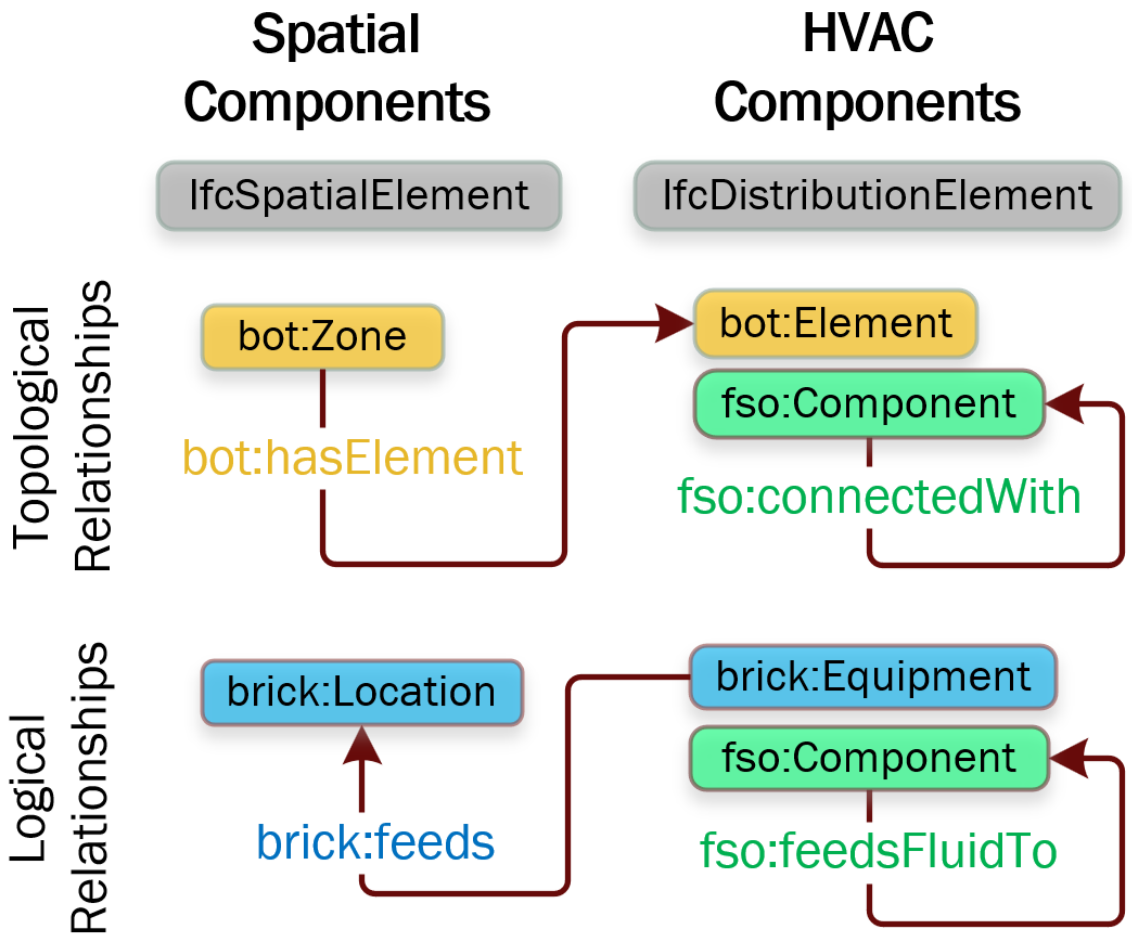
- Brick supports **Smart Analytics** and **Control** applications.
- Focus on real-time data, used in **O&M phases**
- **Overlap** with IFC (different philosophy)
- **Application-focused** vs Domain-focused (BOT/FSO)



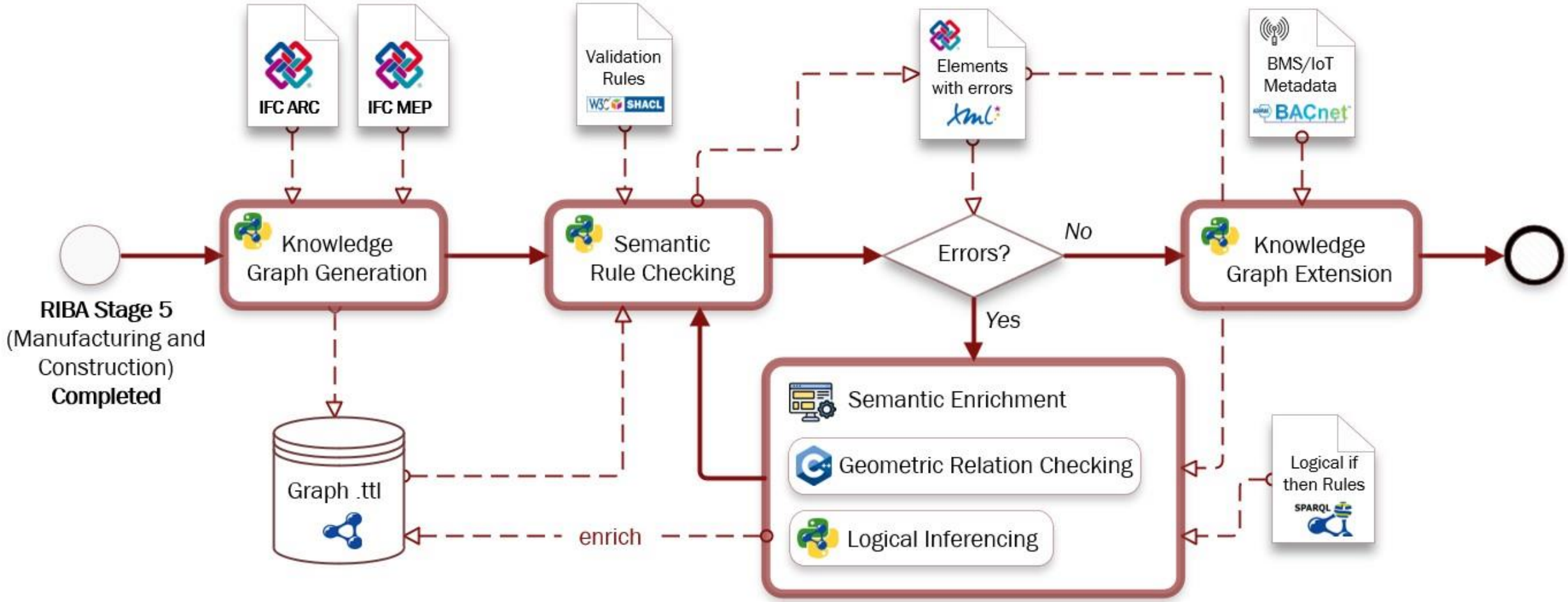



# Ontology-based HVAC representation

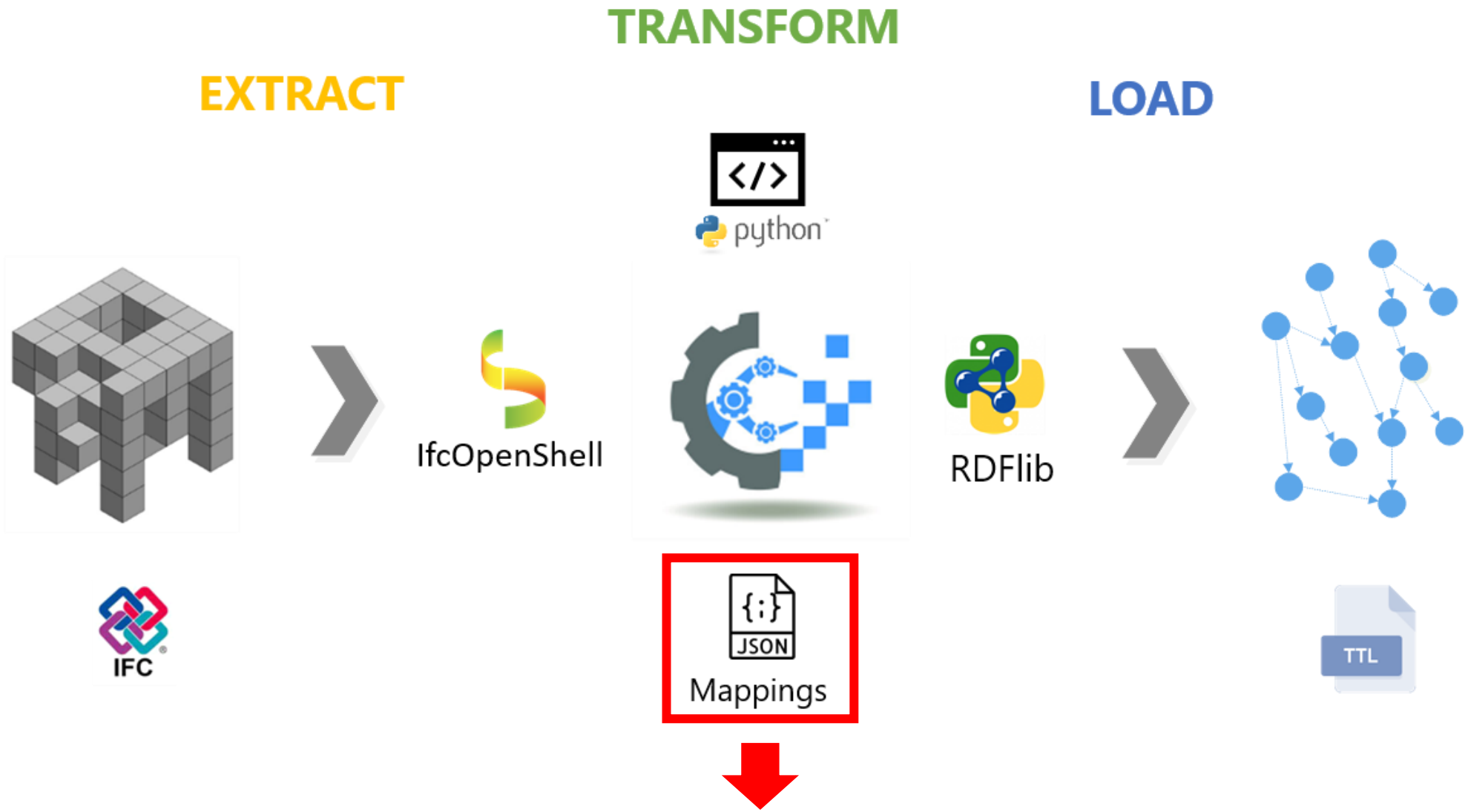
- Ontologies from the building domain:
  - **BOT**: Basic topological aspects of buildings.
  - **FSO**: Systems and components with material or energy flow connections.
  - **Brick**: Supports Analytics and Control applications.



# Transform – Check – Enrich



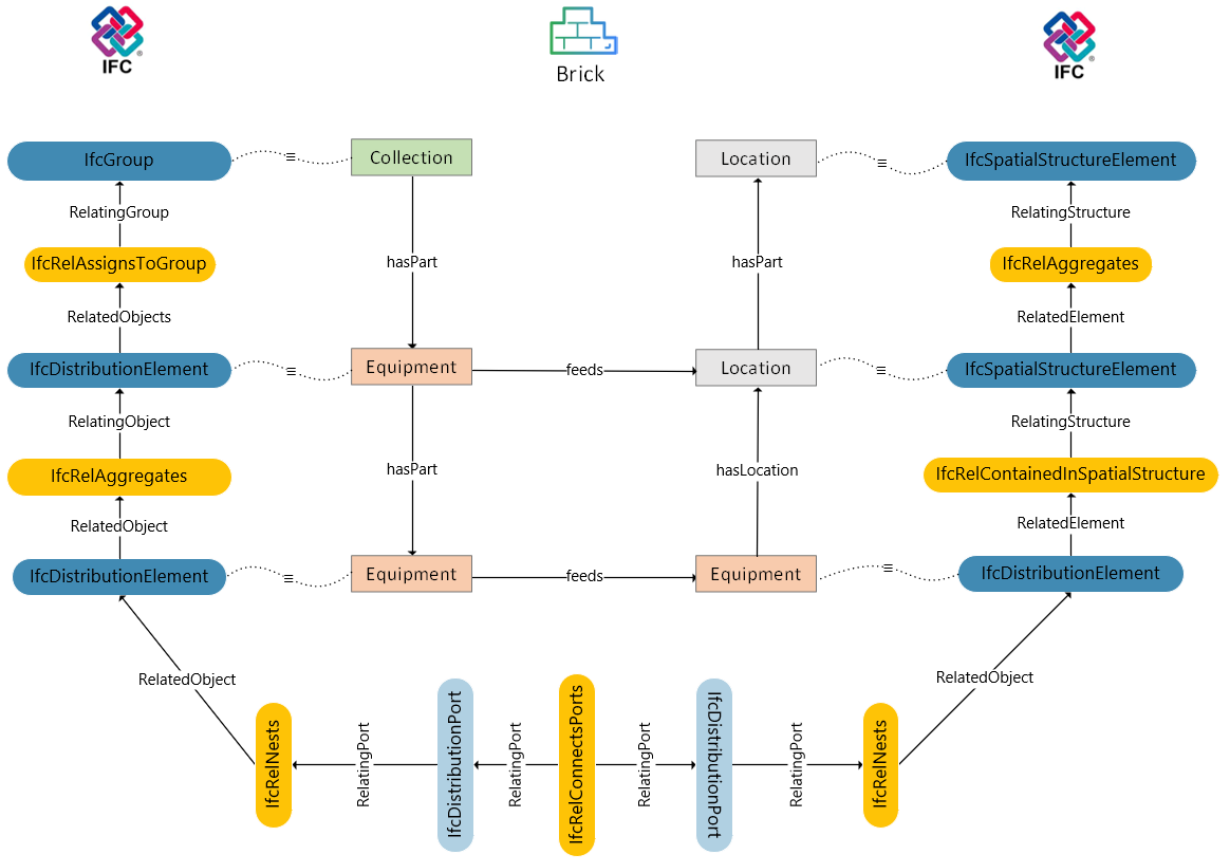
# Knowledge Graph Generation (ETL)



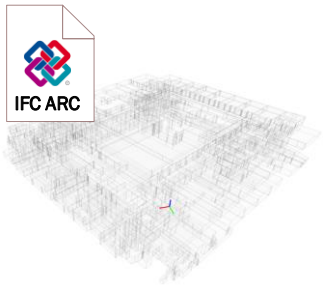
# Knowledge Graph Generation (Semantic Alignment)

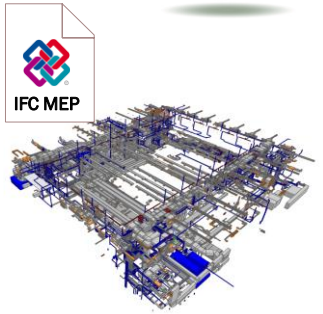
Table 1: Alignment of IFC classes with FSO and Brick ontologies (Sample of classes)

| IFC CLASS | bot: | fso: | brick: |
|---|---|---|---|
| **IfcGroup** | | | **Collection** |
| IfcSystem | | System | System |
| IfcDistributionSystem.AIRCONDITIONING | | DistributionSystem | Air_System |
| IfcDistributionSystem.GAS | | DistributionSystem | Gas_System |
| ... | | ... | ... |
| IfcZone | | | Zone |
| **IfcDistributionElement** | | | **Equipment** |
| IfcDuctSegment | Element | Segment | |
| IfcPipeSegment | Element | Segment | |
| IfcDuctFitting | Element | Fitting | |
| IfcPipeFitting | Element | Fitting | |
| IfcDuctSilencer | Element | TreatmentDevice | |
| IfcFilter | Element | TreatmentDevice | Filter |
| ... | ... | ... | ... |
| IfcBoiler | Element | EnergyConversionDevice | Boiler |
| IfcChiller | Element | EnergyConversionDevice | Chiller |
| IfcCoil | Element | EnergyConversionDevice | Coil |
| ... | ... | ... | ... |
| IfcAirTerminalBox | Element | FlowController | Terminal_Unit |
| IfcAirTerminalBox.CONSTANTFLOW | Element | FlowController | CAV |
| IfcAirTerminalBox.VARIABLEFLOW | Element | FlowController | VAV |
| IfcDamper | Element | FlowController | Damper |
| ... | ... | ... | ... |
| IfcCompressor | Element | FlowMovingDevice | Compressor |
| IfcFan | Element | FlowMovingDevice | Fan |
| ... | ... | ... | ... |
| IfcTank | Element | StorageDevice | Water_Tank |
| ... | ... | ... | ... |
| IfcFlowTerminal | Element | Terminal | Air_Diffuser |
| ... | ... | ... | ... |
| IfcUnitaryControlElement.THERMOSTAT | Element | | Thermostat |
| ... | ... | | ... |
| IfcBuildingElementProxy | Element | | |
| ... | ... | ... | ... |
| **IfcSpatialStructure** | | | **Location** |
| IfcSite | Site | | Site |
| IfcBuilding | Building | | Building |
| IfcBuildingStorey | Storey | | Storey |
| IfcSpace | Space | | Space |
| IfcSpace.PARKING | Space | | Parking_Space |
| IfcSpatialZone | Zone | | Zone |
| IfcSpatialZone.LIGHTING | Zone | | Lighting_Zone |
| IfcSpatialZone.FIRESAFETY | Zone | | Fire_Zone |
| ... | ... | | ... |

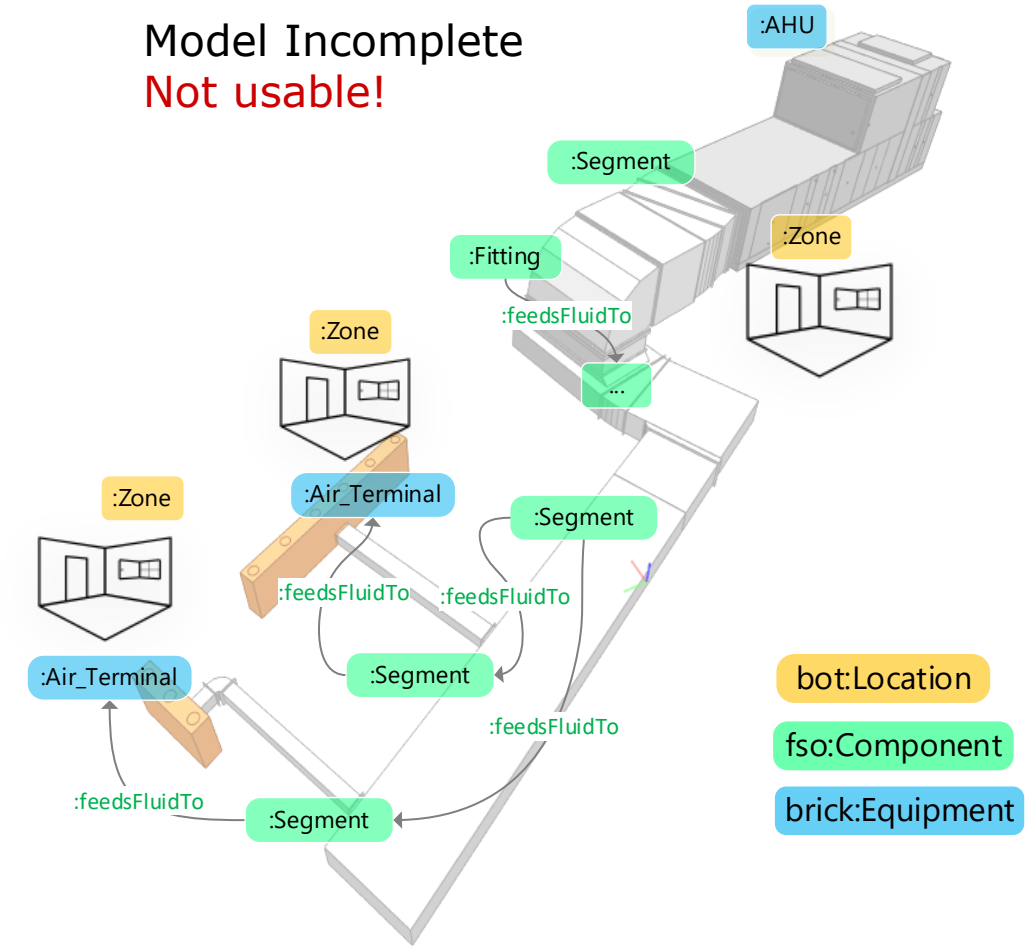


# Knowledge Graph Generation



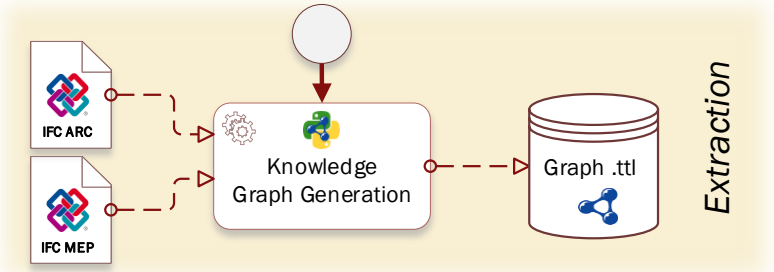

Model Incomplete
Not usable!




bot:Location

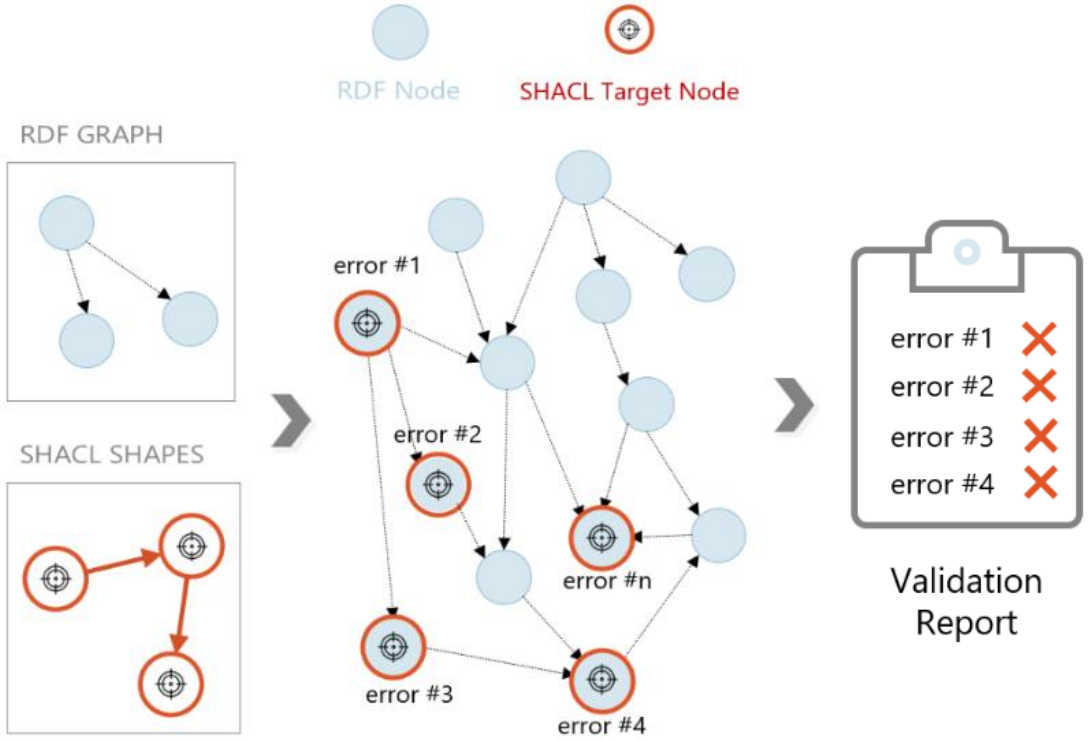
fso:Component

brick:Equipment



# Semantic Rule Checking

- Validate the **semantic completeness** of the RDF knowledge graph
- **SHACL** (SHApes Constraint Language) takes the RDF graph and the SHACL Shapes
- Validation Engine (i.e., Pyshacl) returns a **validation report** including **errors**.



# Expressing Semantic Rules (Constraints) with SHACL

- Topological:
  - Rule1: Every **bot:Element** must be located in **one and only one bot:Zone**
  - Rule2: Every **fso:Terminal** must be connected with **one and only one fso:Segment**
  - …
- Logical:
  - Rule7: Every **brick:Equipment** must feed **at least one brick:Location**
  - …

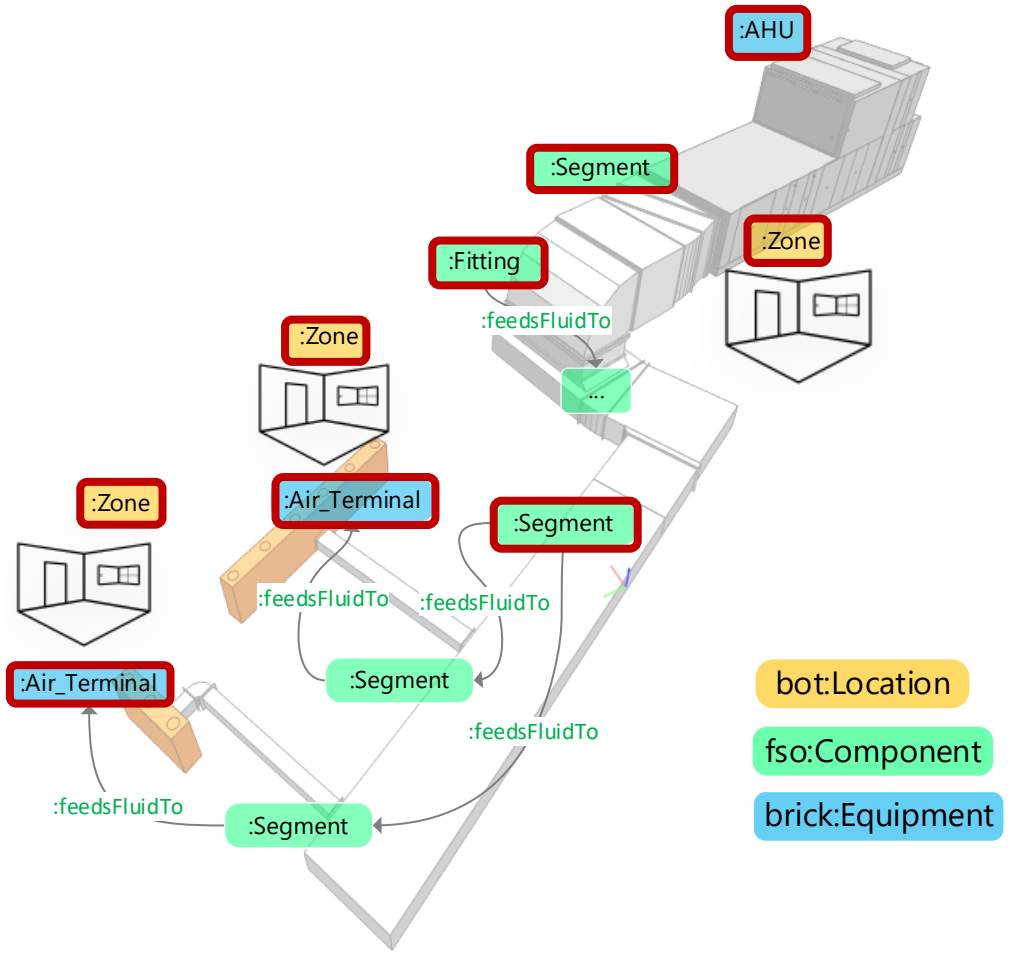
*Table 2: Rules for checking Topological relationships*

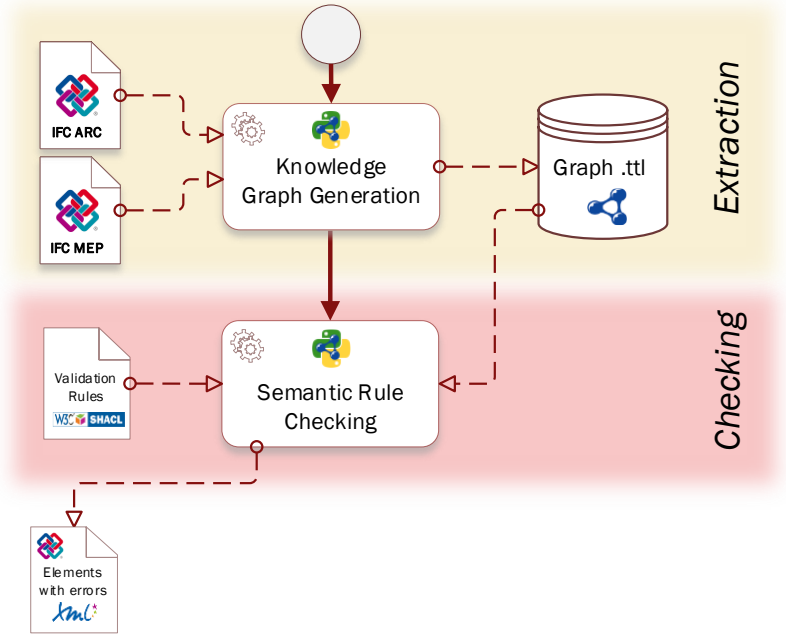
| Node | Edge | Node | Card. |
|---|---|---|---|
| bot:Zone | bot:hasElem. | bot:Elem. | 1 |
| fso:Term. | fso:con...With | fso:Segm. | 1 |
| fso:Segment | fso:con...With | fso:Comp. | 2...* |
| fso:Fitting | fso:con...With | fso:Comp. | 2...* |
| fso:Compon. | fso:con...With | fso:Comp. | 1...* |

*Table 3: Rules for checking Logical relationships*

| Node | Edge | Node | Card. |
|---|---|---|---|
| fso:Compon. | fso:feedsFl. | fso:Compon. | 1 |
| fso:Term. | fso:feedsFl. | brick:Loc. | 1 |
| brick:Equip. | brick:feeds | brick:Loc. | 1...* |

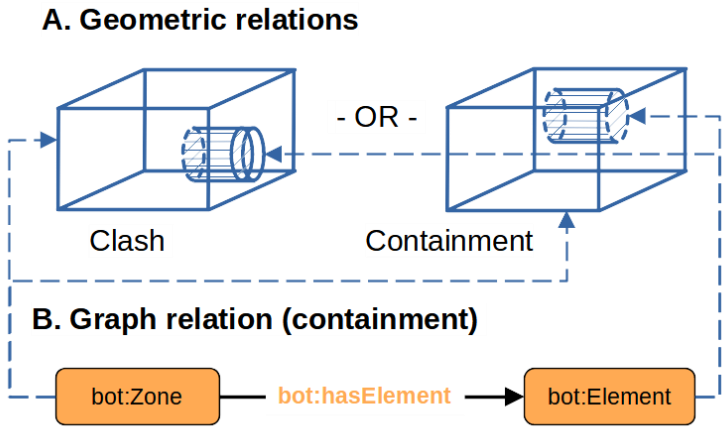
# Semantic Rule Checking

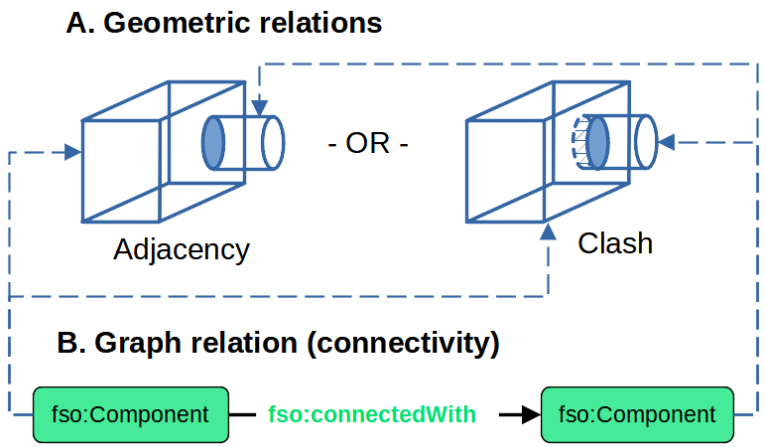


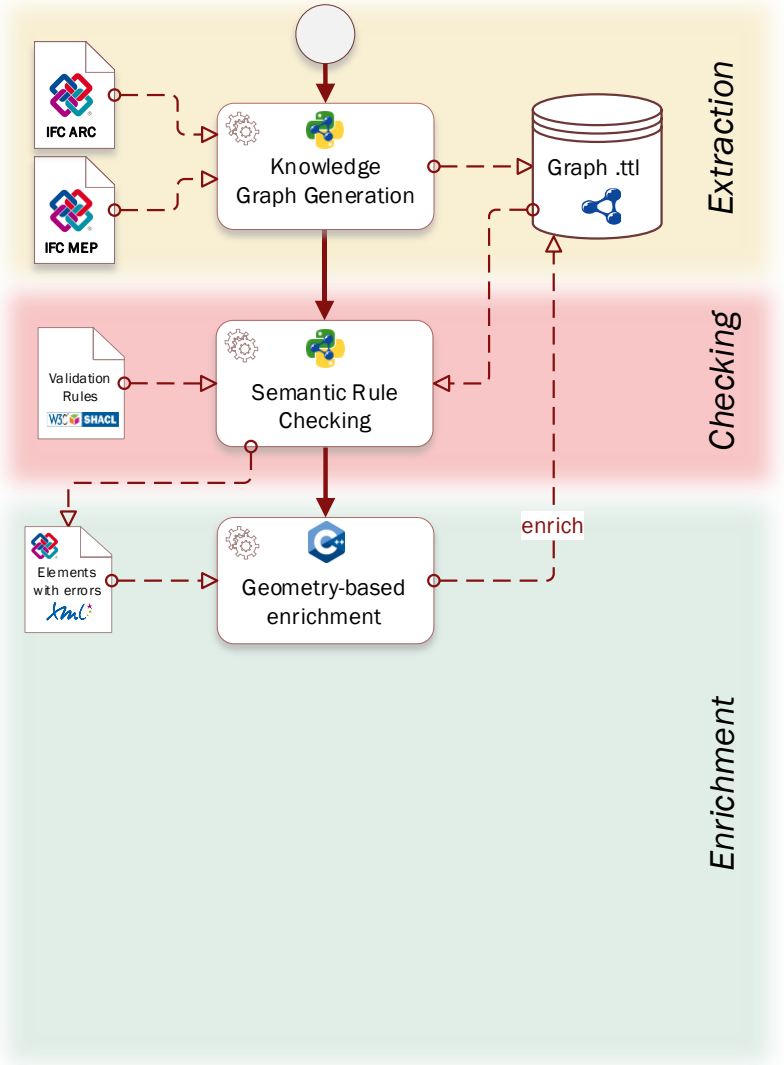



# Geometry Relation Checking (GRC)

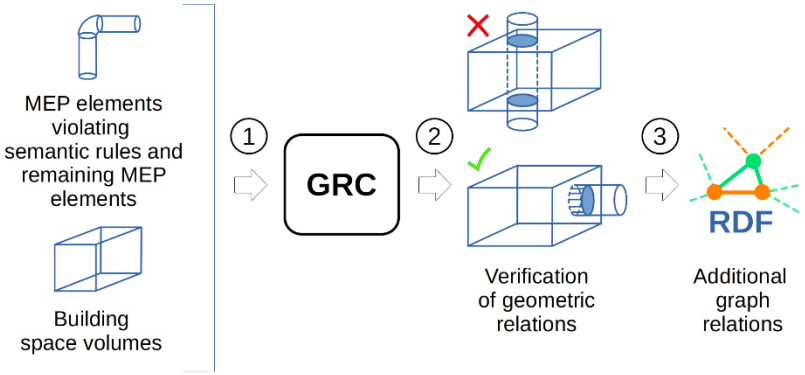
- Semantic Enrichment tool based on **IFC geometry**
- Takes IFC geometry inputs and returns **BOT/FSO relationships**
- Geometric Relation Checker (**GRC**) detects:
  - (1) Clash
  - (2) Adjacency
  - (3) Containment
  - (4) Proximity (not yet)



# Enrichment through Geometry

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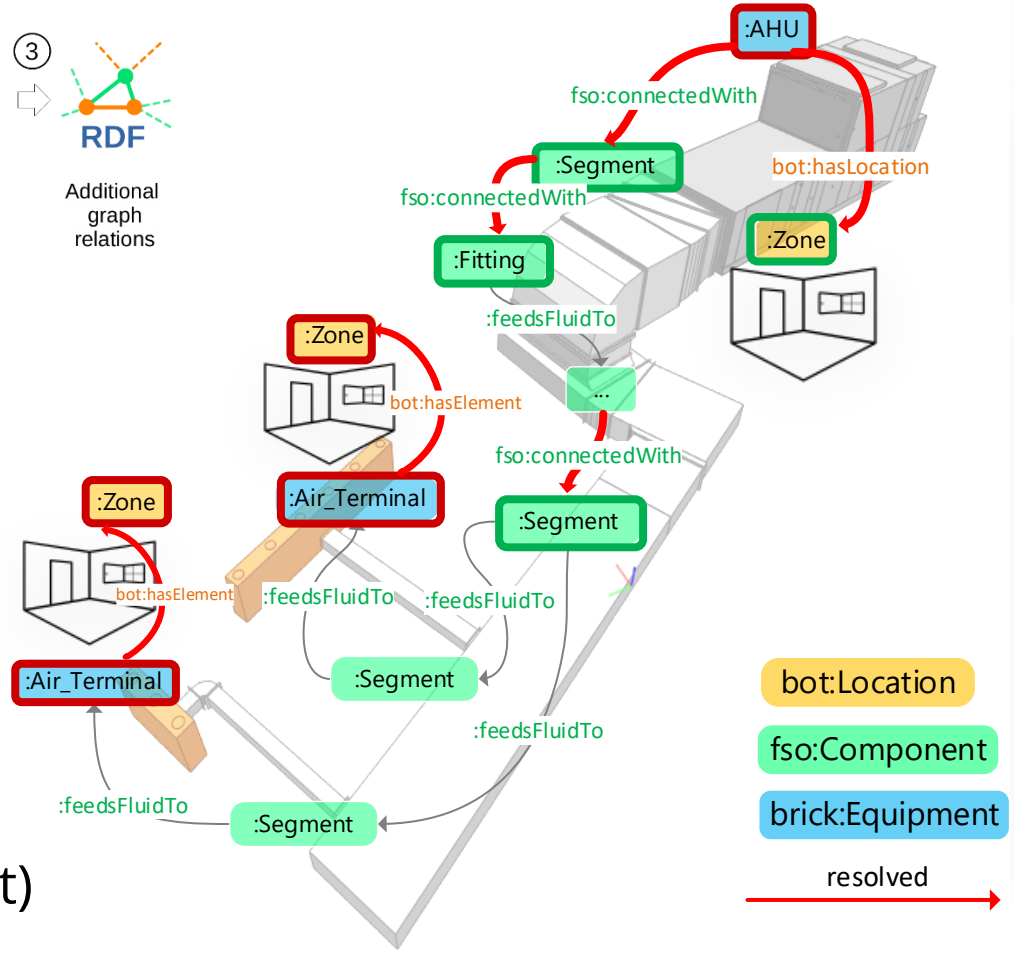
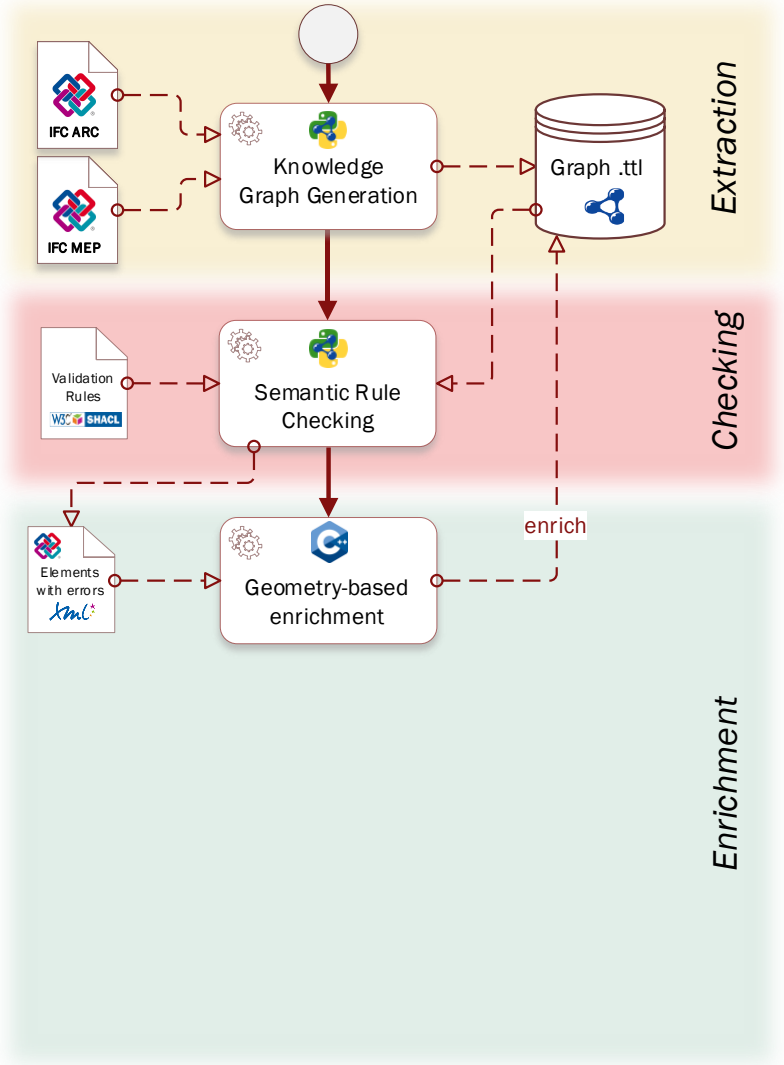


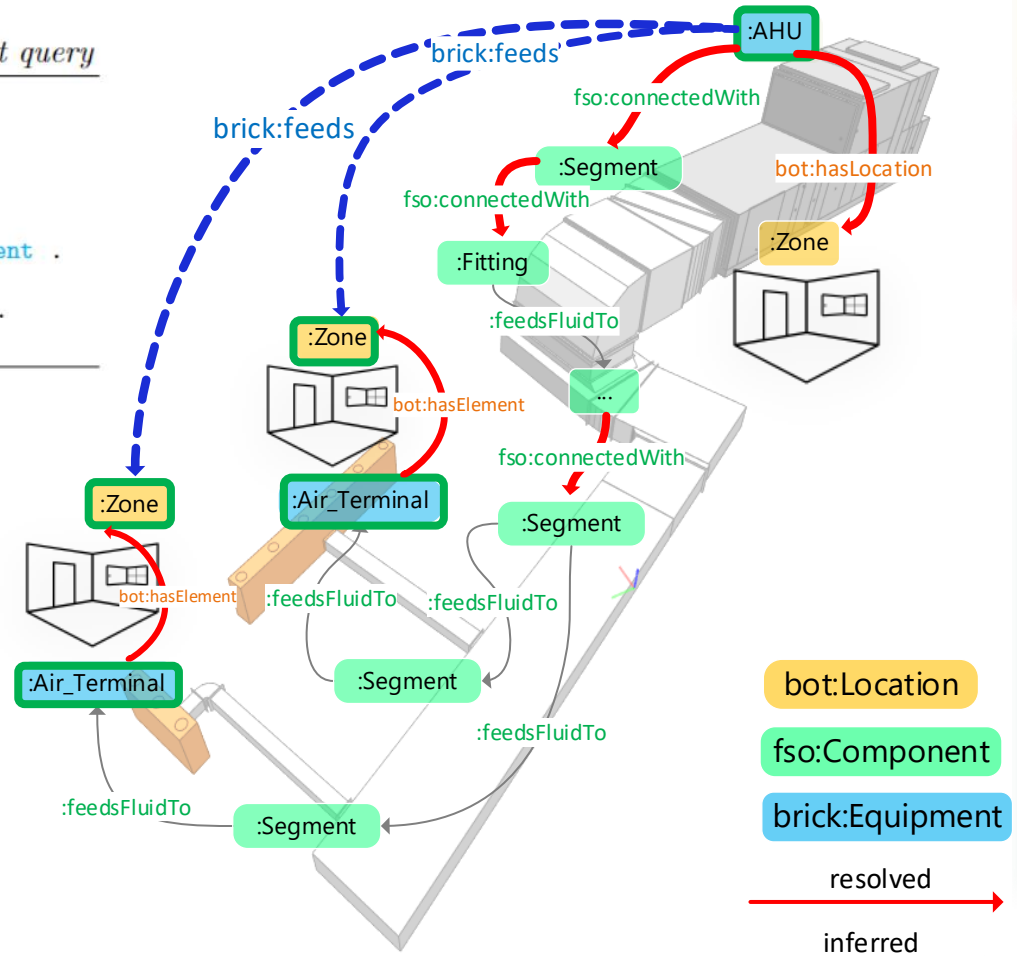



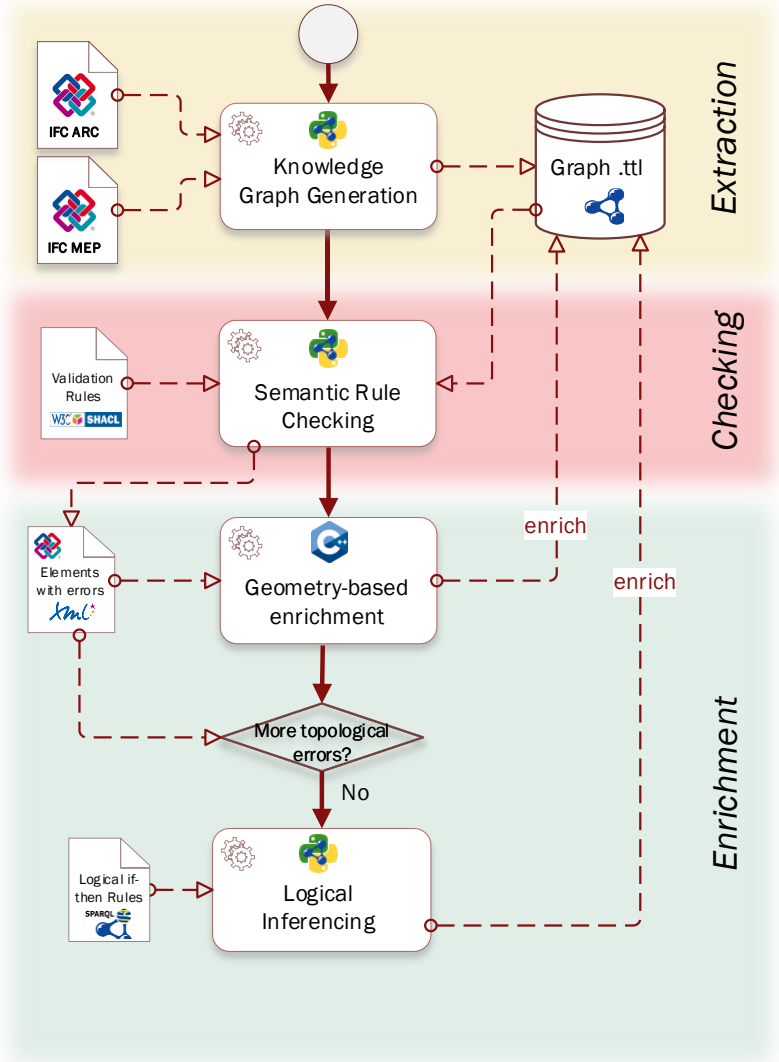
# Enrichment through Logical Inferencing

*Listing 2: If-then rule as SPARQL Construct query*

```
CONSTRUCT {
    ?terminal brick:feeds ?space .
    ?equipment brick:feeds ?space }.
WHERE {
    ?terminal a fso:Terminal .
    ?equipment a brick:Equipment, fso:Component .
    ?space a bot:Zone, brick:Location .
    ?equipment fso:feedsFluidTo+ ?terminal .
    ?terminal bot:hasLocation ?space }.
```

- Simple **if-then rules** to **infer** more **abstract** relationships such as what equipment "**serves**" what spaces

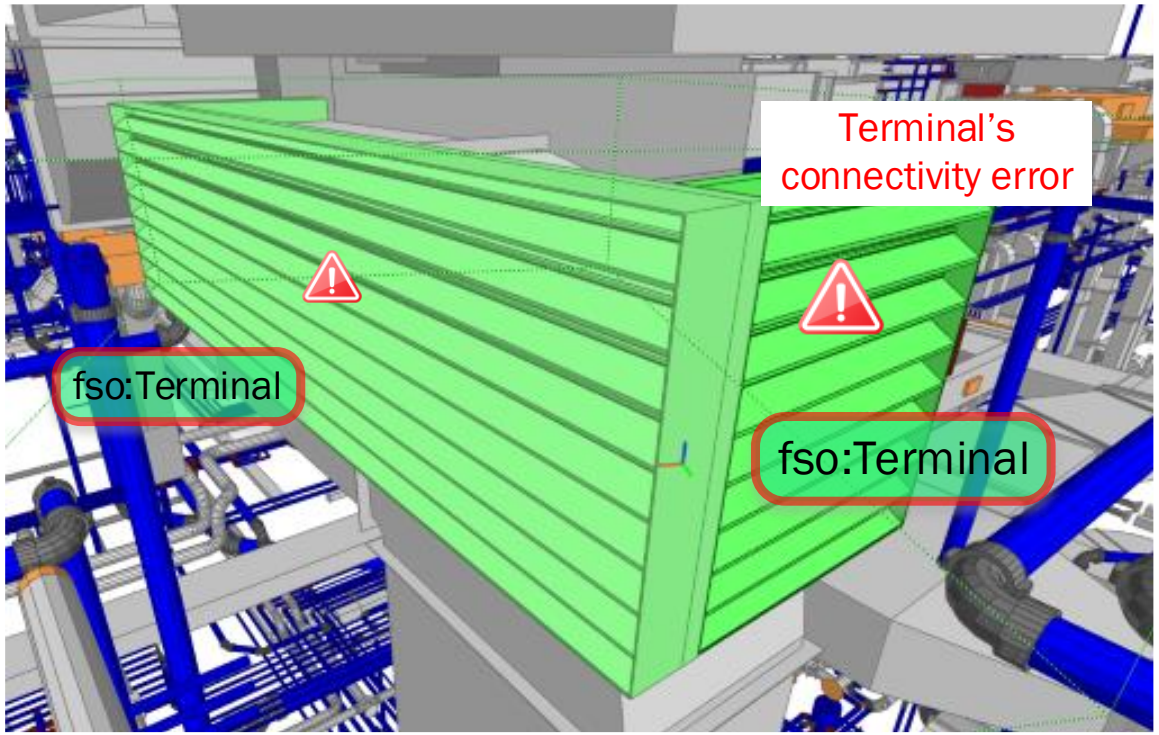


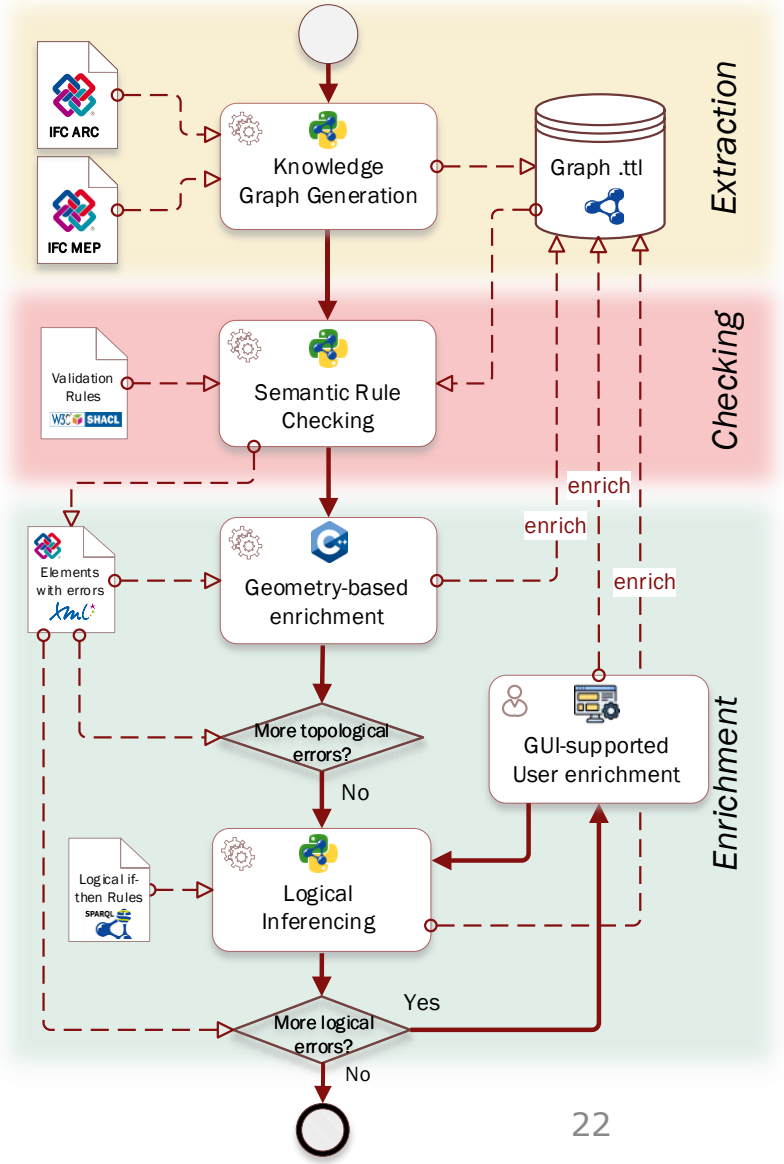




bot:Location
fso:Component
brick:Equipment
resolved
inferred

# GUI-supported resolution

- Enrichment tools **failed to resolve** all issues
- **Navigate users** to resolve unresolved errors through a GUI



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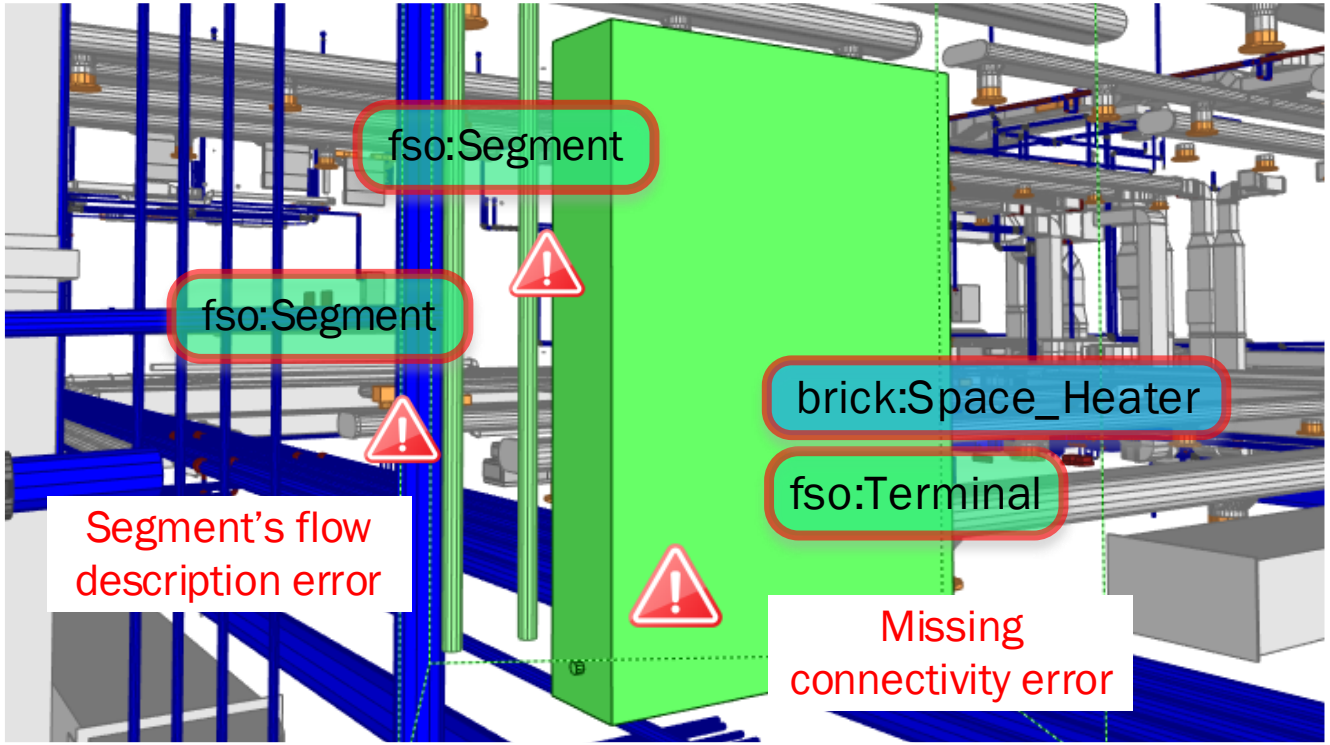
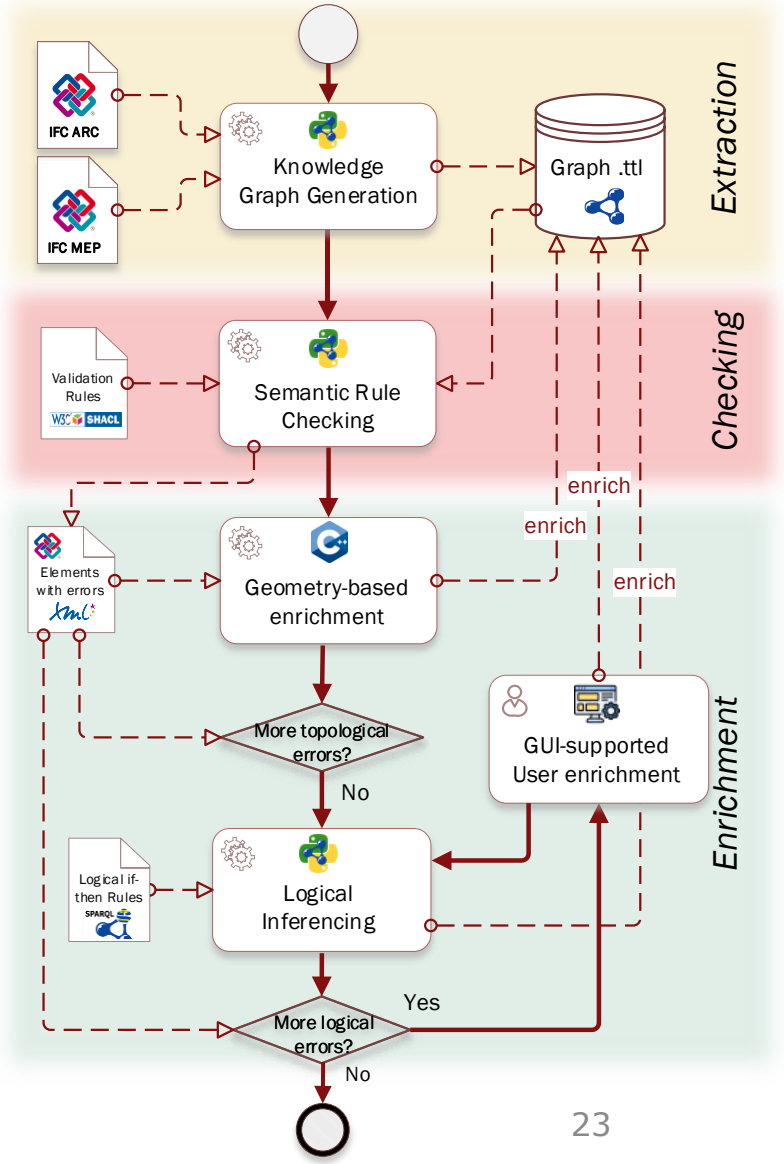
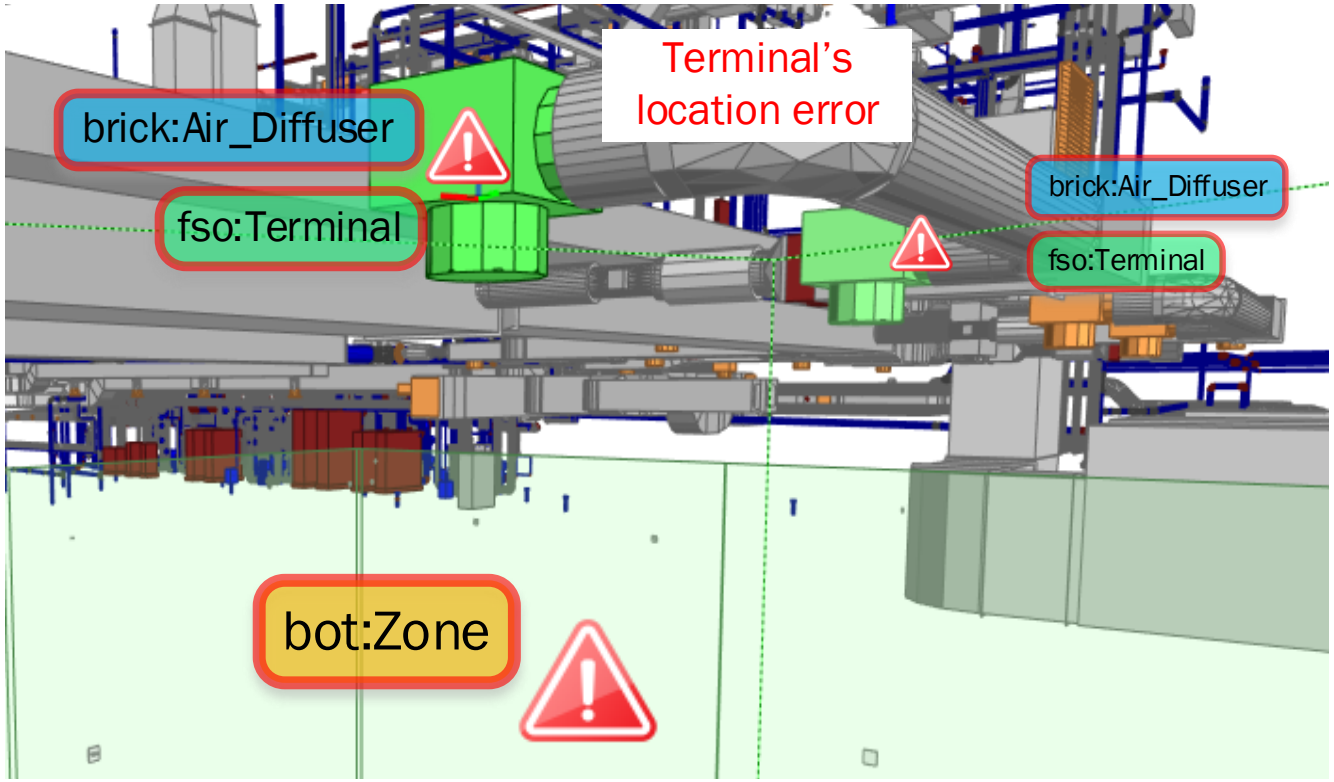
- **Navigate users** to resolve unresolved errors through a GUI

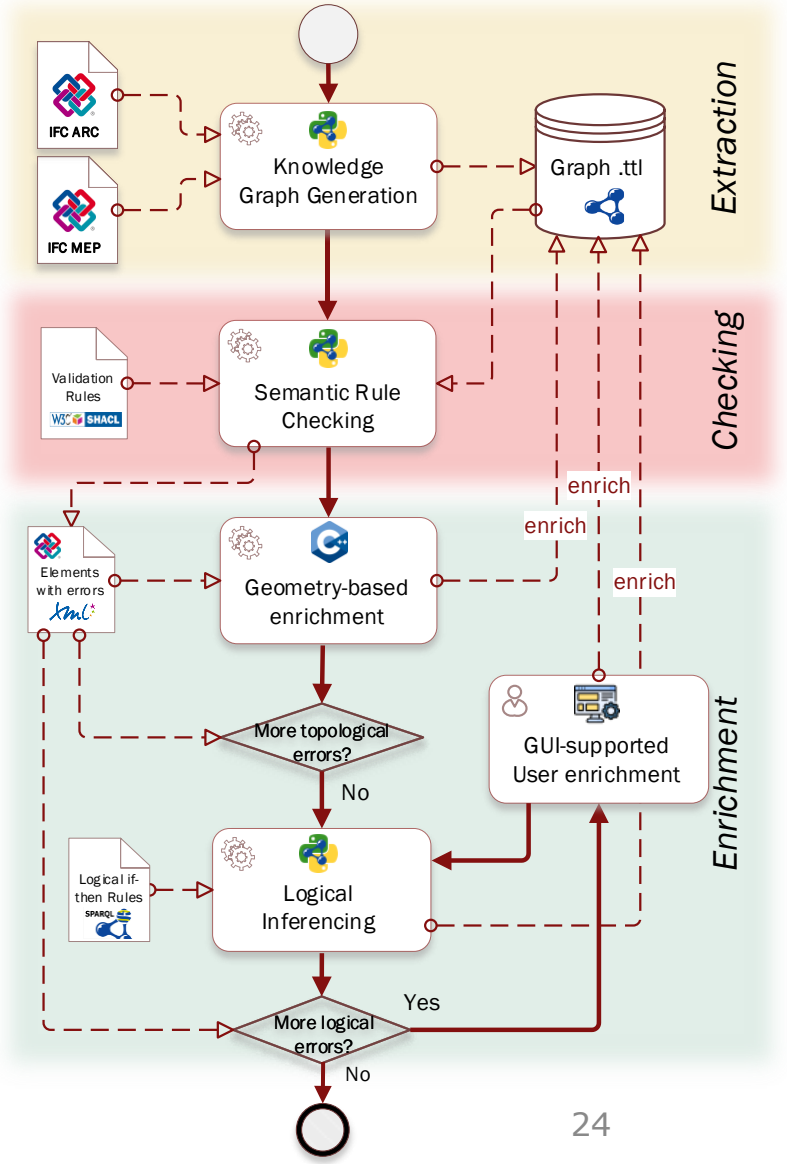


# GUI-supported resolution

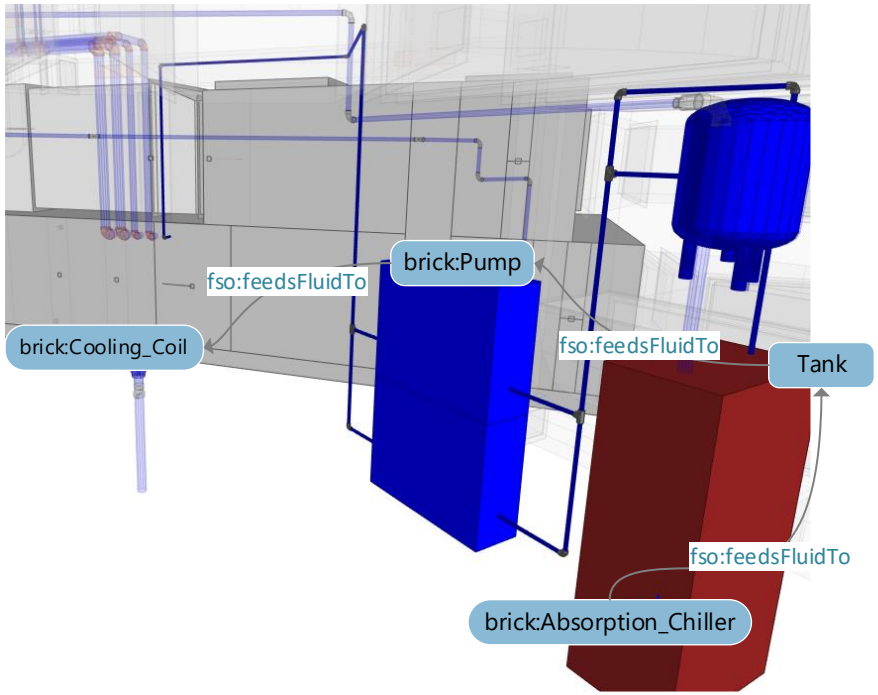
- Enrichment tools **failed to resolve** all issues
- **Navigate users** to resolve unresolved errors through a GUI

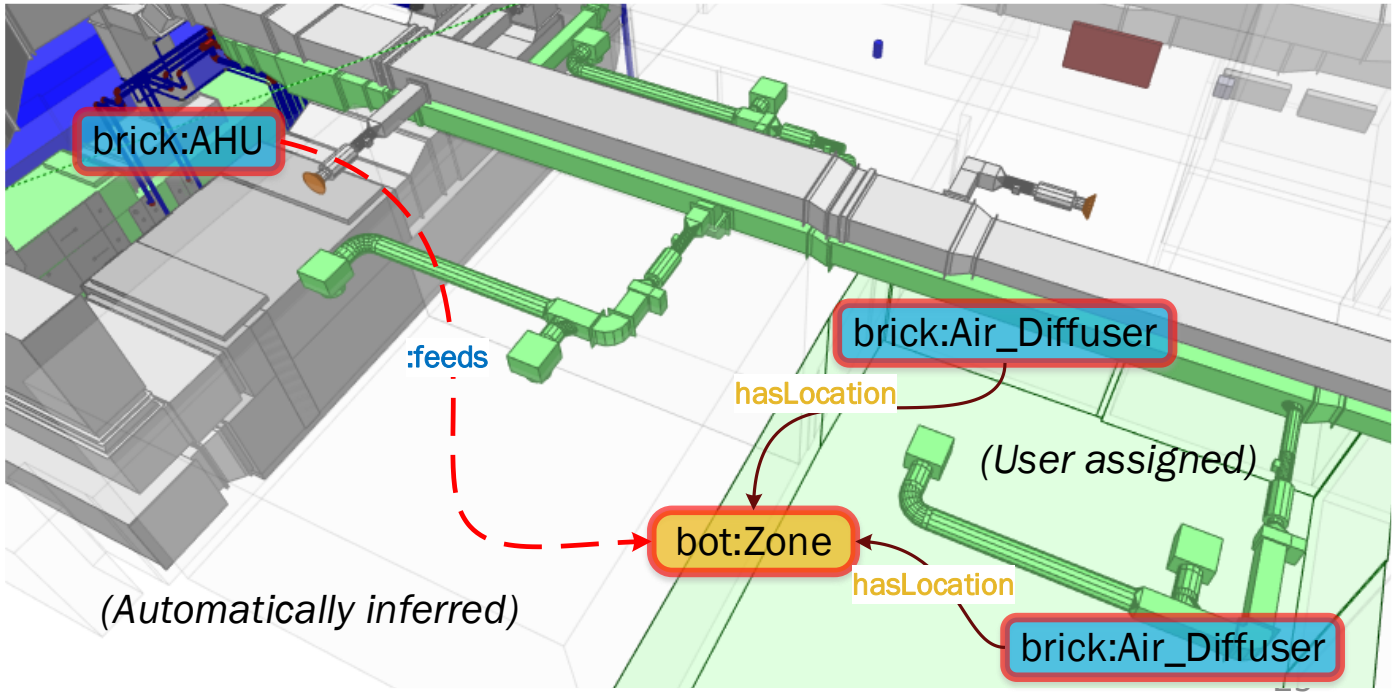


# Insights from the MoL

- ❑ **Discovered** 19,933 errors only from topological rules.
- ❑ **Only 77** additional `brick:feeds` relationships inferred before GRC
- ❑ GRC **resolved** 14,140 errors (~**70%**), especially connecting Spatial with HVAC components
- ❑ ~30% errors were left for **manual inspection** (mainly due to proximity)



# Conclusions & Next Steps

- **Identified** and **corrected** missing relationships of HVAC topology in a **real-world model**
  - **Considerable effort** to manually resolve unresolved errors.
  - **One-off** process navigating the users to "clean" the model.
- **Flexible data access** through SPARQL queries – no need to author an IFC model
- **Further development of GRC** to identify advanced relationships e.g., **spatial proximity**
- Evaluate the ability of the workflow to **generate usable HVAC inputs** for energy models
- Opens-up the discussion for a general **data governance** approach **to reuse IFC in operation**



# Thank you!

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