Tooling for Creation, Validation and Integrated Use of ASHRAE 223P, Brick and Haystack Semantic Metadata Models

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Learning Objectives

- - Attendees will be able to conceptualize how the ASHRAE 223P, Brick, Haystack, and RealEstateCore ontologies can cooperatively model a building to support diverse use cases

- - Attendees will gain basic familiarity with NREL's BuildingMOTIF tool and learn how to use BuildingMOTIF to create a metadata model using 223P

- - Attendees learn how to use BuildingMOTIF to validate a semantic metadata model against a set of representative use cases

Semantic Metadata Models for Buildings

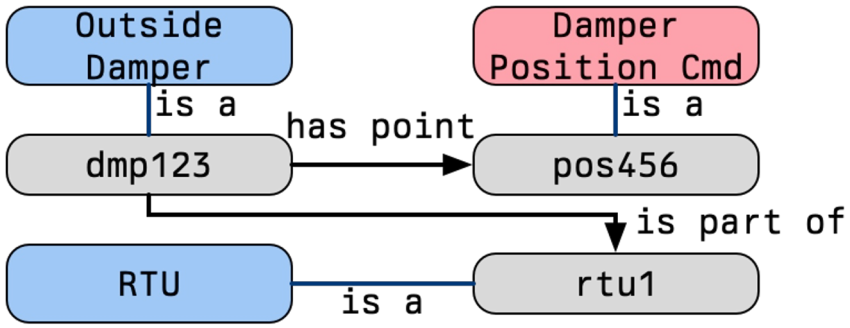
Haystack

- Uses tags to flexibly describe data/assets
- Lacks consistency between implementations
- Meaning requires *human interpretation*

```
id: 'd83664ec RTU-1 OutsideDamper'
air: ✓
cmd: ✓
cur: ✓
damper: ✓
outside: ✓
point: ✓
```

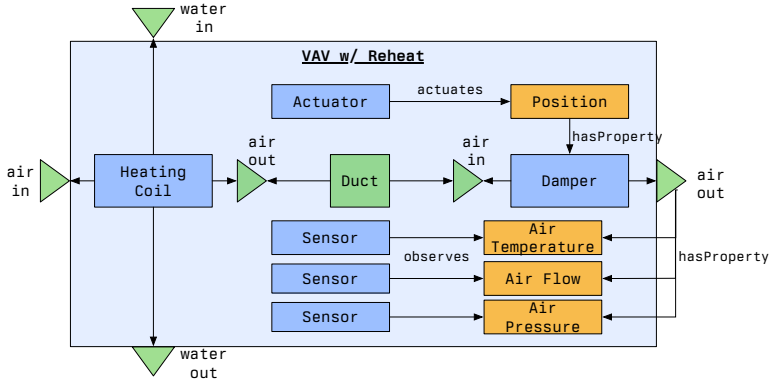
Brick and RealEstateCore (Rec)

- Explicit and formal descriptions of assets
- Expressive relationships
- Extensible and comprehensive
  - Hundreds of classes
- Not *standardized*



ASHRAE 223P

- Fully elaborated connection topologies
- Cross-subsystem and inter-domain models:
  - Electrical, mechanical, plumbing, …
- Emphasizes precision to enable semantic interop
- Harder to extend due to standards process

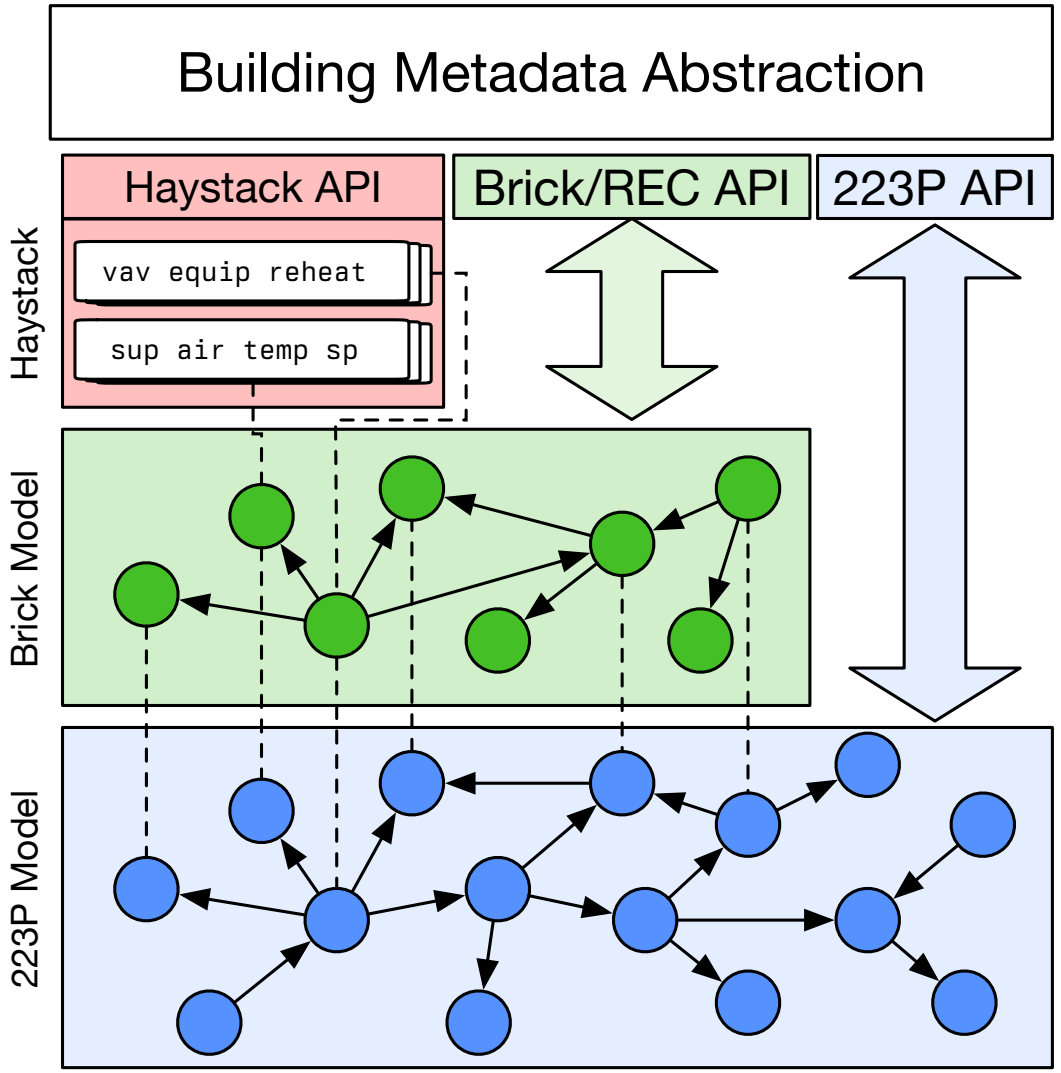


Metadata Models can be Complementary

- Key idea is to model a building at multiple levels of abstraction
  - Reach for as much detail as you need to get the job done

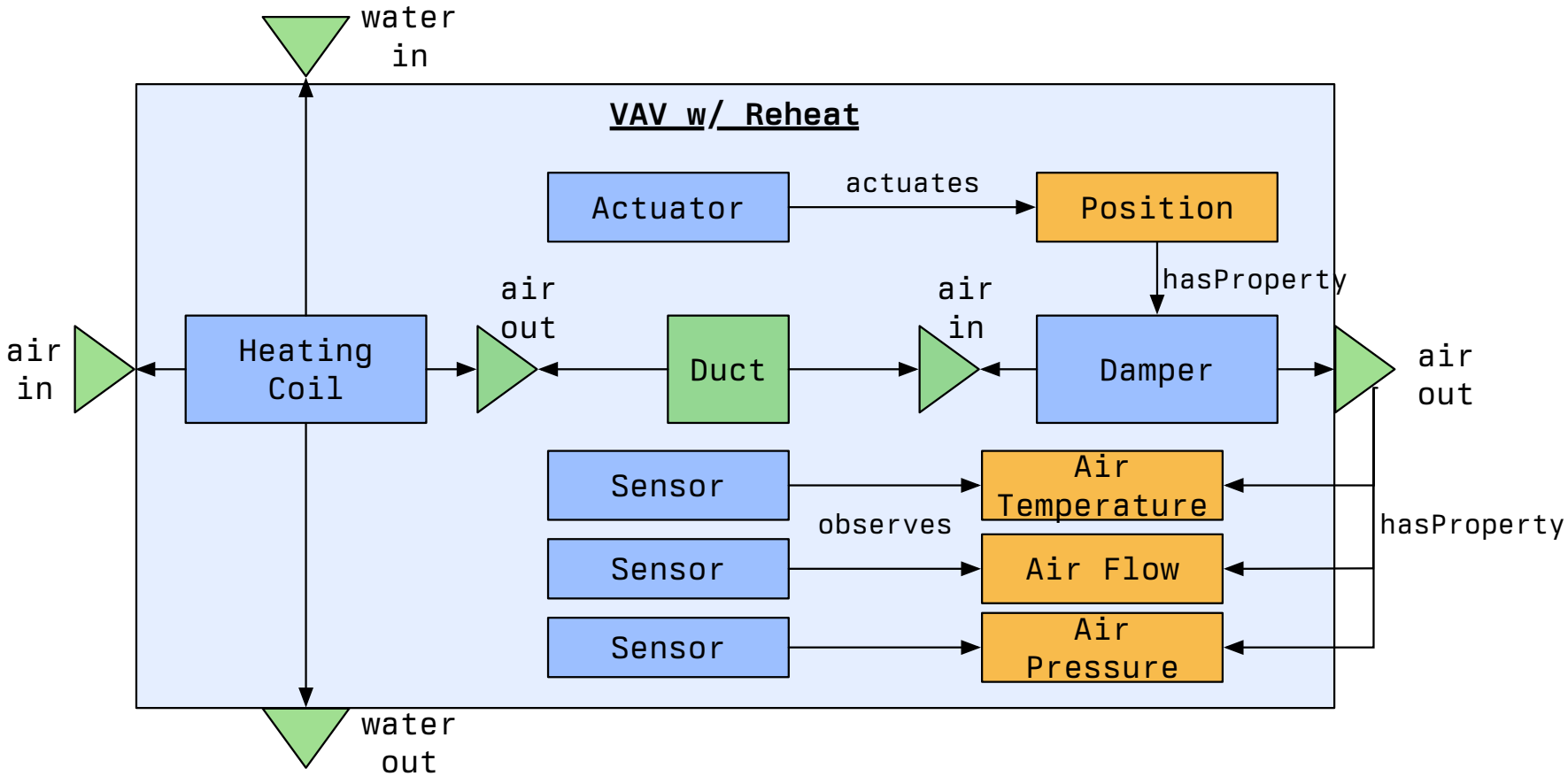
- **ASHRAE 223P**
  - Detailed and precise
  - → larger models and more complex queries
- **Brick** and **RealEstateCore**
  - Lean on common understandings and nomenclature
  - → less precise, but easier to query
- **Project Haystack**
  - Simple tag/document-based data model
  - → simpler query + API, but not as expressive

Complementary Metadata Designs



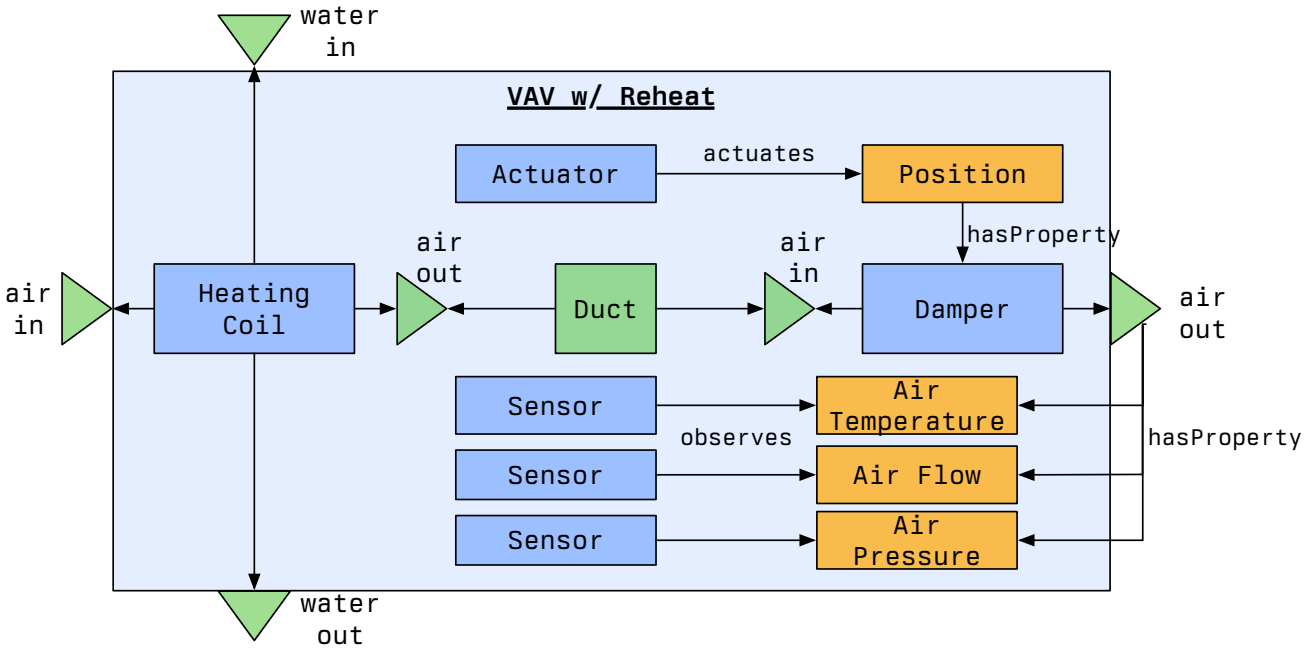
- 223P models the fundamental components of a building
- Brick/REC provide human-facing application-centric vocabulary
  - **Programmatically generated from 223P**
- Haystack provides one possible high-level abstraction over RDF / graph models
  - **Programmatically generated from Brick/REC**

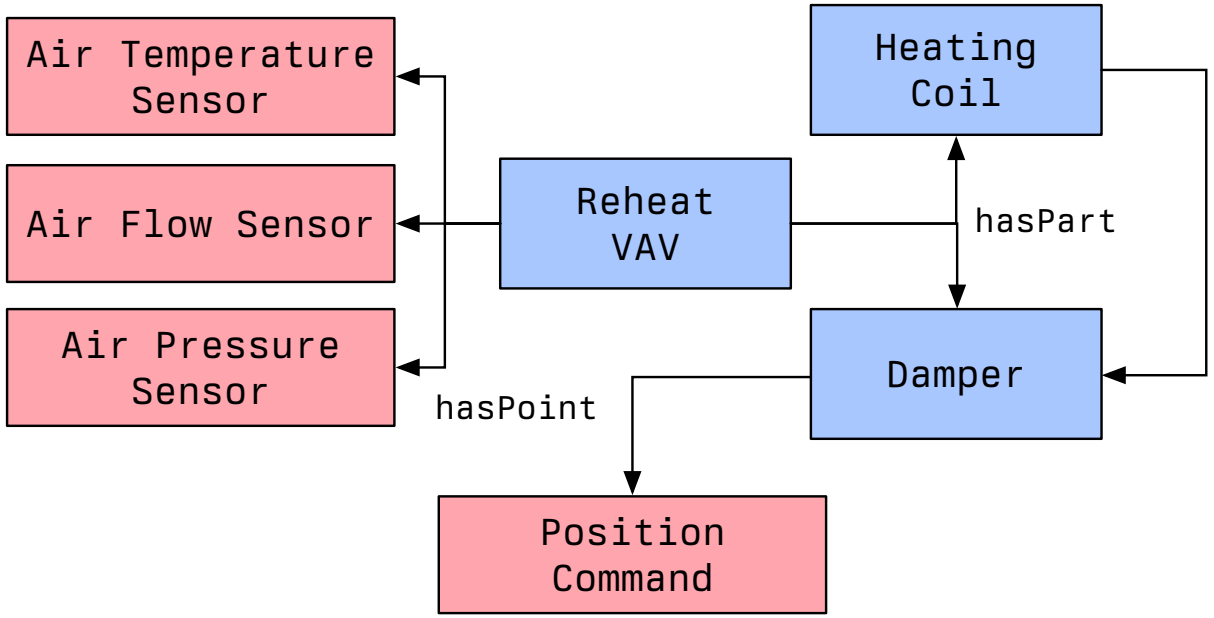
VAV w/ Reheat: 223P



- Directionality, substance, properties propagated through process flows
- Equipment composition, explicit sensor observation relationships
- *Some details removed for ease of visualization*

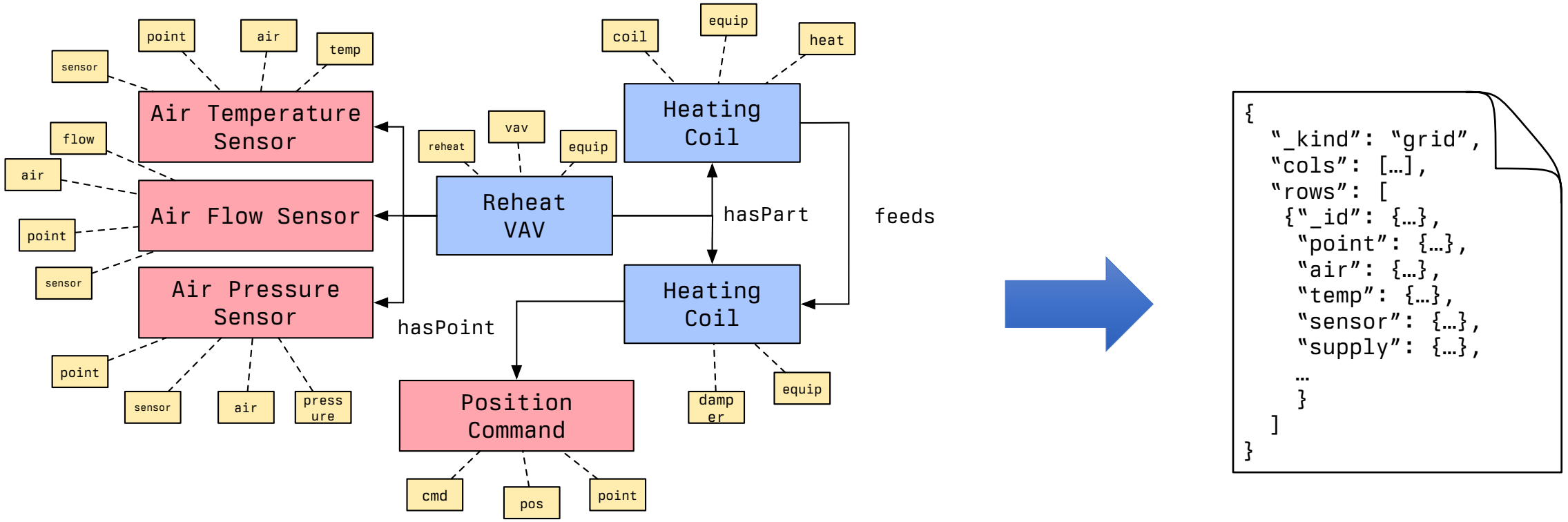
VAV w/ Reheat: 223P → Brick/REC





- Brick model captures composition, flow, relationship to BMS points
  - Simplification of the 223P model with more specific names
- Brick model is programmatically generated from the 223P model
  - Uses SHACL to infer types, add necessary relationships

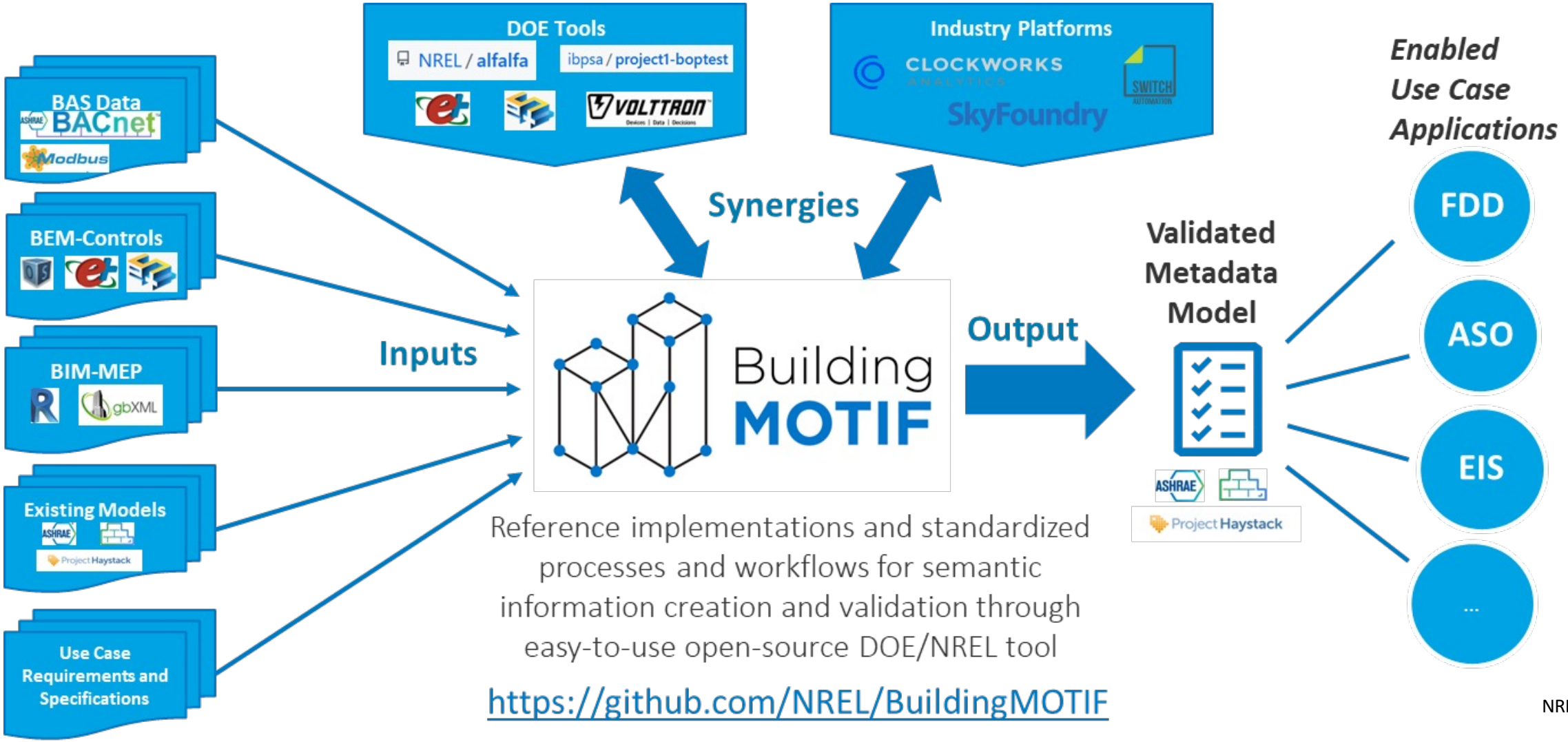
VAV w/ Reheat: 223P → Brick/REC → Haystack



- Application of SHACL rules adds Haystack tags to Brick entities
  - Rules constructed automatically from Xeto type definitions
  - Adds ref tags and (*soon!*) value tags
- Haystack import formats (e.g. JSON) generated from the augmented RDF model

DOE/NREL Open-Source Tool: BuildingMOTIF

MOTIF = **M**etadata **O**n**T**ology **I**nteroperability **F**ramework



Reference implementations and standardized processes and workflows for semantic information creation and validation through easy-to-use open-source DOE/NREL tool

https://github.com/NREL/BuildingMOTIF

How to Work With Semantic Metadata Models

- Creating a semantic metadata model of a building
  - Hide complexity of working with RDF models
  - Help to direct/prioritize human effort
- Validating a semantic metadata model of a building
  - Ensure model contains correct / enough metadata to configure controls, FDD rules, digital twins, …
- *Two parts of a larger workflow*

Shapes: Formalizing Application Metadata Requirements

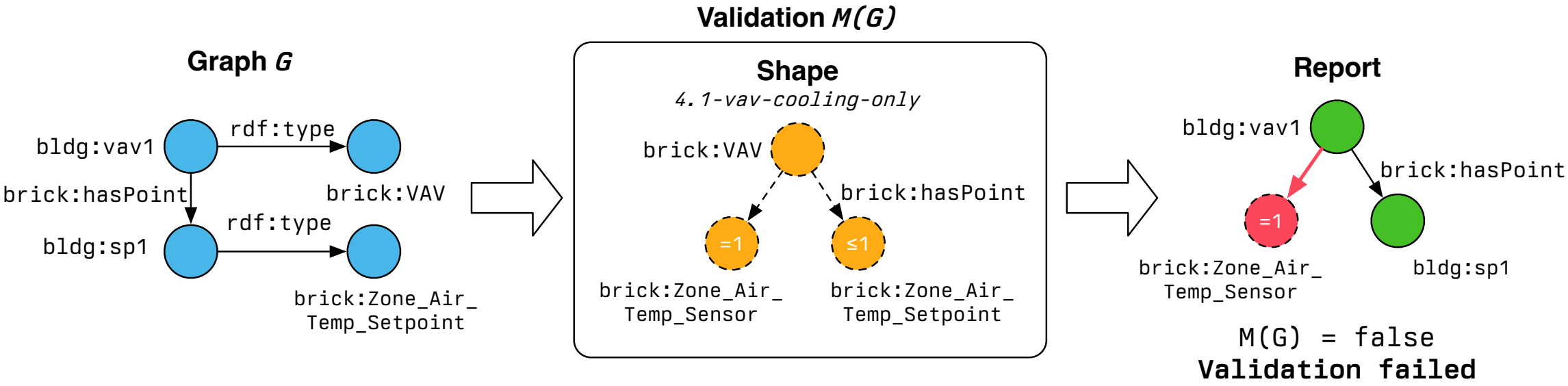
4.2 VAV Terminal Unit with Reheat

Required?	Description	Type	Device
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating signal	AO OR two DOs	Modulating valve OR Floating actuator OR Modulating electric heating coil
R	Discharge airflow	AI	DP transducer connected to flow sensor
R	Discharge air temperature (DAT)	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO_2 level (if applicable)	AI	Room CO_2 sensor

- Come in many different forms…
- **At right**: point lists from ASHRAE Guideline 36
- SOO for high-perf forced-air systems
- How to ensure 223P, Brick, REC, etc model contains the right metadata?

Shapes: Formalizing Application Metadata Requirements

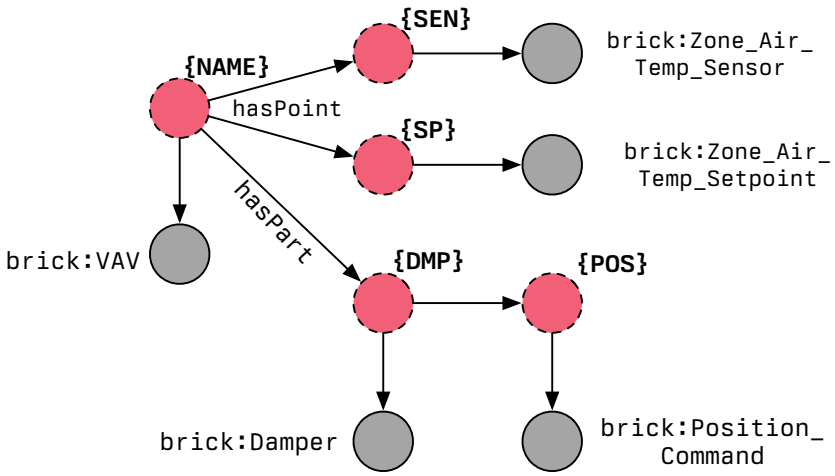
- **Shape**: set of constraints, requirements, conditions on parts of the graph
- Function returns T/F when evaluated on a graph
  - Plus some information about ”what went wrong”



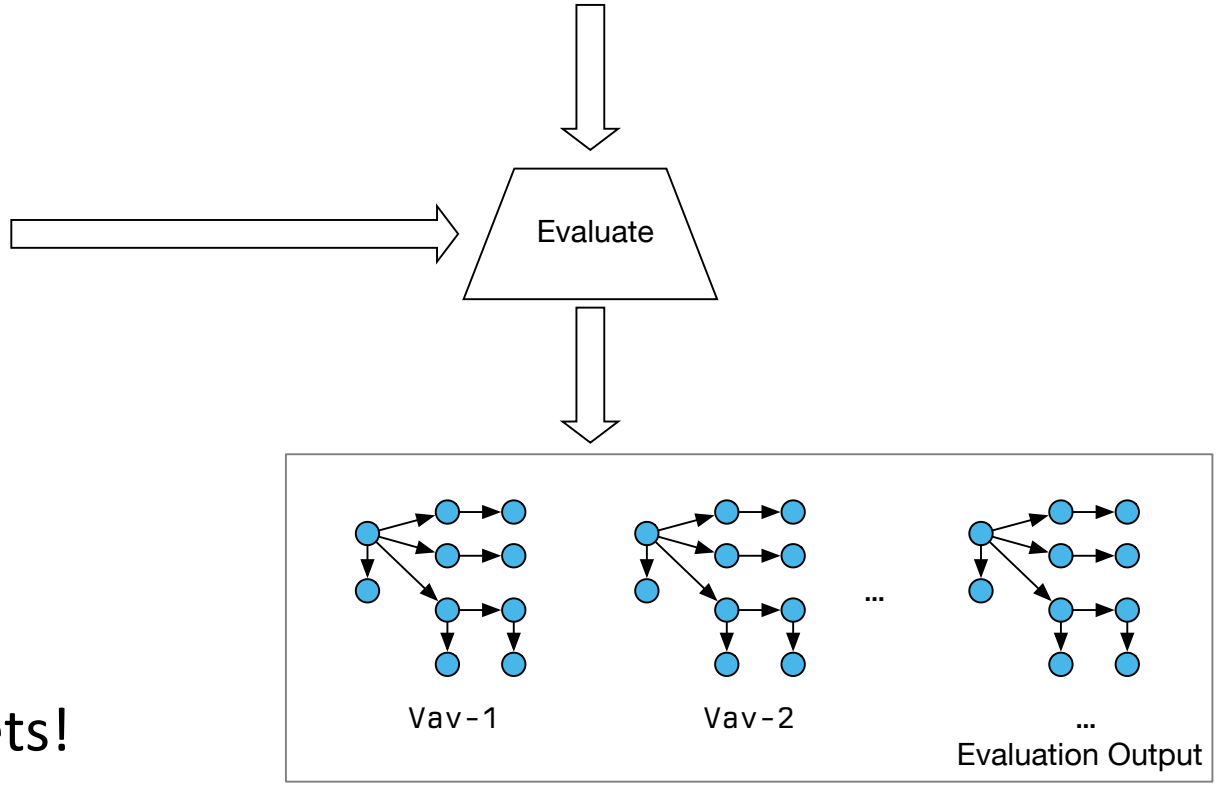
- Defined using W3C SHACL standard

Templates: Simplifying Model Creation

- **Template**: function that generates a graph



{NAME}	{SEN}	{SP}	{DMP}	{POS}
Vav-1	ZTS-A	ZTSP-A	DMP-12	POS-12
Vav-2	ZTS-B	ZTSP-B	DMP-23	POS-23
…	…	…	…	…



- Simplifies RDF graph creation
  - Tabular input: web forms! Spreadsheets!
  - Easier to integrate (pull from BACnet, etc)

Quick Demonstration

1. Use BuildingMOTIF to create a 223P model for a simple HVAC system:
   - 1 Makeup Air Unit feeding 1 VAV with reheat
   - Include the VAV hot water coil
   - Include all the filters, fans, coils, etc in the MAU
   - *Without touching any RDF!*

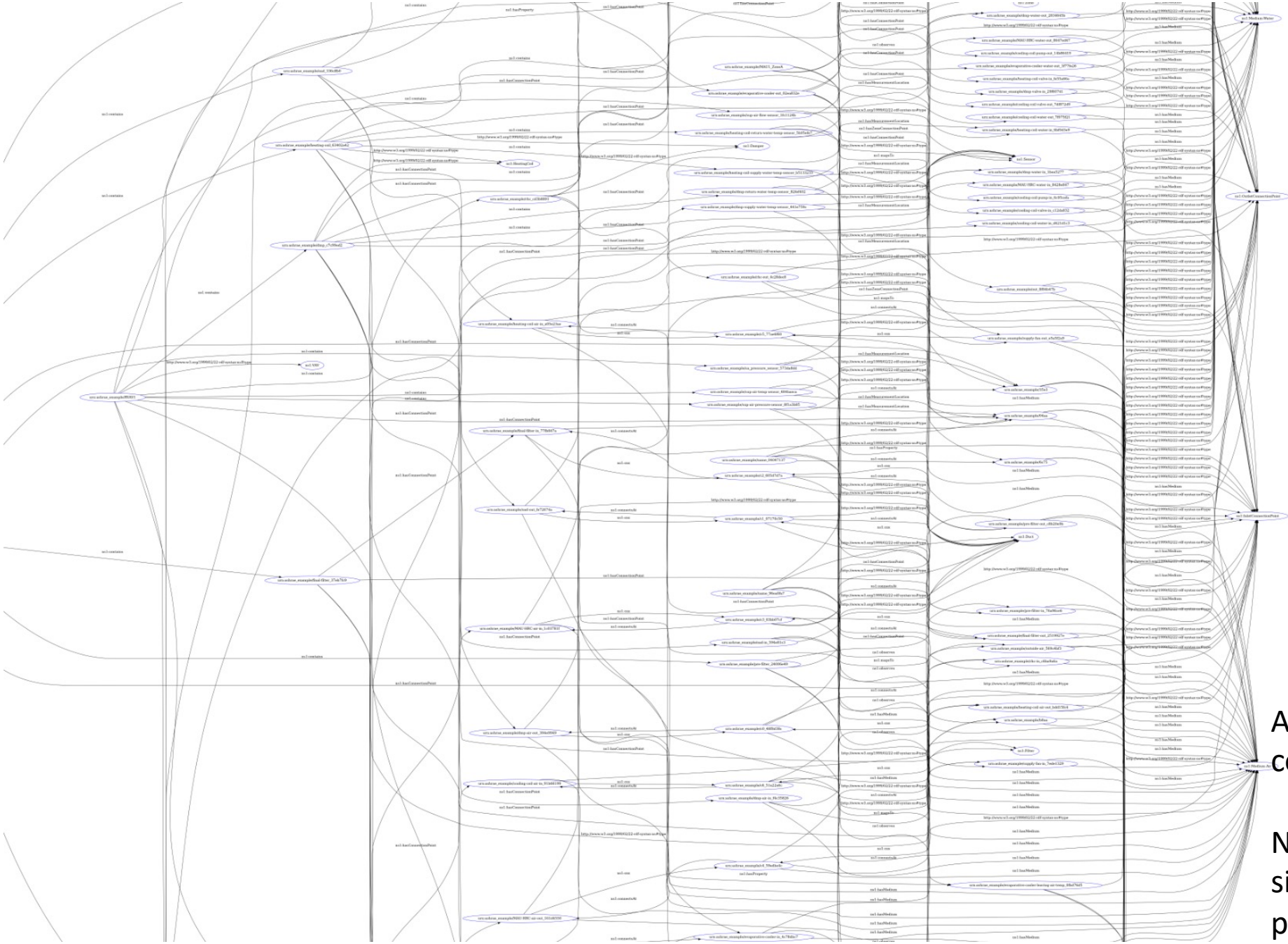
2. Use BuildingMOTIF to ensure the model contains sufficient metadata to support a Guideline 36 sequence

```python
from rdflib import Namespace
from buildingmotif import BuildingMOTIF
from buildingmotif.dataclasses import Library, Model, Template
from buildingmotif.namespaces import bind_prefixes

# connect BuildingMOTIF to a SQLite database (also supports Postgres)
bm = BuildingMOTIF("sqlite://")

# load in 223P definitions
s223 = Library.load(ontology_graph=r"ontologies/223p.ttl")

# load in an NREL template library
nrel = Library.load(directory="libraries/ashrae/223p/nrel-templates")

# load in helper library to assist with common model constraints
constraints = Library.load(ontology_graph="constraints/constraints.ttl")



# find relevant templates by browsing BuildingMOTIF web interface
mau_templ = nrel.get_template_by_name("makeup-air-unit")
rvav_templ = nrel.get_template_by_name("vav-reheat")
zone_templ = nrel.get_template_by_name("hvac-zone")
duct_templ = nrel.get_template_by_name("duct")
```

```python
from rdflib import Namespace

# create a namespace to 'contain' all building entities
BLDG = Namespace("urn:ashrae_example/")
# create a new metadata model in BuildingMOTIF
bldg = Model.create(BLDG)

# instantiate the templates to create the 3 main entities
# These templates already contain the common components -- we can give them names if we want
MAU1 = mau_templ.evaluate({'name': BLDG.MAU1}, warn_unused=False)
RVAV1 = rvav_templ.evaluate({'name': BLDG.RVAV1}, warn_unused=False)
ZoneA = zone_templ.evaluate({'name': BLDG.MAU1_ZoneA}, warn_unused=False)

# It's all just plain Python, so I can create new functions that automate
# the "boring" stuff

def make_air_connection(t1: Template, from_param: str, t2: Template, to_param: str):
    t1, duct = link(t1, from_param, duct_templ, 'a')
    t2, duct = link(t2, to_param, duct, 'b')
    add_to_model(duct)
    return t1, t2

# link the MAU to the RVAV
MAU1, RVAV1 = make_air_connection(MAU1, 'air-supply', RVAV1, 'air-in')
# link the RVAV to the Zone
RVAV1, ZoneA = make_air_connection(RVAV1, 'air-out', ZoneA, 'air-in')


add_to_model(MAU1, RVAV1, ZoneA)
```

```python
res = bldg.validate([s223, constraints])
print(f"Is model valid? {res.valid}")
print("Reasons why not:")
for r in res.diffset:
    print(r.reason())
```

```
Is model valid? False
Reasons why not:
urn:ashrae_example/outside-air_5f30 needs exactly 1 instance of s223:Connection on path s223:connectsThrough
```



A bit like looking at “machine code”…

New visualization tools will simplify this and make it easier to parse visually

```
# ensure 1 AHU connected to 1 RVAV as defined above
manifest:ahu-count a sh:NodeShape ;
    sh:message "Model has 1 AHU" ;
    sh:targetNode manifest: ;
    constraint:exactCount 1 ;
    constraint:node [
        a sh:NodeShape ;
        sh:class s223:AirHandlingUnit ;
        sh:property [
            sh:path s223:connectedTo ;
            sh:qualifiedValueShape [ sh:class manifest:ReheatVAV ] ;
            sh:qualifiedMinCount 1 ; sh:qualifiedMaxCount 1 ;
        ] ;
    ] ;
.


# create our own "reheat VAV" type
manifest:ReheatVAV a sh:NodeShape, owl:Class ;
    sh:class s223:SingleDuctTerminal ;
    sh:property [
        sh:path s223:contains ;
        sh:qualifiedValueShape [ sh:class s223:HeatingCoil ] ;
        sh:qualifiedMinCount 1 ; sh:qualifiedMaxCount 1 ;
    ] ;
    sh:property [
        sh:path s223:connectedTo ;
        sh:qualifiedValueShape [ sh:class s223:Zone ] ;
        sh:qualifiedMinCount 1 ; sh:qualifiedMaxCount 1 ;
    ] ;
    sh:node g36:pointlist_4_2 ; # require that the RVAVs support G36 pointlist
.
```

4.2 VAV Terminal Unit with Reheat

Required?	Description	Type	Device
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
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A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
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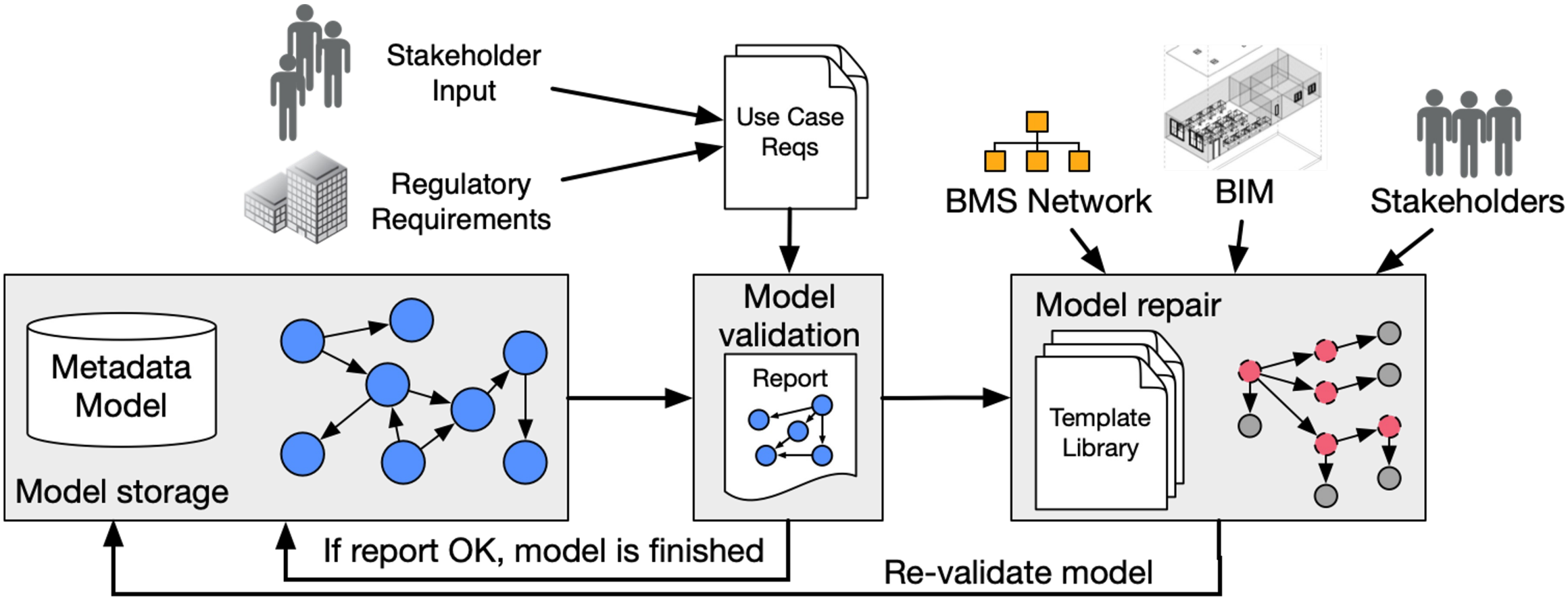
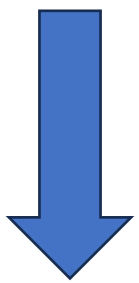
BuildingMOTIF Model Create/Validate Workflow



- 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

```python
manifest = Library.load(ontology_graph='manifest.ttl')
res = bldg.validate([s223, constraints, manifest])
print(f"Is model valid? {res.valid}")
print("Reasons why not:")
for r in res.diffset:
    print(r.reason())
```

```
Is model valid? False
Reasons why not:
- urn:ashrae_example/RVAV1 needs exactly 1 instance of g36:ZoneTemperatureSensor on s223:contains
- urn:ashrae_example/RVAV1 needs exactly 1 instance of g36:DischargeAirTemperatureSensor on s223:contains
- urn:ashrae_example/RVAV1 needs exactly 1 instance of g36:HeatingSignal on s223:contains
...
```



BuildingMOTIF generates automatic "repairs" for the model

```python
for r in res.as_templates():
    print(r.name, r.parameters)
```

```
fix-missing-ZoneTemperatureSensor {'name', 'zone'}
fix-missing-DischargeAirTemperatureSensor {'name', 'terminal_unit'}
...
```

End-to-end: BuildingMOTIF-enabled RDF to Haystack

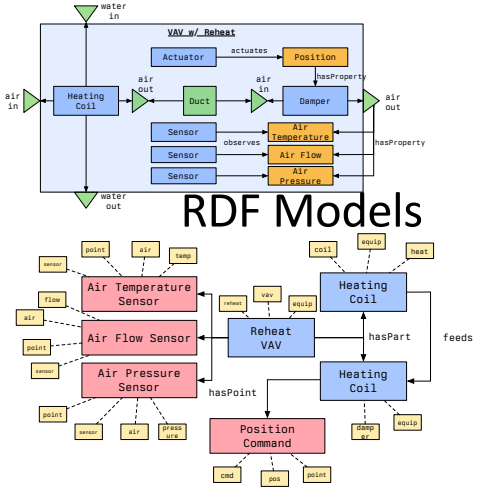
sup-air-flow-sensor	sup-air-pressure-sensor	name	sup-air-temp-sensor
saf1	sap1	vav1	sat1
saf2	sap2	vav2	sat2

Spreadsheet input

(or BACnet scan, BMS dump, etc…)

Evaluate template

Building MOTIF



Xeto-enabled SHACL inference

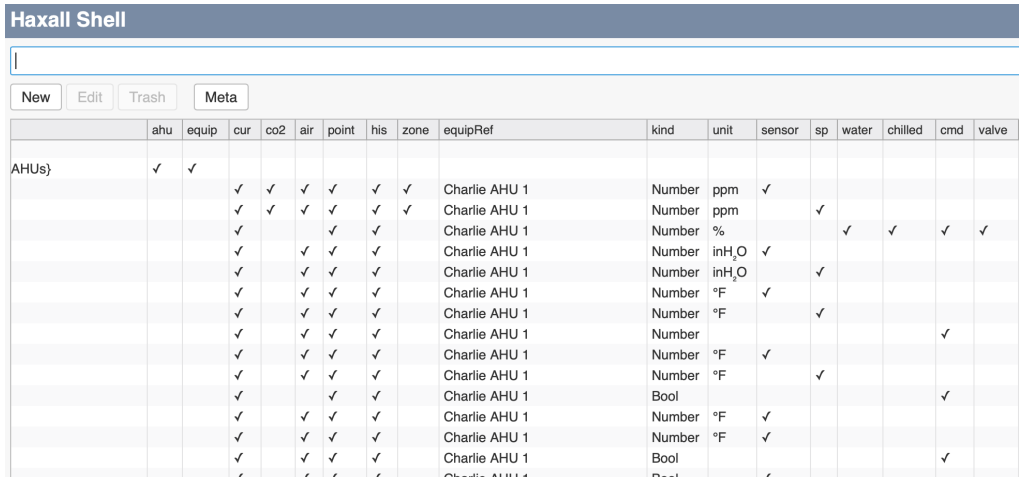
Haxall Shell

New | Edit | Trash | Meta

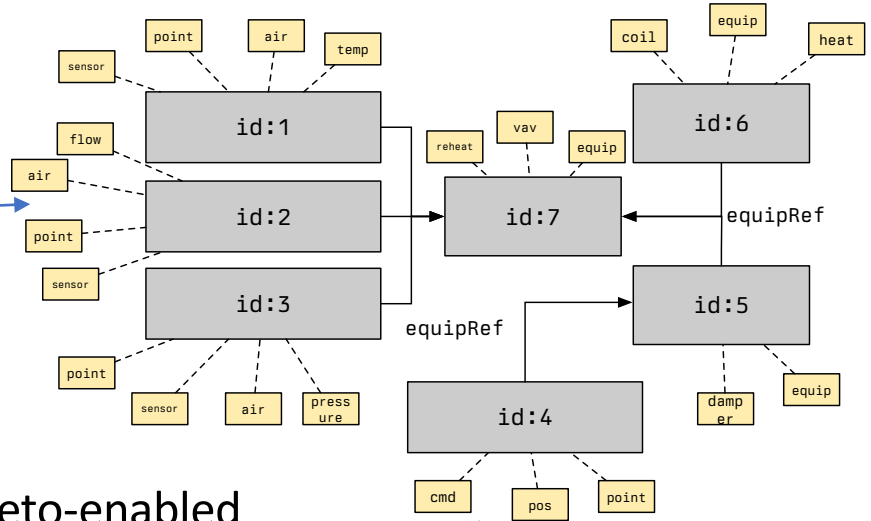
hvac	damper	mod	equipment	point	equip	equipRef	id	air	pressure	supply	sensor	vav	terminal	unit	temp	flow
ⓘ ✓	✓	5-Jun-2023 Mon 5:57:23AM UTC	✓	✓	✓	vav1	name-dmp_88531965									
ⓘ ✓	✓	5-Jun-2023 Mon 5:57:23AM UTC	✓	✓	✓	vav2	name-dmp_13616c16									
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav2	sap2	✓	✓	✓	✓					
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav1	sap1	✓	✓	✓	✓					
ⓘ ✓		5-Jun-2023 Mon 5:57:23AM UTC	✓	✓	✓		vav1					✓	✓	✓		
ⓘ ✓		5-Jun-2023 Mon 5:57:23AM UTC	✓	✓	✓		vav2					✓	✓	✓		
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav2	sat2	✓		✓	✓				✓	
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav1	sat1	✓		✓	✓				✓	
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav2	saf2	✓		✓	✓					✓
ⓘ		5-Jun-2023 Mon 5:57:23AM UTC		✓		vav1	saf1	✓		✓	✓					✓

Haystack model

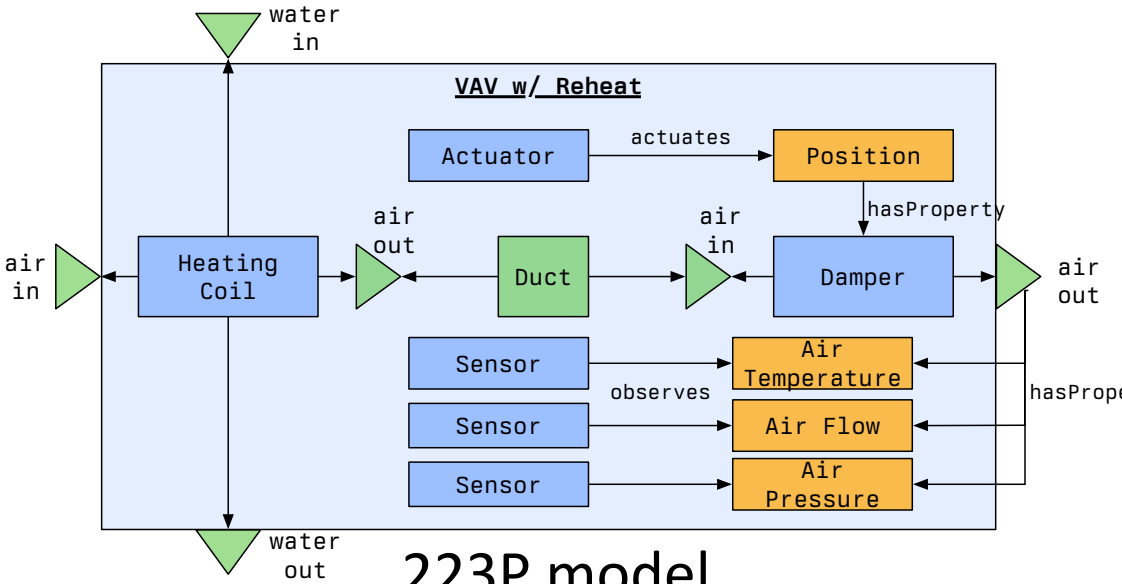
End-to-end: BuildingMOTIF-enabled Haystack to RDF



Haystack RDF model

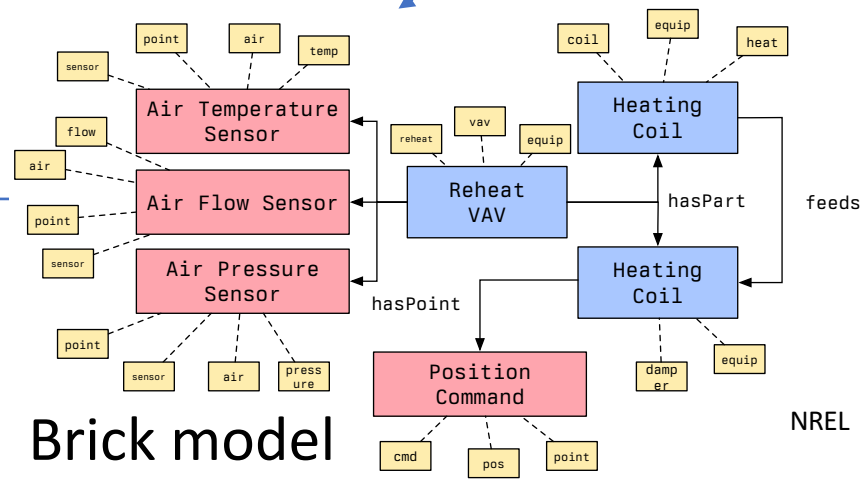


Xeto-enabled SHACL inference



223P model

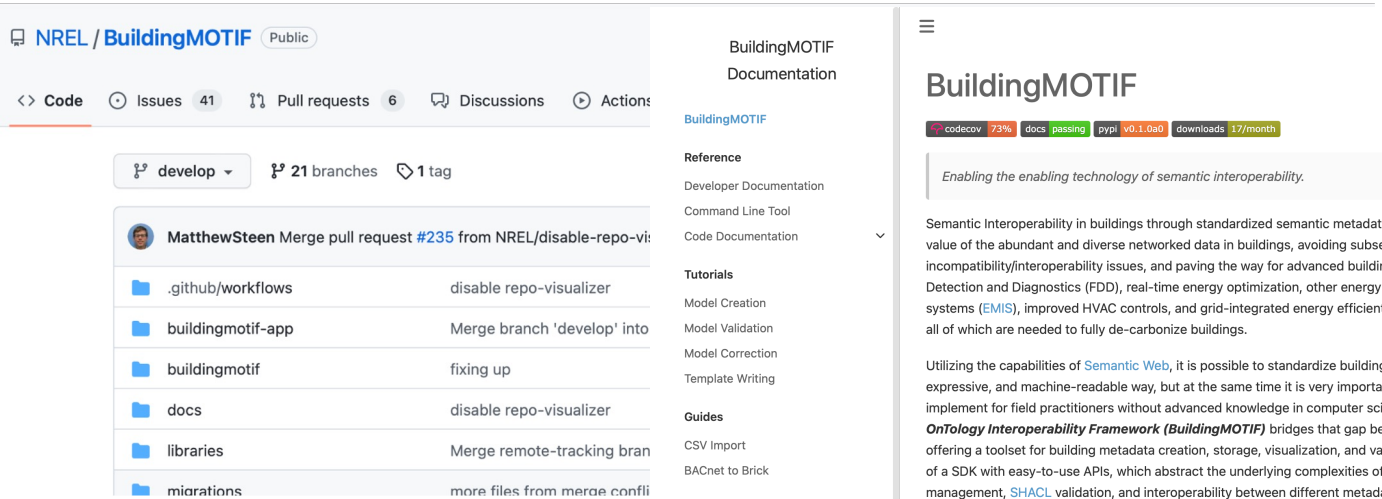
SHACL inference

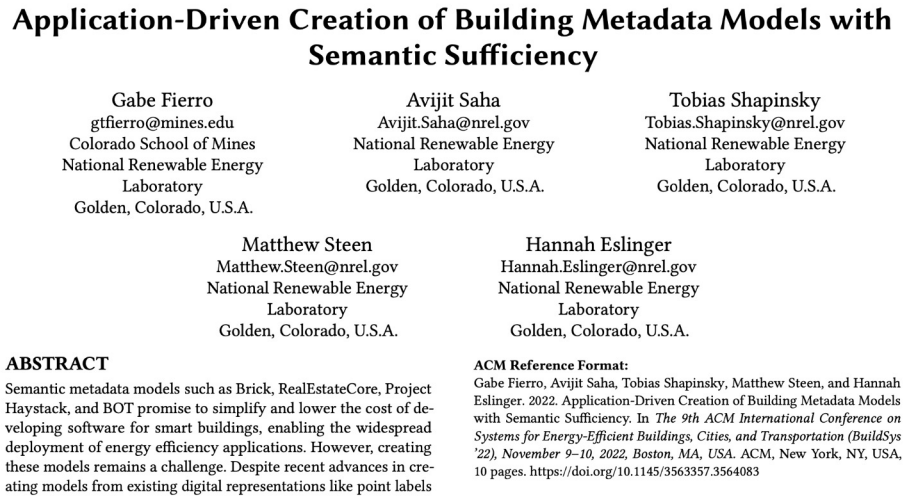


Brick model

Open Source Code!

- BuildingMOTIF is open source (*and in pre-alpha*)
  - https://github.com/NREL/BuildingMOTIF
  - Released under permissive BSD 3 Clause license
  - Tutorials, notebooks, demo web interface
  - Support for Brick, 223P, RealEstateCore and Haystack underway
- Check out other tools on https://open223.info





Thanks!

- Questions, feedback, comments?
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  - gtfierro@mines.edu