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Seminar 14: Better Data and Analytics Enable Better Decision Making on Building Operations and Decarbonization

Metadata Ontologies for Data Discovery and Portable Analytics

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Learning Objectives

- Understand FAIR principles of data: Findability, Accessibility, Interoperability, and Reusability
- Learn where to find open building performance datasets
- Understand how dataset and analytics can provide insights to improve building operations
- Learn various data tools (ontology, schema, models) used to represent semantic and metadata of building and system data

Acknowledgements

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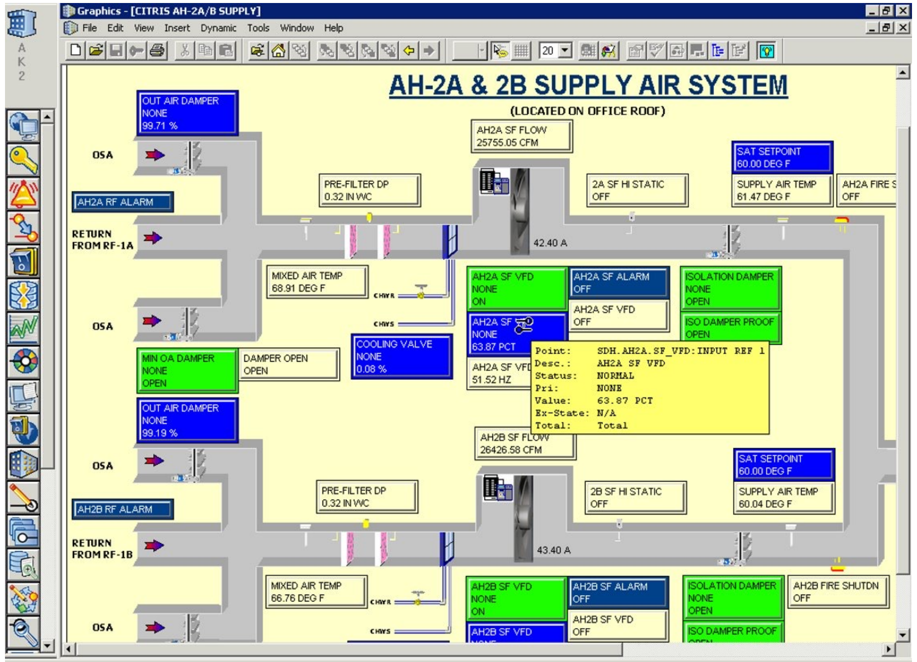
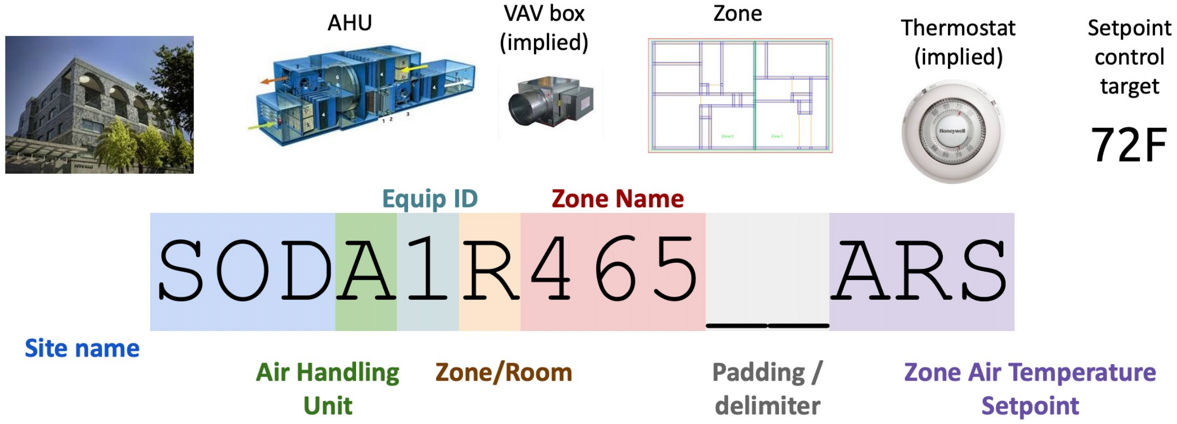
Outline/Agenda

- Overview of 223P and Brick ontologies
- Modeling buildings and building data with ontologies
- Accessing data through ontologies
- Using data to build fault detection and thermal models

Framing the Problem

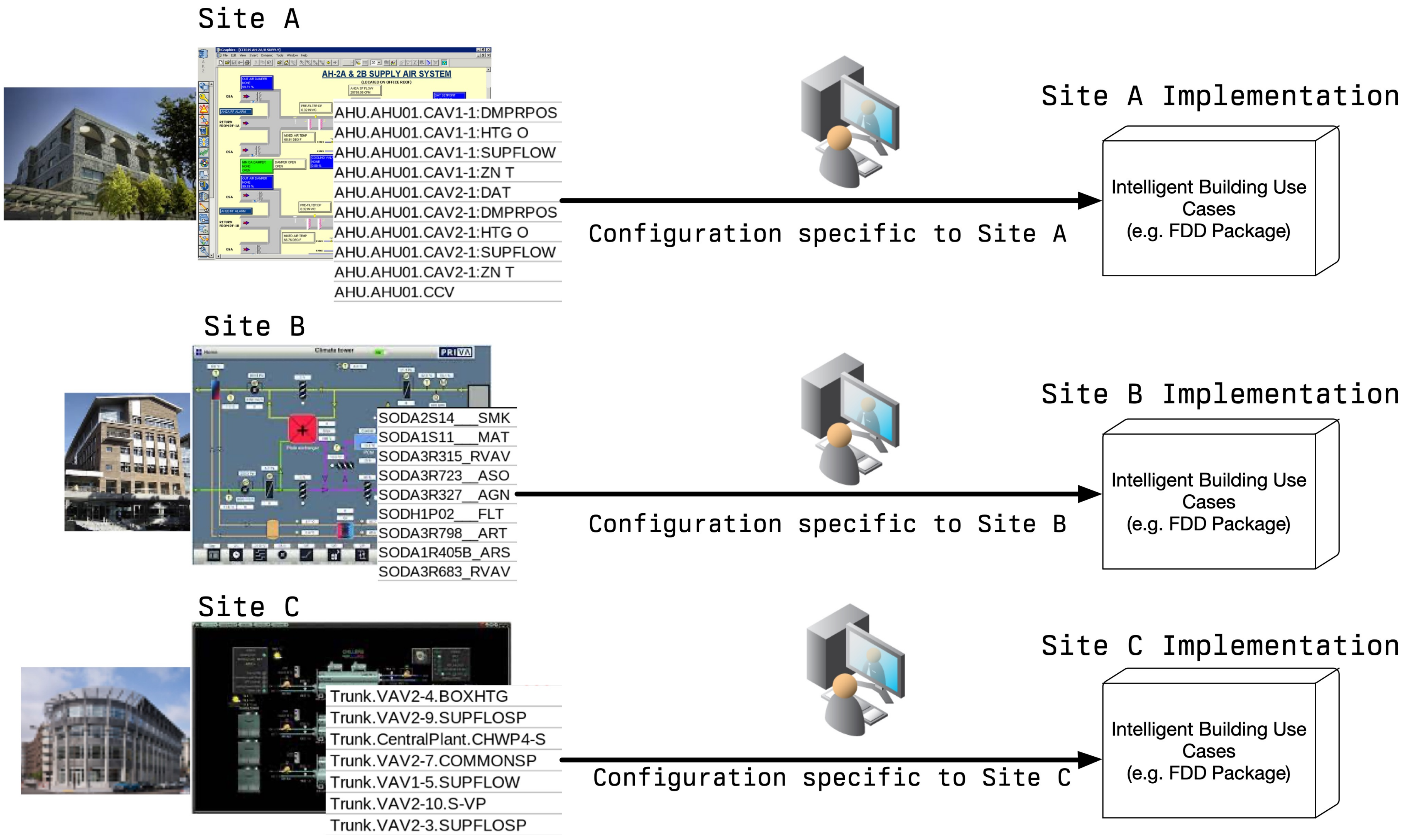
- *Data rich, but information poor*
- Building data often hidden away behind proprietary silos, semi-structured naming conventions





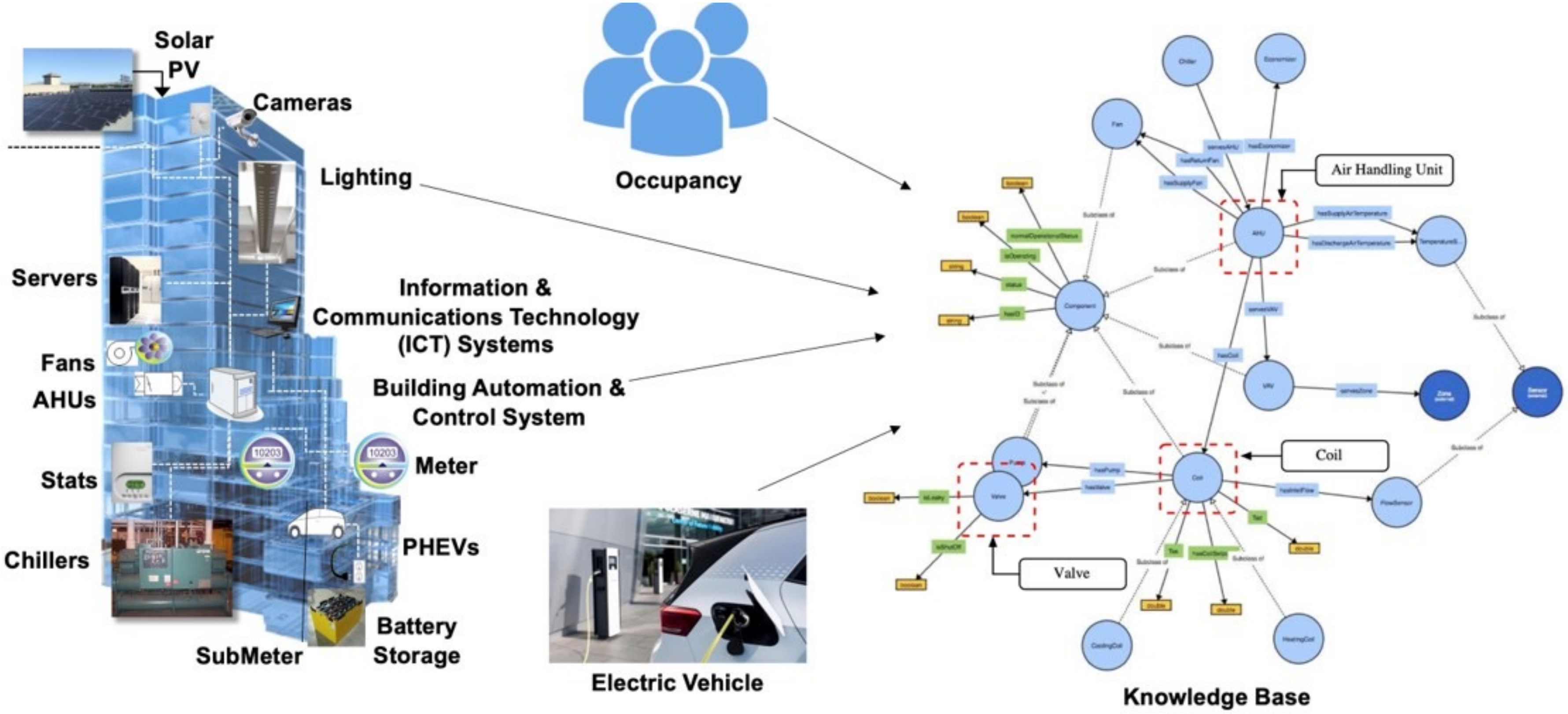
- Focus on operational data in this talk
- BMS point labels (above) are the primary identifiers of data

Implementing Software Requires Manual Configuration



What is ASHRAE 223P?

ASHRAE 223P standard defines concepts and methodologies to create interoperable, **machine-readable semantic models** for representing building information for analytics, control, and automation.

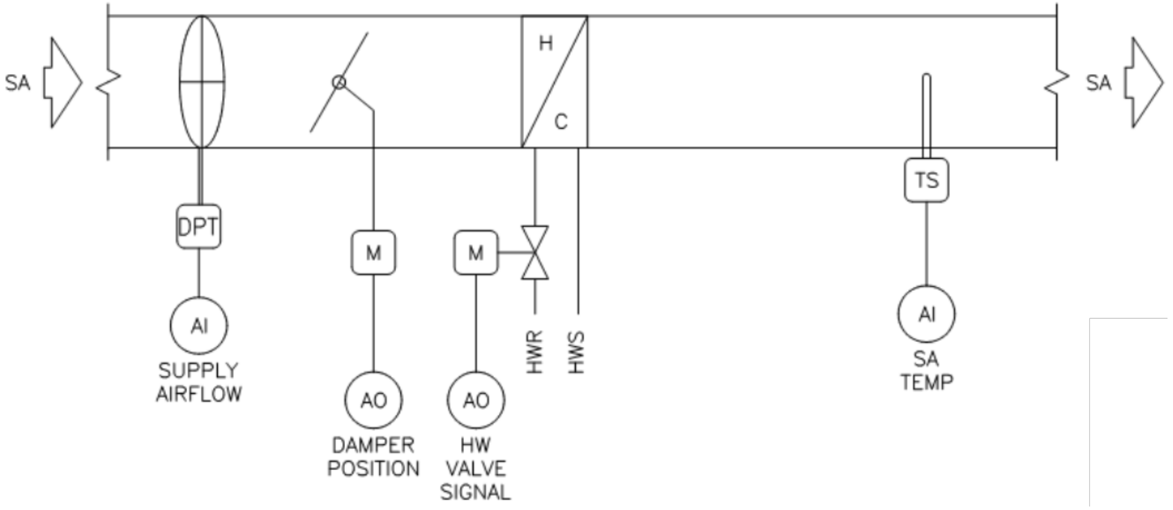


- Control
- Energy Auditing
- Fault Detection and Diagnostics
- Commissioning
- Smart Grid Interactions
- **ASHRAE 231P**

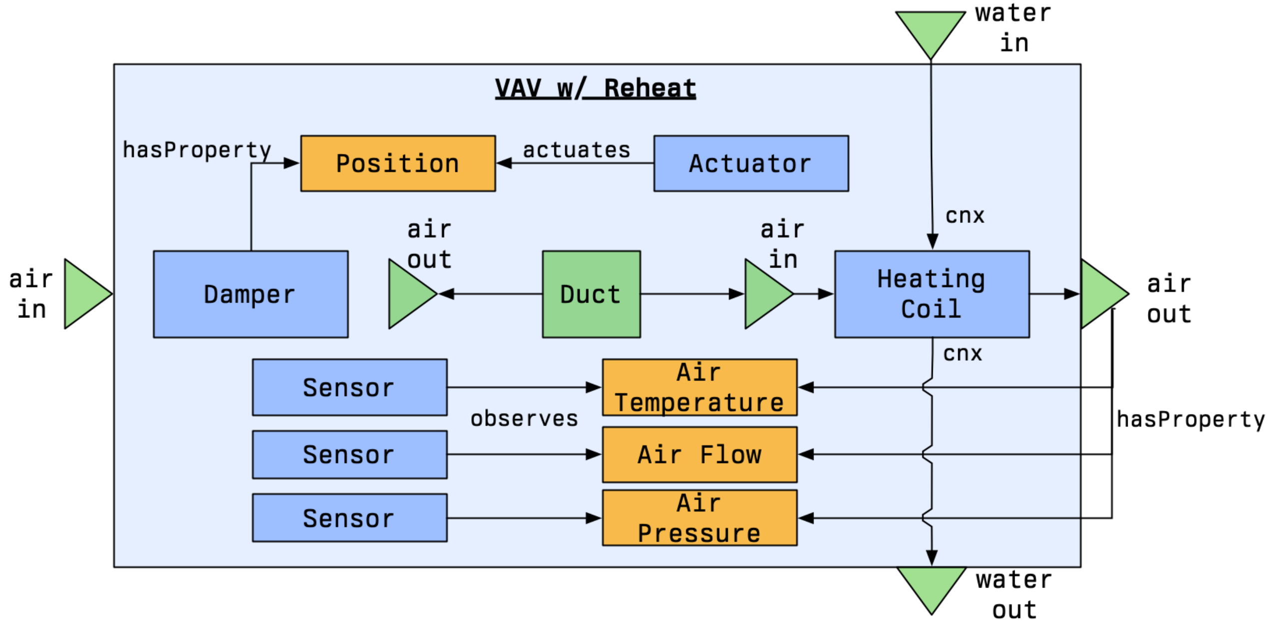
Physical, logical systems ← represents ← **Semantic Model** ← access ← **Applications**

Ontologies and Semantic Models

- A **semantic model** is a digital graph-based representation of a building
  - *Entities*: equipment, sensors, actuators, properties, connections
  - Includes useful attributes of these entities
  - Models how entities relate to each other and compose into systems

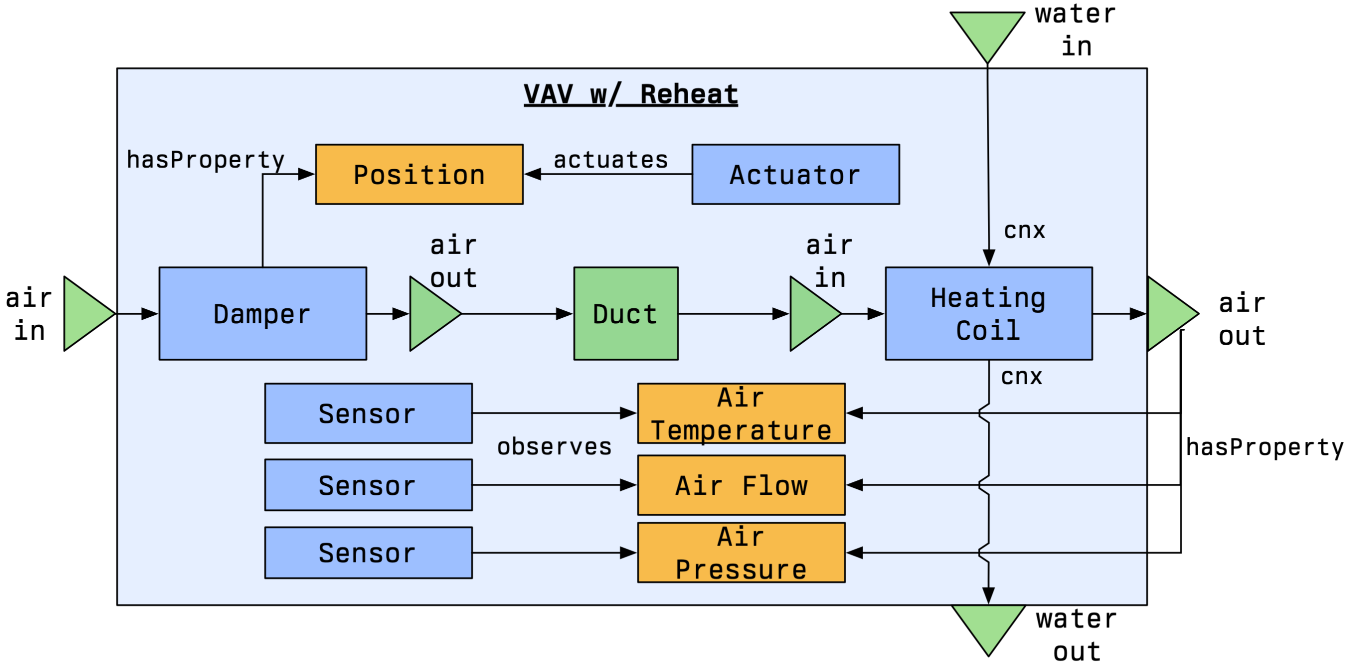


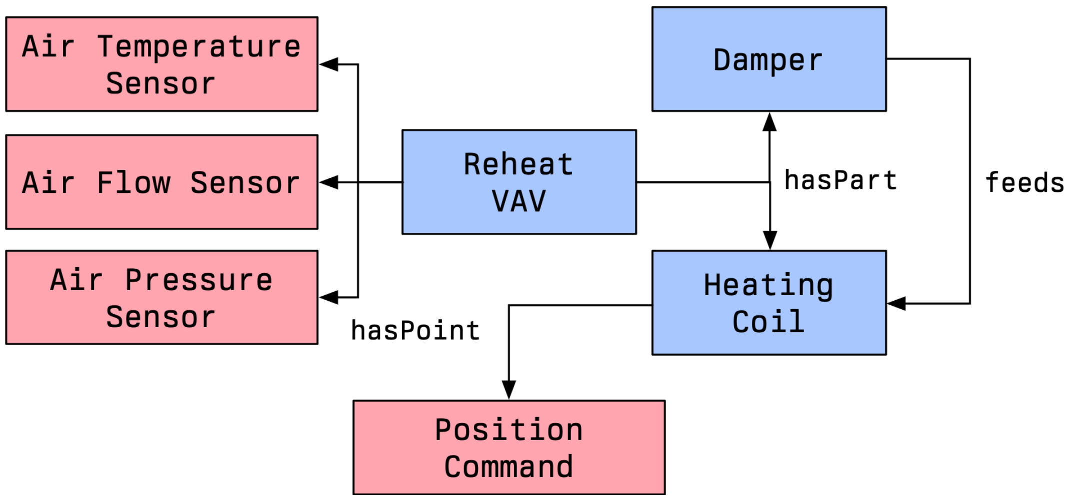
VAV with Reheat Mechanical Diagram



Graphical representation of 223P model

Brick is a Simplification of 223P



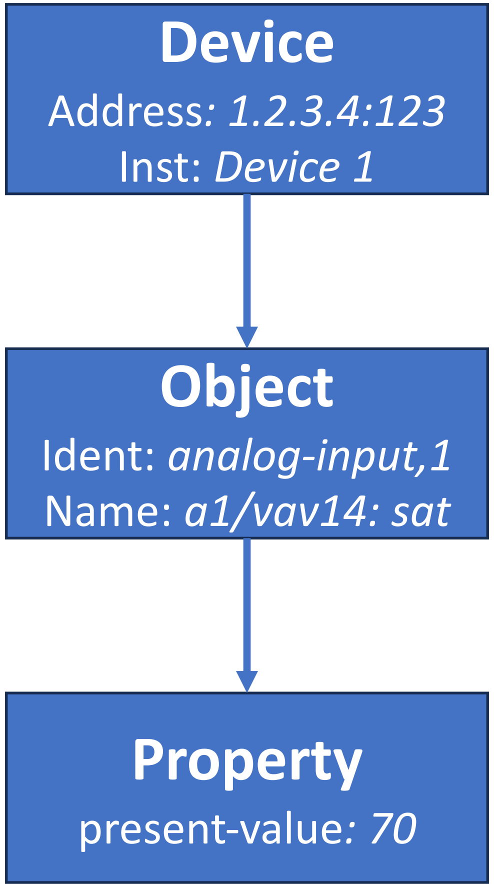


- Detailed topological information in 223P is helpful for some apps, but unnecessary for many others
- Use familiar terminology found in point lists, application descriptions
- Smaller models, easier to query → works better for common systems
- Can always reach into 223P for concepts not covered by Brick

Ontologies and Semantic Models

- ASHRAE 223P and Brick are **ontologies**
  - Formal definition of directed, labeled graph data structure
  - Analogous to a schema (think XML, databases, etc)
- Provides structure to semantic models, enabling
  - Automated verification/validation of semantic models
  - (Semi-)automated configuration of applications
  - (Semi-)automated creation and maintenance of semantic models
- Builds on open standards
  - **RDF (Resource Description Framework):** W3C standard for directed graphs
  - **SPARQL**: W3C standard query language for graphs
  - **SHACL**: W3C standard constraint language for graph validation

How do Ontologies Work with Building Data?



BACnet

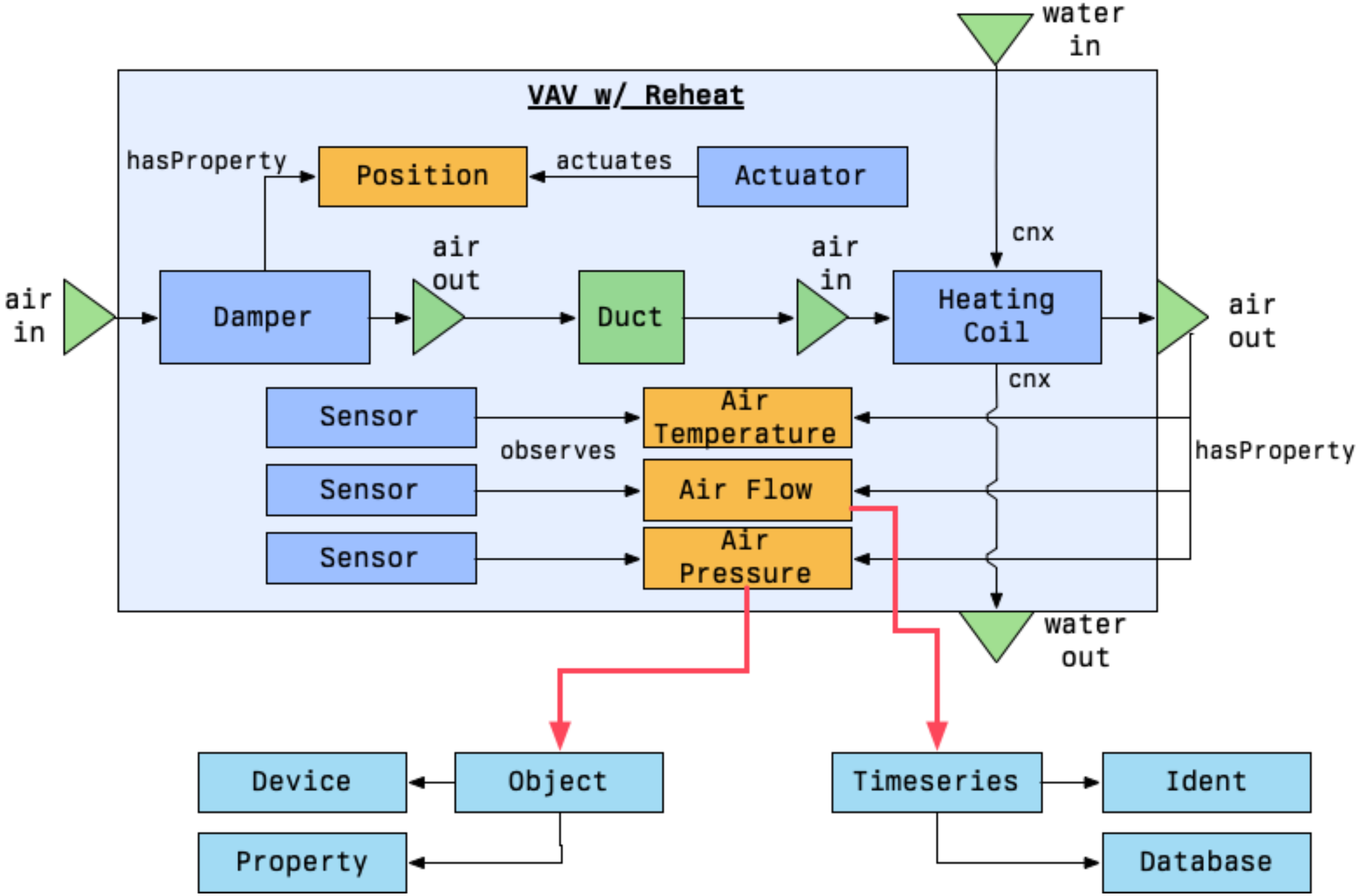
Ident	Time	Value
a1/vav14: sat	2024-06-21T10:15:00	70
a1/vav14: sat	2024-06-21T10:30:00	70
a1/vav14: sat	2024-06-21T10:45:00	70.5
a1/vav14: sat	2024-06-21T11:00:00	70.1

Timeseries DB

- Consider two sources of data
- **Live data** through interacting with BACnet objects
- **Historical data** through an archival service
- Nothing fundamental here:
  - Easily support MQTT, BACnet-SC, Modbus, …

How do Ontologies Work with Building Data?

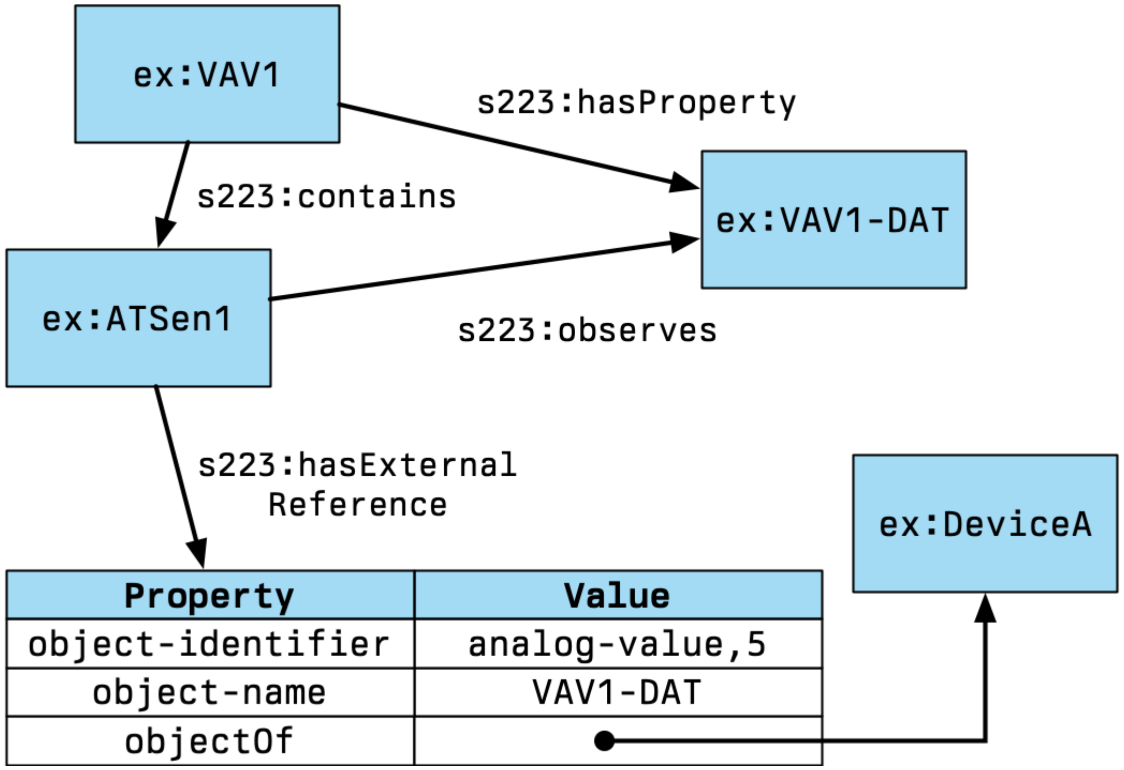
- Explicit representation of data context
  - What kind of point, who hosts it does it relate to equipment, how those equipment connect, etc
- Move away from naming conventions and "ctl-f"
- Use queries to describe and discover data by "meaning" and "context", not by name
  - "Early" vs "late" binding
  - We use google.com, not an IP address



Linking to data

- External References are 223P entities which contain the necessary properties required to retrieve data
  - From a timeseries database…
  - From a BACnet object…
  - From a Modbus register…
  - Etc

- Query the external reference for a property to find the data



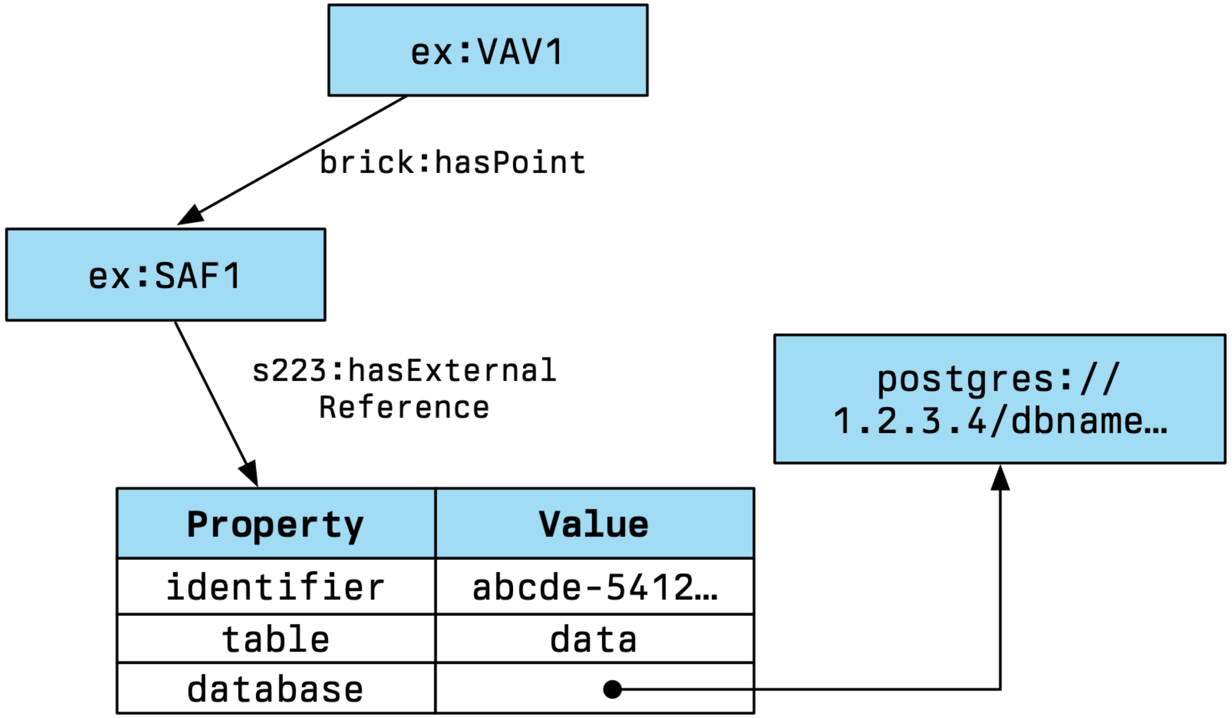
BACnet example

Linking to data (2)

- External References are *also* supported in the Brick ontology

- Query the external reference for the foreign key, table, and database URI for historical data

- The “secret” is just including the necessary client parameters required to connect



BACnet example

Queries to find data

- Same pattern for Brick/223P
- Use the right level of detail for the job:
    - "supply air flow sensor on a vav" → Brick
    - "all temperature sensors on the condenser water loop" → 223P or Brick
    - "all temperature sensors on the condenser water loop, and their measurement locations" → 223P

Types of points (quantity kind, substance, input/output)

External reference

Association of point to assets, equipment, connections

Context or identity of those assets, equipment, connections

Using Queries to Find Data

Types of points (quantity kind, substance, input/output)

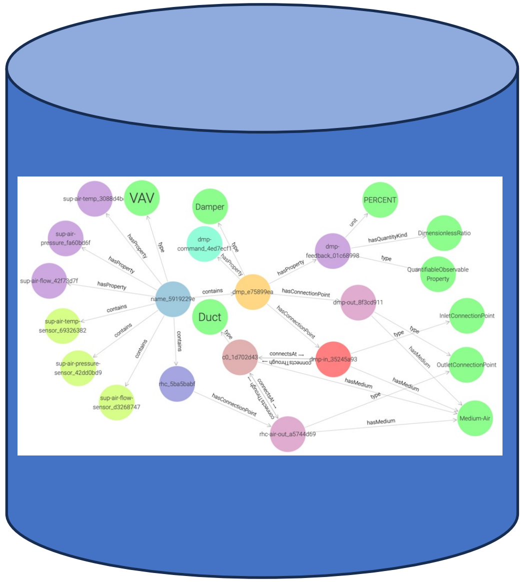
External reference

Association of point to assets, equipment, connections

Context or identity of those assets, equipment, connections

```
SELECT * WHERE {

   ?sensor rdf:type/rdfs:subClassOf* s223:Sensor ;
           s223:observes ?property .
   ?property qudt:hasQuantityKind qk:Temperature ;

           s223:hasExternalReference ?ref .
   ?ref bacnet:isObjectOf ?device ;
        bacnet:object-identifier ?ident .

   ?device rdf:type s223:TerminalUnit ;
           s223:contains ?sensor .

   ?device s223:connectsFrom building:AHU1 .

}
```

Using Queries to Find Data



Semantic model stored in graph database

- **SPARQL queries** retrieve information from semantic models
- Example: retrieving all temperature sensors and where they observe temperature

```
SELECT ?sensor ?location WHERE {
    ?sensor rdf:type/rdfs:subClassOf* s223:Sensor .
    ?sensor s223:observes ?property .
    ?property qudt:hasQuantityKind quantitykind:Temperature .
    ?sensor s223:hasObservationLocation ?location
}
```

?sensor	?location
sup-air-temp-sensor_69326382	vav_out_name_a871635f
rhc-ret-water-temp-sensor_40bc	rhc-valve-in_5060b895

From our earlier VAV Reheat example

Building Applications with Data

- Example: Fault Condition from ASHRAE Guideline 36
  - Low Mixed Air Temperature detection for single zone VAVs

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

- Use a SPARQL query to
  a) identify all locations in the model (building) where this rule can run
  b) retrieve the data necessary to run the rule
- Write the rule itself in the Python programming language

Example FDD rule application

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

<u>Need to find:</u>

- Mixed air temperature
- Return air temperature
- Outside air temperature

```
PREFIX s223: <http://data.ashrae.org/standard223#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX qudt: <http://qudt.org/schema/qudt/>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bacnet: <http://data.ashrae.org/bacnet/2020#>

SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .

    # Mixed Air Temperature Sensor
    ?mat rdf:type s223:Sensor ;
         s223:observes ?mixedAir .
    ?mixedAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Mixed ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?matId .

    # Return Air Temperature Sensor
    ?rat rdf:type s223:Sensor ;
         s223:observes ?returnAir .
    ?returnAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Return ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?ratId .
}
```

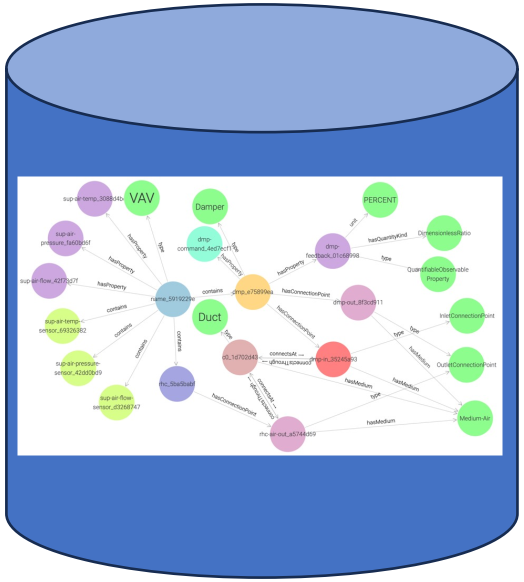

```
SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .
```


SPARQL query retrieves names and BACnet object IDs for all sensors

Example FDD rule application

```
PREFIX s223: <http://data.ashrae.org/standard223#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX qudt: <http://qudt.org/schema/qudt/>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bacnet: <http://data.ashrae.org/bacnet/2020#>

SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .

    # Mixed Air Temperature Sensor
    ?mat rdf:type s223:Sensor ;
         s223:observes ?mixedAir .
    ?mixedAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Mixed ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?matId .

    # Return Air Temperature Sensor
    ?rat rdf:type s223:Sensor ;
         s223:observes ?returnAir .
    ?returnAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Return ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?ratId .
}
```

Execute query against semantic model



ahu	inst	matId
urn:ex/single-zone-ahu	123	analog-value,6

oatId	ratId
analog-value,5	analog-value,7

Query Results

- Now we have all the information necessary to read live data from our BACnet network!
- External references also let us read data out of databases, etc

Example FDD rule application

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

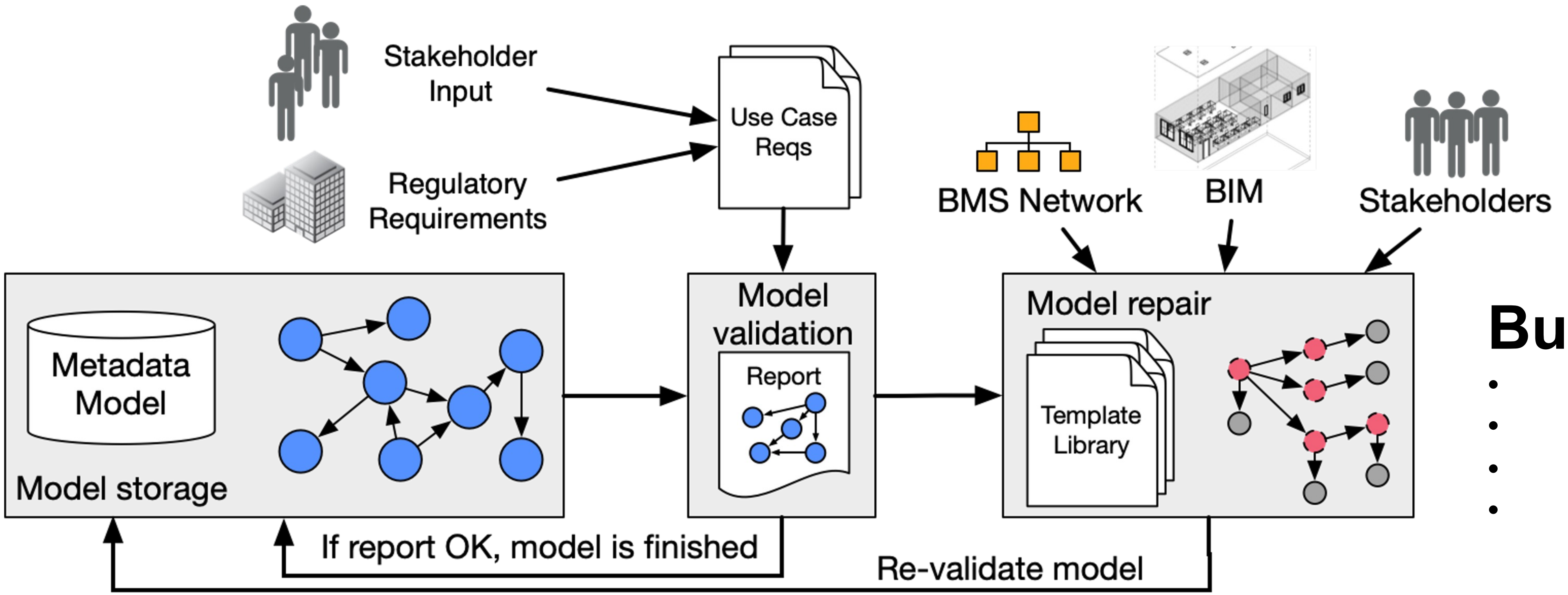
- Write out FDD rule as a Python function
- Use query results to generate a dataset with the correct column names
- Run the function!

```
def run_fc2(df):
    """
    Check MAT + ε_MAT < min[(RAT − ε_RAT), (OAT − ε_OAT)] at each timestamp and
    print out the timestamps where the inequality is true.
    """
    # Assuming ε values as constants, they can be changed as per actual values
    epsilon_MAT = epsilon_RAT = epsilon_OAT = 1
    # List to store timestamps where the inequality holds true
    timestamps_where_true = []
    # Iterate over the dataframe
    for index, row in df.iterrows():
        # Check the inequality condition for each row
        if row['mat'] + epsilon_MAT < min(row['rat'] - epsilon_RAT, row['oat'] - epsilon_OAT):
            timestamps_where_true.append(index)
    # Print out the timestamps
    for timestamp in timestamps_where_true:
        print(f"Fault condition true at: {timestamp}")
```

```
[19]: run_fc2(df)
```

```
Fault condition true at: 2023-01-01 06:30:00
Fault condition true at: 2023-01-01 08:30:00
Fault condition true at: 2023-01-01 09:45:00
```

Open-Source Software for Semantic Models



BuildingMOTIF

- Open source, BSD-licensed
- Developed by NREL
- Available on GitHub
- *"Software 1"*

- Incorporate formal use case requirements into iterative workflow
- Ensure that delivered metadata model fulfills all use cases
- Automate / simplify authoring through templates, imports from other sources
- Generate SPARQL queries from application requirements

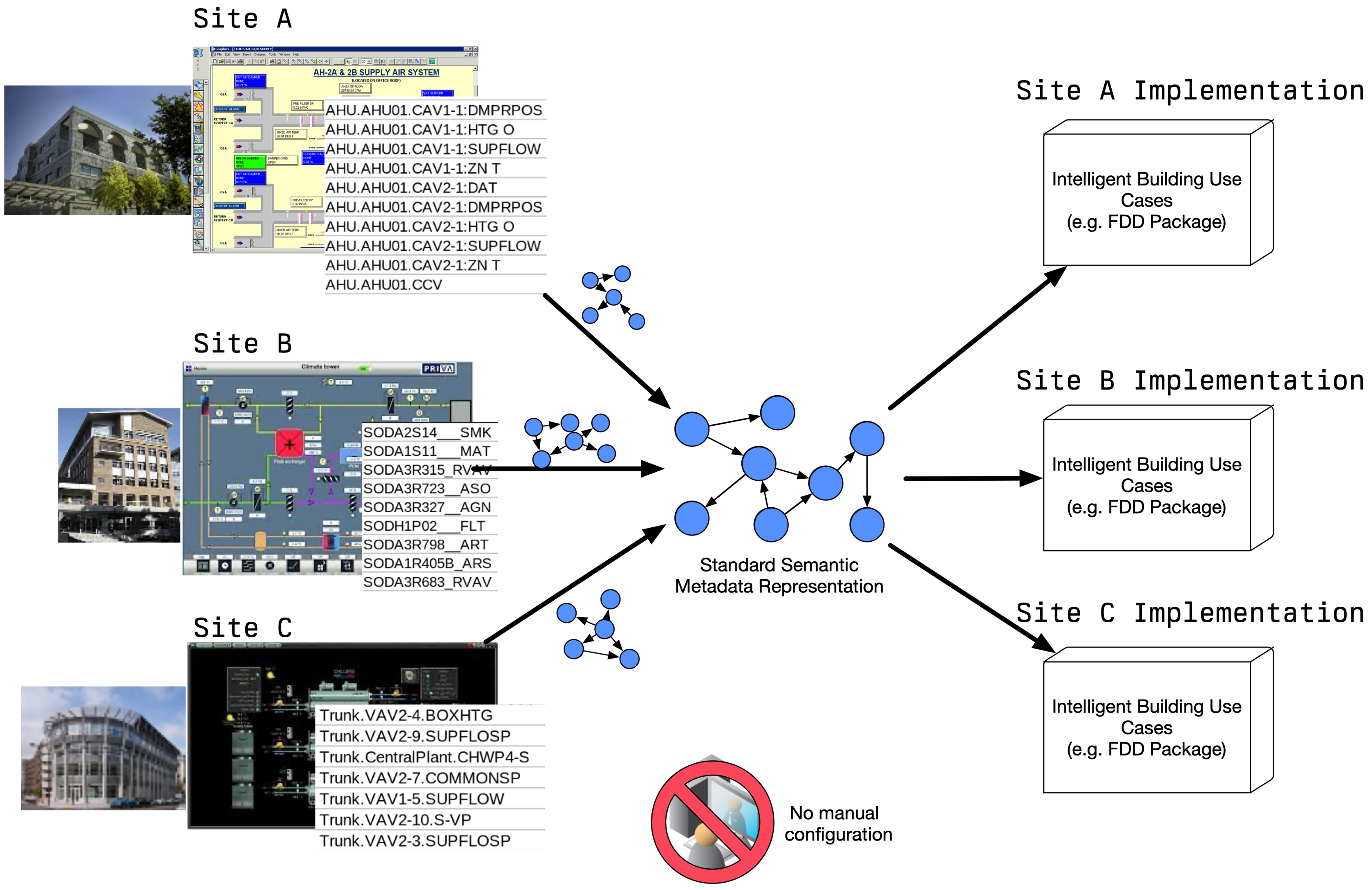
Deriving Queries from "Shapes"

```
:zone-temp-model a sh:NodeShape ;
    sh:targetClass brick:RVAV ;
    sh:property [
        sh:path brick:hasPoint ;
        sh:name "hvac_mode" ;
        sh:qualifiedMinCount 1 ;
        sh:qualifiedValueShape [ sh:class brick:HVAC_Mode_Command ] ;
    ] ;
    sh:property [
        sh:path brick:hasPoint ;
        sh:name "supply_air" ;
        sh:qualifiedMinCount 1 ;
        sh:qualifiedValueShape [ sh:class brick:Supply_Air_Temperature_Sensor ] ;
    ] ;
    sh:property [
        sh:path brick:feeds
        sh:qualifiedMinCount 1 ;
        sh:name "room" ;
        sh:qualifiedValueShape [
            sh:class brick:Room ;
            sh:property [
                sh:path brick:hasPoint ;
                sh:qualifiedMinCount 1 ;
                sh:name "room_temp" ;
                sh:qualifiedValueShape [ sh:class brick:Air_Temperature_Sensor ] ;
            ] ;
        ] ;
    ] ;
    sh:property [
        sh:path brick:hasPart ;
        sh:qualifiedMinCount 1 ;
```

```
SELECT * WHERE {
  ?target     rdf:type/rdfs:subClassOf* brick:RVAV ;
        brick:hasPoint          ?supply_air ;
        brick:feeds          ?room ;
        brick:hasPart          ?coil .
  ?room     rdf:type/rdfs:subClassOf* brick:Room ;
        brick:hasPoint          ?room_temp .
  ?coil     rdf:type/rdfs:subClassOf* brick:Heating_Coil ;
        brick:hasPoint          ?heating_valve .
  ?supply_air     a brick:Supply_Air_Temperature_Sensor .
  ?room_temp     a brick:Air_Temperature_Sensor .
  ?heating_valve     a brick:Position_Command .
}
```

- Shape is a specification of what information **must** be contained within a model
  - Check for required points, equipment, annotations
  - *Software 1* evaluates requirements on a model and suggests fixes
- Think of a shape as a **schema** for a desired dataset
- *Software 1* can convert shapes (validation) into queries (retrieval)

Portable Analytics



Conclusion

- Semantic models like Brick and 223P can provide rich contextual annotations to building data sets
- Queries retrieve data sources from models using properties and characteristics, *not identifiers*
- Semantic models can link to external data sources like BACnet objects and timeseries historian services
- All of this is built on open standards; open-source software provides simpler and easier interfaces

Questions?

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