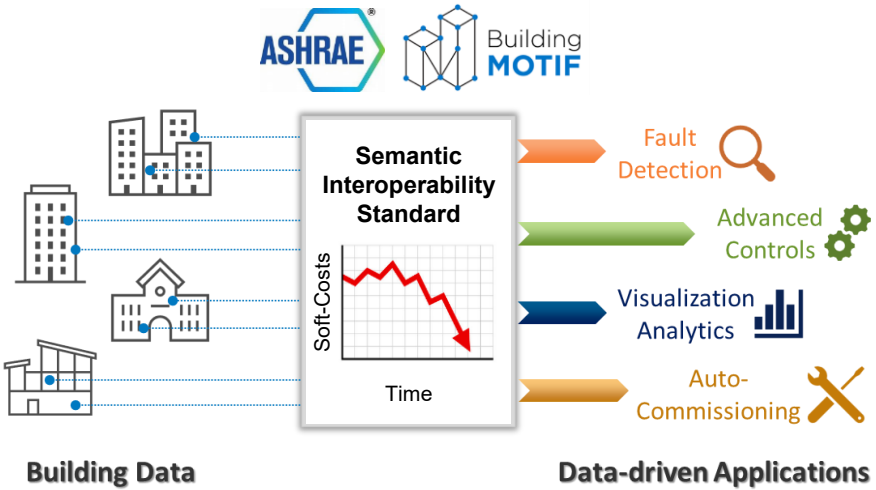
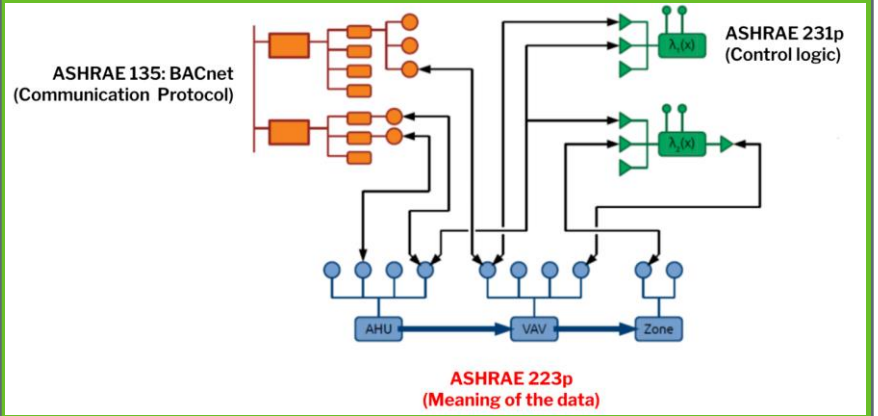
Reduce Barriers to Deployment of Building Control and Analytics Applications



ORG	WBS	Type	PI Name	Email
NREL	3.2.6.19	AOP	Avijit Saha	Avijit.Saha@nrel.gov
LBNL	3.4.6.69	AOP	Marco Pritoni	Mpritoni@lbl.gov
PNNL	3.2.1.05	AOP	Michael Poplawski	Michael.Poplawski@pnnl.gov
NIST	-	-	Steven Bushby	Steven.Bushby@nist.gov

Project Summary

OBJECTIVE: Disseminate and support adoption of "semantic" interoperability standard in collaboration with ASHRAE, industry, and building owners.
OUTCOME: Coordination efforts and developed tools, resources, and field implementations will facilitate the adoption of the standard in industry products and building systems.
IMPACT: Reduce the cost of installation, configuration, and commissioning of building controls, analytics, and data-driven applications, accelerating their adoption.



TEAM & PARTNERS

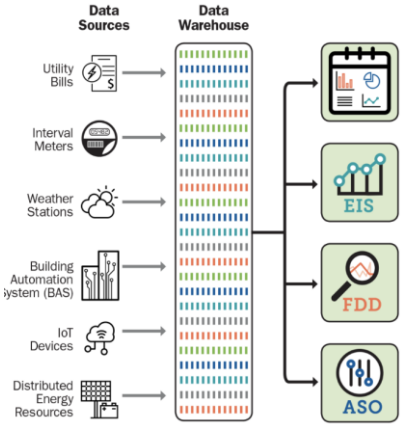
Team: NREL, LBNL, PNNL, NIST
Standard committee: ASHRAE - SSPC 135 (BACnet)
Significant representation from industry: JCI, Siemens, Schneider Electric, Trane, Delta, Clockworks Analytics.

STATS

Performance Period: 10/1/2022-9/30/2025
DOE Budget: $925k/year
Milestone 1: Standard release
Milestone 2: Reference models and tooling
Milestone 3: Field testing with partners

Emerging Controls, Analytics, and Data-Driven Applications Can Help Decarbonize Buildings

- Advanced Controls
  - Energy-related emissions from commercial buildings: 34% [1]
- Fault Detection & Diagnostics (FDD)
  - Waste due to poor operation: ~30% [2]
- Automated Demand Response
  - Peak load reduction potential of emerging control apps: 20% [3]
- Advanced Visualization, Reporting & Analytics



These applications need to access, understand/contextualize and use building data

[1] 1. EIA (2023). CBECS Table C1. [2] Fernandez, N, Katipamula, S, Wang, W, Xie, Y, Zhao, M, Corbin, C. (2017). Impacts of commercial building controls on energy savings and peak load reduction.
[3] Kiliccote, S, Olsen, D, Sohn, M, and Piette, MA. (2016). Characterization of Demand Response in Commercial, Industrial, and Residential Sectors in the U.S.

Barriers to Implementation

- Specification/delivery of controls is error-prone, time-consuming and costly [1]
  - Performance can vary >60% by implementation [2]

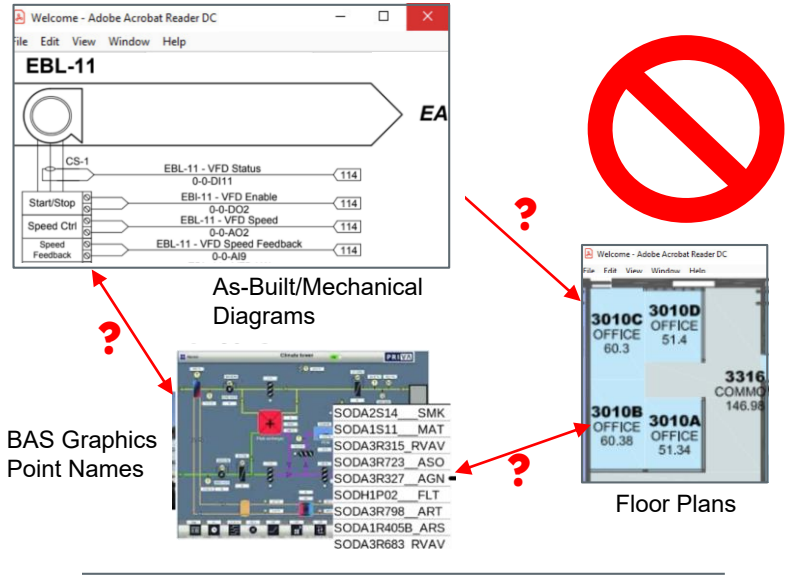
- Data analytics, AFDD are too expensive to deploy widely, in part due to manual configuration [4]
- The next generation workforce must be proficient in data analysis and software [3]
  - Cost and penetration of data-driven apps are also impacted by shrinking workforce which is not digital-ready [3]

- Data workers spend 50-80% of time collecting and preparing data for use, in part due to lack of standards [5]

Standards for semantic interoperability are crucial to reducing cost of development and deployment of controls, analytics, and data-driven applications

[1] Gwelen Paliaga *et al.*, "Re-Envisioning RCx: Achieving Max Potential HVAC Controls Retrofits through Modernized BAS Hardware and Software," 2020, doi: 10.20357/B7NC8P. [2] Pang, X., Piette, M. A., & Zhou, N. (2017). Characterizing variations in variable air volume system controls. *Energy and Buildings*, *135*, 166–175. https://doi.org/10.1016/j.enbuild.2016.11.031
[3] Truitt, S., Bean, J., Sullivan, J., Paranjothi, G., & Moe, A. (2022). *Completing the Circuit: Workforce Development for Advanced Building Construction and Grid-Interactive Efficient Buildings* (NREL/TP-5500-80480, 1855580, MainId:42683; p. NREL/TP-5500-80480, 1855580, MainId:42683). https://doi.org/10.2172/1855580
[4] Heimar Andersen, K., Pommerencke Melgaard, S., Johra, H., Marszal-Pomianowska, A., Lund Jensen, R., & Kvols Heiselberg, P. (2024). Barriers and drivers for implementation of automatic fault detection and diagnosis in buildings and HVAC systems: An outlook from industry experts. *Energy and Buildings*, *303*, 113801. https://doi.org/10.1016/j.enbuild.2023.113801
[5] https://www.nytimes.com/2014/08/18/technology/for-big-data-scientists-hurdle-to-insights-is-janitor-work.html

Standard Semantic Data Model Reduces Soft-Costs




```
bldg:office-ahu-oa-temp
    a s223:QuantifiableObservableProperty ;
    s223:hasAspect s223:Role-Outside ;
    qudt:hasQuantityKind quantitykind:Temperature ;
    qudt:hasUnit unit:DEG_C .
```

Digital 223P Models

- **Provides human- and machine-readable representation of**:
  - Building data points
  - Building equipment
  - Building subsystems
- **Eliminates time-consuming** and confusing mapping between ad-hoc BAS point conventions, as-built diagrams, BAS graphics, floor plans, etc.
- Significantly **reduces site-specific** configuration **effort** for applications
- Massively reduces costs for **controls + analytics deployment,** and enables automated reasoning and configuration of applications

Project Goals

- Support development of a consensus-based standard for semantic modeling
  - Advisory Public Review **Completed** for ASHRAE 223P ***Semantic Data Model for Analytics and Automation Applications in Buildings***
  - via ASHRAE SSPC 135 (BACnet)
  - Potential for an *ISO standard*
  - Developed with input from future users

- Provide supporting tools/technologies for semantic model construction, maintenance and conformance testing
- Field test, demonstrate proof of value, provide reference implementations

Alignment and Impact

Alignment with Blueprint Cross-Cutting Goals and Strategic Objectives

- **Affordability**: Reduce “soft-costs” required to deploy decarbonization solutions.
- **Resilience**: Ease integration of DERs that facilitate resilience and demand flexibility.
- **EE**: Accelerate adoption of control and analytics in new and existing buildings.
- **Onsite Emissions Reduction**: Reduce barriers to deployment of more complex heating systems (i.e., soft-costs of supporting control applications)
- **Transform the Grid Edge**: Reduce barriers to using building demand flexibility.

<u>Blueprint Goal:</u> By 2035, More than 50% (By 2050, More than 75%) of all homes and businesses have automated control platforms that reduce energy waste and enable flexibility.

Madeline Shunk
US Army Corps of Engineers

“...Efforts like building metadata provides an enterprise approach to operational technology data usage using an industry standard and is incredibly valuable to the Army and industry as a whole.”

Chariti Young
Automated Logic

“The DOE's investment in supporting the creation and dissemination of ASHRAE Standard 223 will have a profound impact on the industry, fostering innovation and setting new benchmarks for energy efficiency. ”

Jayson Bursill
Delta Controls

“The collaboration between National Labs, ASHRAE, and Industry through the semantic interoperability project will accelerate the adoption of advanced data-driven building applications (e.g. AFDD, grid-responsive control, predictive control).”

Alignment and Impact

Software Providers

- Reduce deployment (i.e., installation, configuration) time and cost
- New business opportunities

Owners

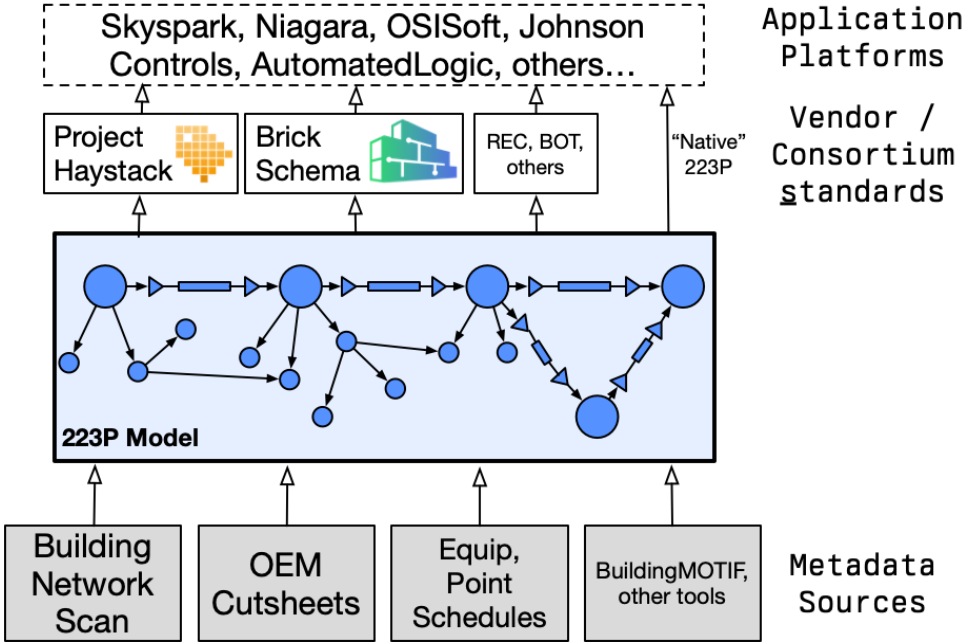
- Enable easier procurement of intelligent controls, FDD, and more
- Reduce vendor lock-in
- Allows verification of software conformance

Society

- Facilitate scalable deployment of analytics and controls to support the energy efficiency and decarbonization goals of BTO

Harmonization with Current Solutions

- **ASHRAE 223P:**
  - More detailed, fine-grained model than existing solutions
  - Defines “building blocks”, not exhaustive dictionary of terms
- **Complement**, don’t compete
  - Formalize existing schemas using 223P
  - Unifies independent efforts!
- Standard representation of building systems
  - Vendor/equipment models
  - Operational system models



Model Capabilities, Features, and Use cases

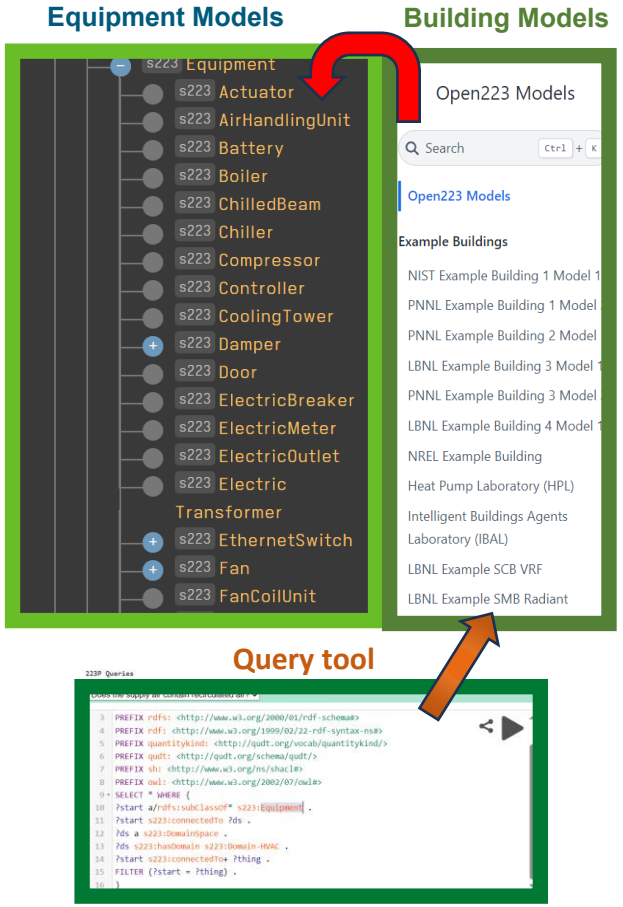
ASHRAE 223P is built upon existing technologies of semantic web such as RDF (Resource Description Framework), SHACL (Constraint Language), SPARQL (Query Language)

1. Formal Modeling (RDF, SHACL)

- Real Equipment Type: Detailed representations of HVAC systems, sensors, and controls.
- Tested to model various types pf real buildings and research labs designed for HVAC operations research.

2. Finding Solutions for Practical Use Cases (SPARQL)

- Users can query about specific information related to equipment performance, system topology, and operational data.



Model Capabilities, Features, and Use cases

3. Conformance Checks (SHACL)

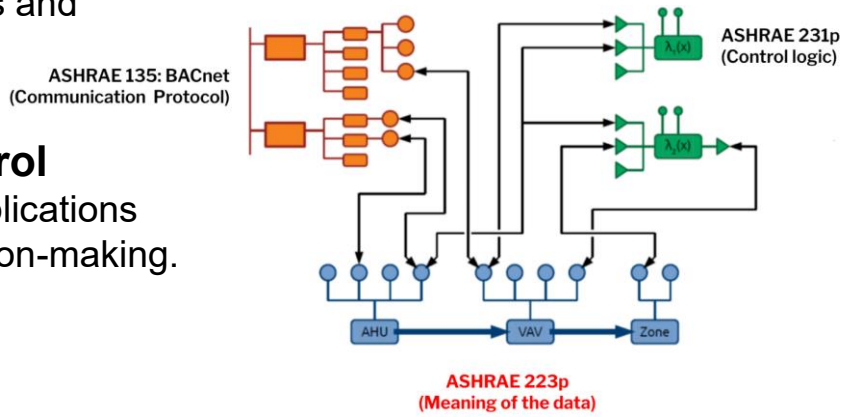
- Ensuring conformance check against existing guidelines and standards (e.g., ASHRAE 231P, G36).

4. Software Configuration for Analytics and Control

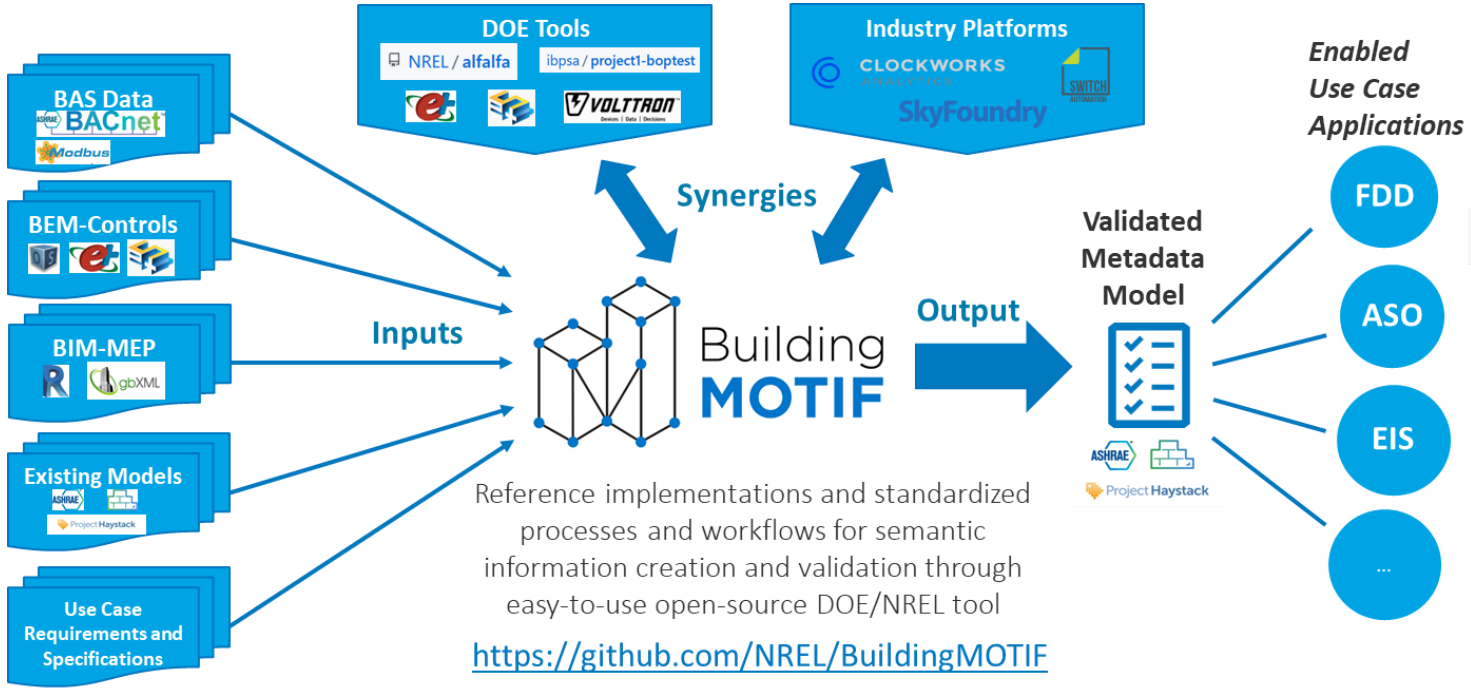
- Advancing the configuration of analytics and control applications for enhanced performance analysis and informed decision-making.

5. Coordinated Development of Standards

- 223p describes the inputs and outputs of a 231p control model, and links to the actual network points to access the data or control the systems.



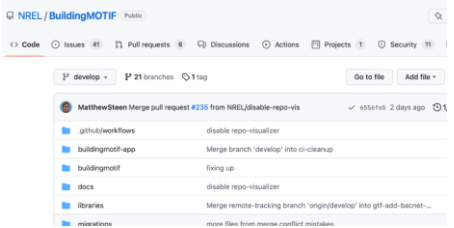
Developing and Publishing Open-source Tools Helps Adoption

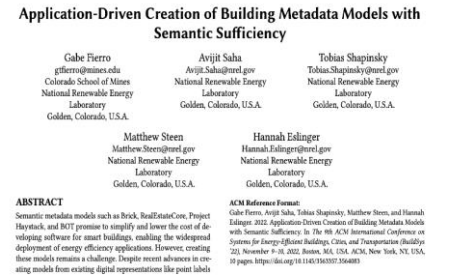


Reference implementations and standardized processes and workflows for semantic information creation and validation through easy-to-use open-source DOE/NREL tool

https://github.com/NREL/BuildingMOTIF

BuildingMOTIF tool helps field practitioners without in-depth RDF expertise to easily create and validate models.





Application-Driven Creation of Building Metadata Models with Semantic Sufficiency

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ABSTRACT

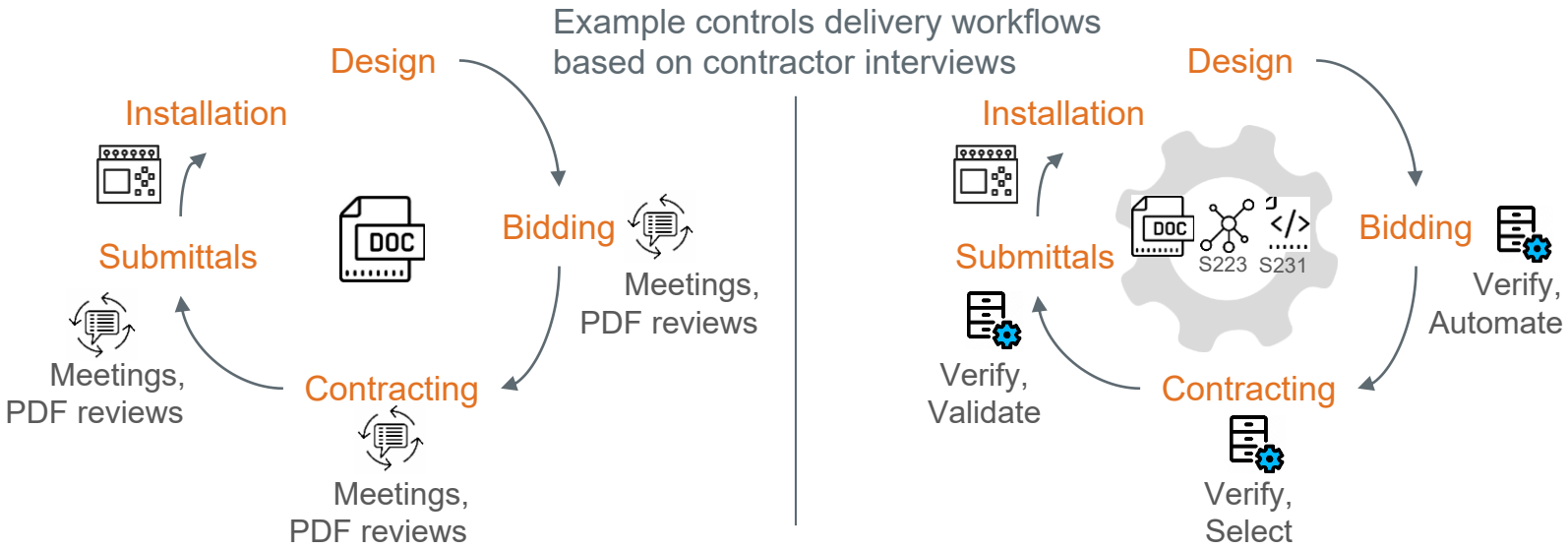
Semantic metadata models such as Brick, RealEstateCore, Project Haystack, and BOT promise to simplify and lower the cost of developing software for smart buildings, enabling the widespread deployment of energy efficiency applications. However, creating these models remains a challenge. Despite recent advances in creating models from existing digital representations like point labels

ACM Reference Format:

Gabe Fierro, Avijit Saha, Tobias Shapinsky, Matthew Steen, and Hannah Eslinger. 2022. Application-Driven Creation of Building Metadata Models with Semantic Sufficiency. *In The 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation (BuildSys '22), November 9–10, 2022, Boston, MA, USA. ACM, New York, NY, USA,* 10 pages. https://doi.org/10.1145/3563357.3564083

Automating Application Delivery Processes

Today's Controls delivery Workflow is a largely human-centric process that transfers paper materials between actors, and relies on human interpretation, validation & verification



The envisioned Application delivery Workflow is a largely automated process that transfers digital material between machines, and leverages more rigorous validation & verification

Progress and Future Work

FY20 – FY23

- Consensus on needs by collecting inputs from all types of stakeholders. Held Technical Advisory Group meetings. Project Merit Reviewed.
- ASHRAE 223 standard development with strong industry engagement.
- DOE vision papers and technical publications. First release of tools.

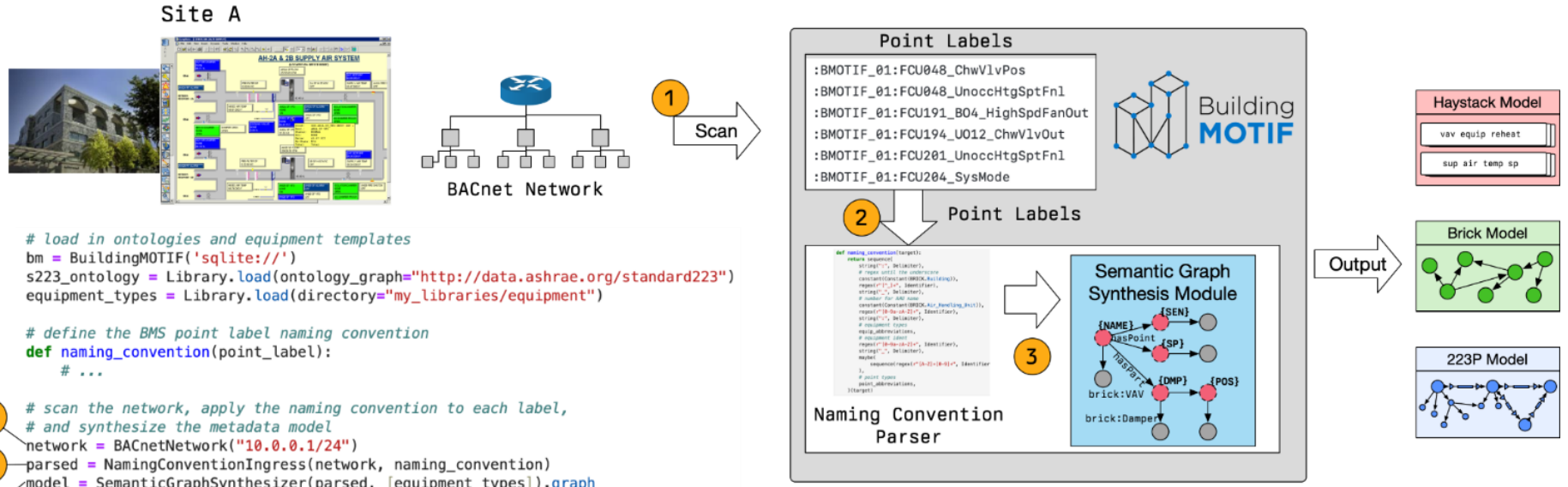
FY23 – FY24

- ASHRAE advisory public review of Standard 223.
- Released improved version of model creation and validation tool.
- Public release of reference models.
- Preliminary field testing and starting partnership with industry for tech transfer.

FY25 - Future

- Release of Final Standard and full suite of tools, reference models, practitioner guidance, preliminary field-testing results
- Deploy with vendors in implementation workflows, real building demonstration, demonstrate integration of standard into procurement specifications

Semantic Modeling in Existing Buildings from BACnet Data

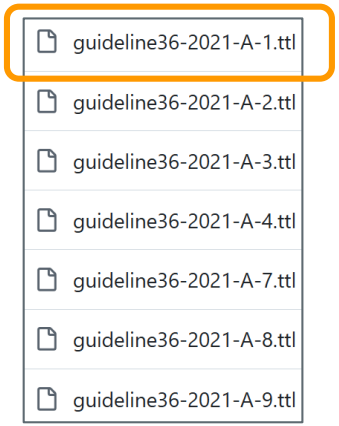



```python
# load in ontologies and equipment templates
bm = BuildingMOTIF('sqlite://')
s223_ontology = Library.load(ontology_graph="http://data.ashrae.org/standard223")
equipment_types = Library.load(directory="my_libraries/equipment")

# define the BMS point label naming convention
def naming_convention(point_label):
    # ...

# scan the network, apply the naming convention to each label,
# and synthesize the metadata model
network = BACnetNetwork("10.0.0.1/24")
parsed = NamingConventionIngress(network, naming_convention)
model = SemanticGraphSynthesizer(parsed, [equipment_types]).graph
```

1
2
3

- **Turnkey development of metadata models**
- BuildingMOTIF scans a BACnet network to find point labels
- Express point naming convention to BuildingMOTIF
- BuildingMOTIF uses ontology definitions to create valid metadata models automatically

Delivered Reference Models



Example models and use-case centered validation requirements are publicly available, demonstrating how standard can be used

```
mysystem:VAVCoolingOnly a s223:SingleDuctTerminal,
        g36:VAVTerminalCoolingOnly ;
    rdfs:label "Vavcoolingonly" ;
    s223:cnx mysystem:VAVCoolingOnly-in,
        mysystem:VAVCoolingOnly-out ;
    s223:contains mysystem:VAVCoolingOnly-damper .
```

https://models.open223.info/intro.html

Validate

ex: Guideline 36 validation requirements use 223P to facilitate modeling and validation of systems that support G36 sequences

```
g36:VAVTerminalCoolingOnly a s223:Class, sh:NodeShape ;
    rdfs:label "VAVTerminalCoolingOnly" ;
    sh:property [sh:minCount 1 ;
        sh:path s223:contains ;
        sh:qualifiedValueShape [ sh:class g36:Damper ]; ].
```

Field Testing in Real Buildings

UC Berkeley Sutardja Dai Hall

Large Commercial Building

Streamlined Controls Deployment

UC Davis Offices

Small Commercial Building

Application-Driven Modeling + MPC

David Brower Center

Medium Commercial Building

Streamlined Controls Deployment

Anthony Quinn Library

Small Commercial Building

Application-Driven Modeling + MPC

LBNL Building 33

Large Commercial Building

G36 Extension Assisted Modeling

LBNL Building 59

Large Commercial Building

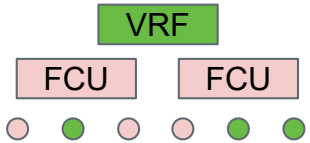
Automated Large Building MPC

Field Test - Application Driven Modeling

@UC Davis, Offices

Streamlined and focused semantic modeling method for existing buildings

Proto-model based on BACnet Information, partly complete



Load application specification - equipment and data points will be validated for application

	system_spec	class
0	mpc:fcu	s223:FanPoweredTerminal
1	mpc:outdoor-unit	s223:HeatPump

Select a point to view details

i_iu_occ

i_iu_oper

O_iu_EV

	equipment	equipment_label	system_spec	class
13	ex1:00039	vrf	mpc:outdoor-unit	s223:HeatPump
12	ex1:01360	TU113	mpc:fcu	s223:FanPoweredTerminal
11	ex1:01253	TU112	mpc:fcu	s223:FanPoweredTerminal

if points are invalid

Possible correct points queried and run against validation rules

Query Results

	T_iu_za	point_name
0	ex1:0011	RT
1	ex1:0017	RAT

Validation Results

Point ex:fcu1-OM missing s223:hasAspect s223:EnumeratoinKind-Occupancy

Graph updated based on validation - which states exactly what is missing

Update Graph

Choose operation

INSERT

DELETE

Update Graph

if points are valid

Points bound to application

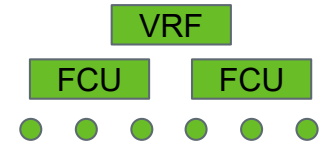
Bind Point to Variable Name

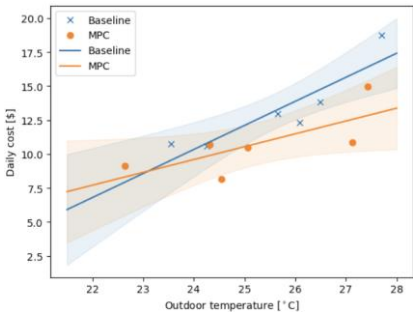
	equipment_name	O_iu_EV_node_match	point_name
0	TU101	ex1:00180	EVP

Bind Point!

Point bound, graph updated.

Semantic model is updated and application instantiated

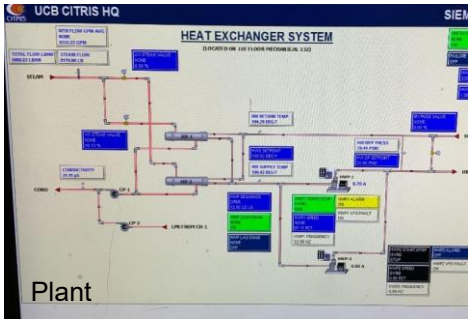


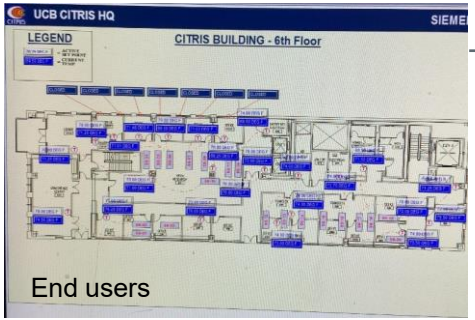


Comparisons of daily HVAC costs: Cooling Tests

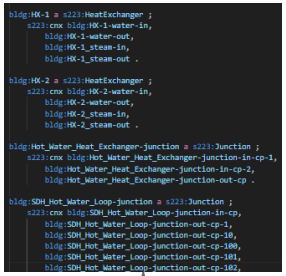
Field Testing - Controls Deployment

@UC Berkeley, Sutardja Dai Hall





ASHRAE BACnet™

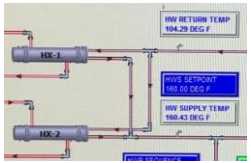


SPARQL

Run queries to get equipment, BACnet information, end users and operation status

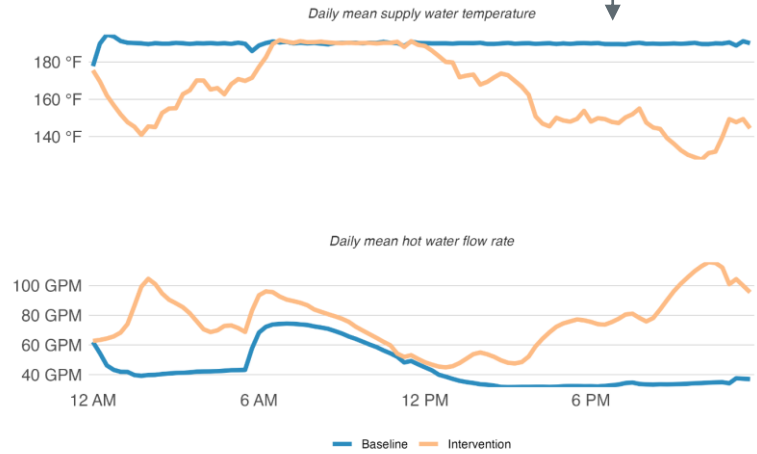
ASHRAE 231P

Send information to ASHRAE Guideline 36 control blocks



Write new equipment setpoint(s)

Results



Commercial Pilot Project - OBC Flex

Best-in-class DF Specifications and Library using 223P and 231P

ASHRAE

Integration with Vendors' Platforms

Field Deployment and Testing *in 4-9 Real Buildings*

Community Engagement

Technology/Knowledge Transfer Activities

Collaboration with ASHRAE for inclusion in guideline 36

BAS Pathway

EMIS Pathway

Carrier/ALC/Taylor

WebCTRL

Tridium/Altura

TRIDIUM niagara4

Skyfoundry/Altura

SkyFoundry

Facil.ai

facil.ai

Buildings IoT

buildingsIOT

Contra Costa Community College District

1-3 buildings

California State University, San Marcos

1-3 buildings

California State University, Dominguez Hill

1 building 1 central plant

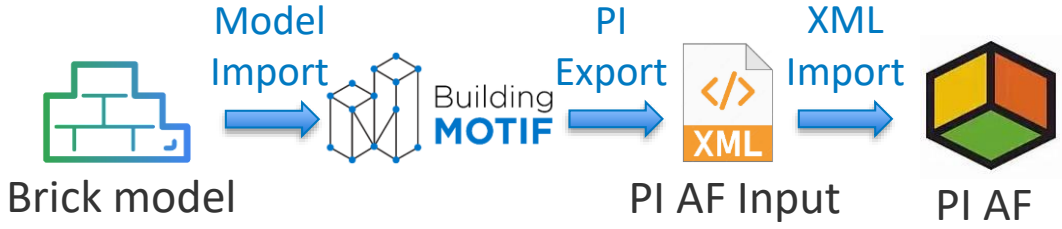
San Diego State University

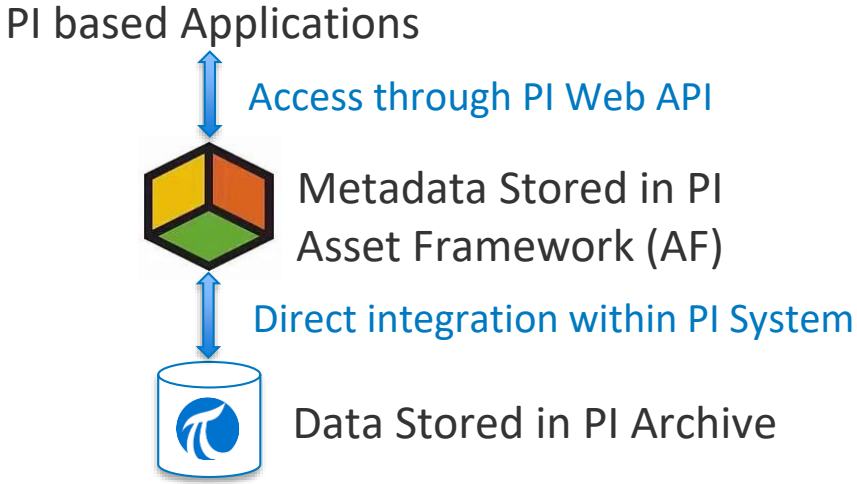
1 building

Demonstration with Army and Navy through Synergistic ESTCP Project

- Partnering with US Army Corps of Engineers: Construction Engineering Research Laboratory (CERL)
- Demonstration Sites:
  - Navy Base at Norfolk
  - Army Base at Ft Liberty
- Demonstration Objectives:
  - Metadata modeling and integration with DoD Control Systems
  - Integration of metadata requirements within DOD's Construction Specifications

Example Implementation in Navy's PI System





Thank you

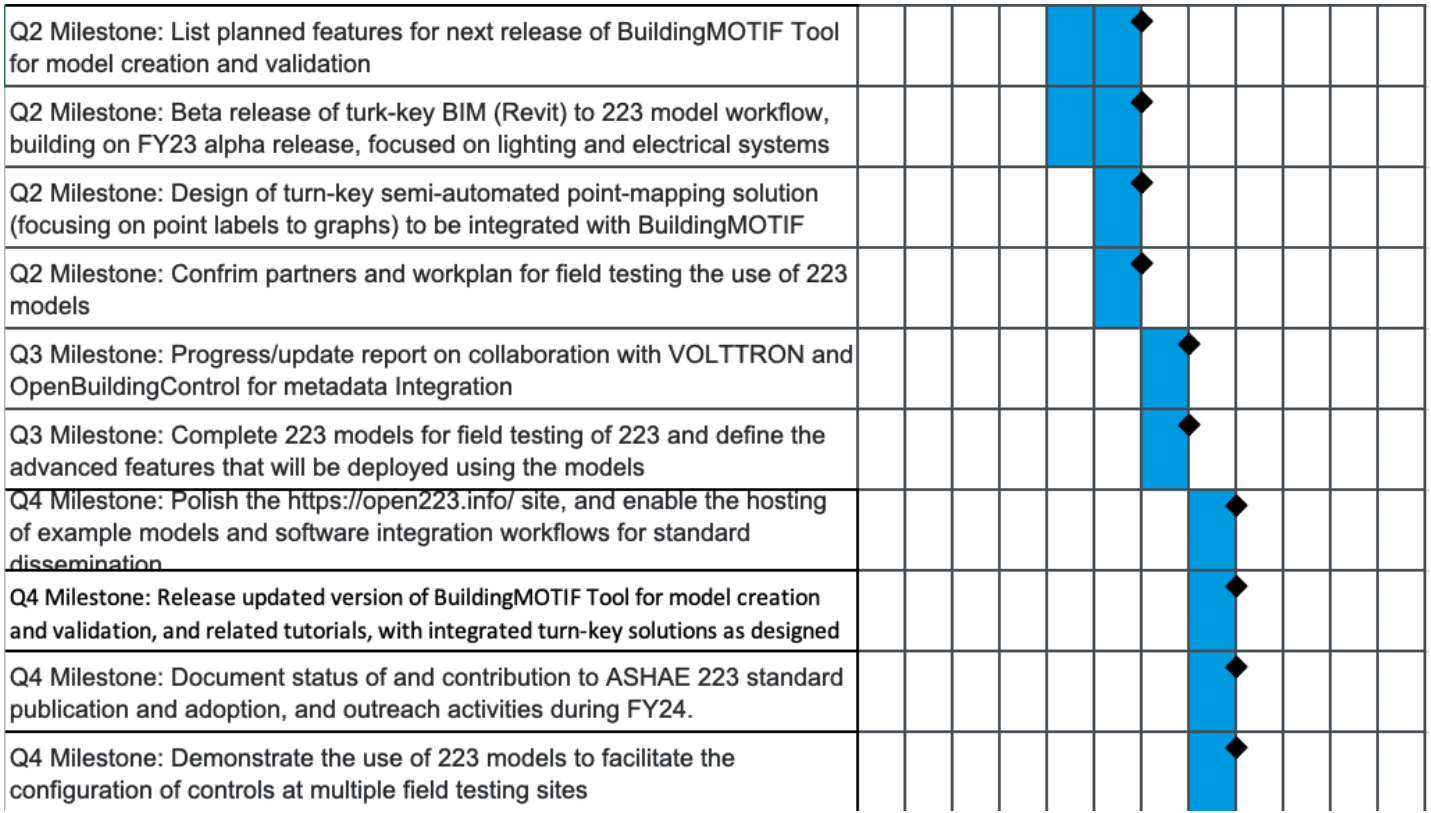
ORG	WBS	Type	PI Name	Email
NREL	3.2.6.19	AOP	Avijit Saha	Avijit.Saha@nrel.gov
LBNL	3.4.6.69	AOP	Marco Pritoni	Mpritoni@lbl.gov
PNNL	3.2.1.05	AOP	Michael Poplawski	Michael.Poplawski@pnnl.gov
NIST	-	-	Steven Bushby	Steven.Bushby@nist.gov

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$925,000				$925,000				$925,000			
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Finalize methodology for evaluating the potential impact of the standard by targeting use cases for LCB and SMCB that are most relevant to stakeholders	◆											
Q2 Milestone: List planned features for Beta version of BuildingMOTIF Tool for model creation and validation		◆										
Q3 Milestone: Define the first set of partners and plans for field tests for SMCB and LCB.			◆									
Q3 Milestone: Publish the first set of reference models for LCB and SMCB.			◆									
Q4 Milestone: Release Beta version of BuildingMOTIF Tool for model creation and validation, and related tutorials.				◆								
Q4 Milestone: Release Alpha version of Revit-to-TTL tool for lighting and electrical system model creation, and related workflow and tutorials.				◆								
Q4 Milestone: Document early results of field deployment of 223P standard integrated with CDL/231P (Topic B)				◆								
Q4 Milestone: Document status of and contribution to ASHAE 223 standard publication and adoption, and outreach activities during FY23.				◆								

Project Execution



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