Semantic Interoperability for Building Operations

2021 IBPSA Virtual Expert Meeting
Day 2 - Semantic Modeling

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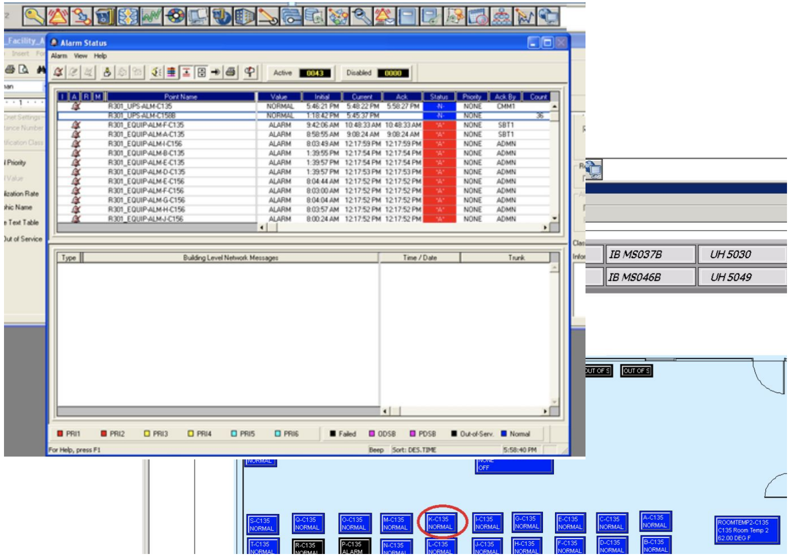
Agenda

- *My practical and opinionated view of semantic modeling for building operations*
  - (my) Motivation
  - Review of semantic schemas (Haystack, Brick, 223p)
  - Landscape of Metadata Schemas in 2021
  - Workflows using Modelica
  - Open Questions in Semantic Modeling

My starting point: UCD Campus Data Warehouse

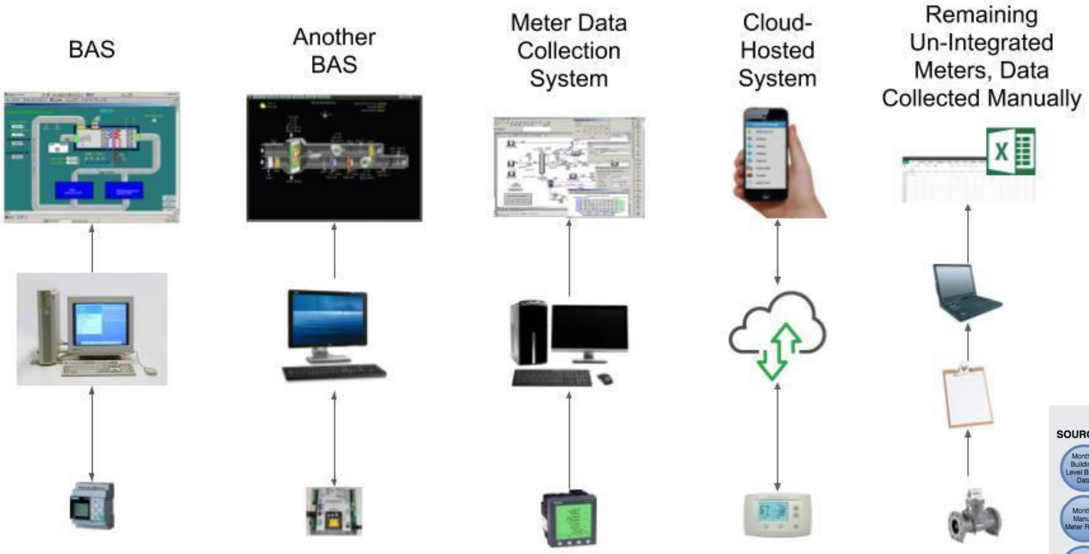


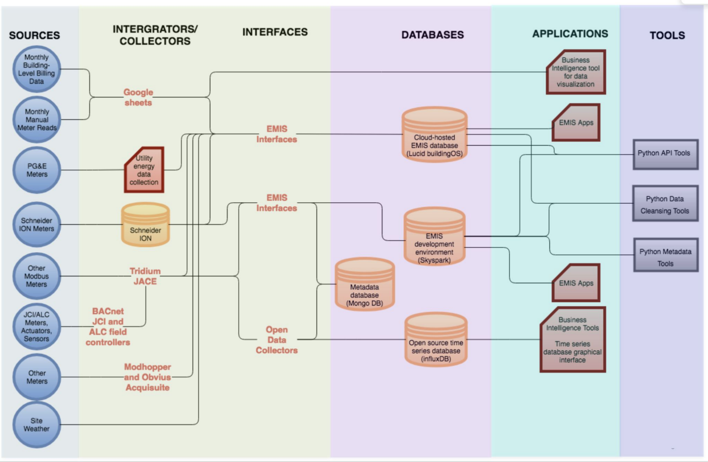
- 100-300k points
- Unusably slow DB
- Poor metadata
- Inadequate I/O

Siemens DB → OsiSoft PI

- Much Faster TS DB
- Non ideal metadata schema (complex and rigid hierarchy or based on point names)

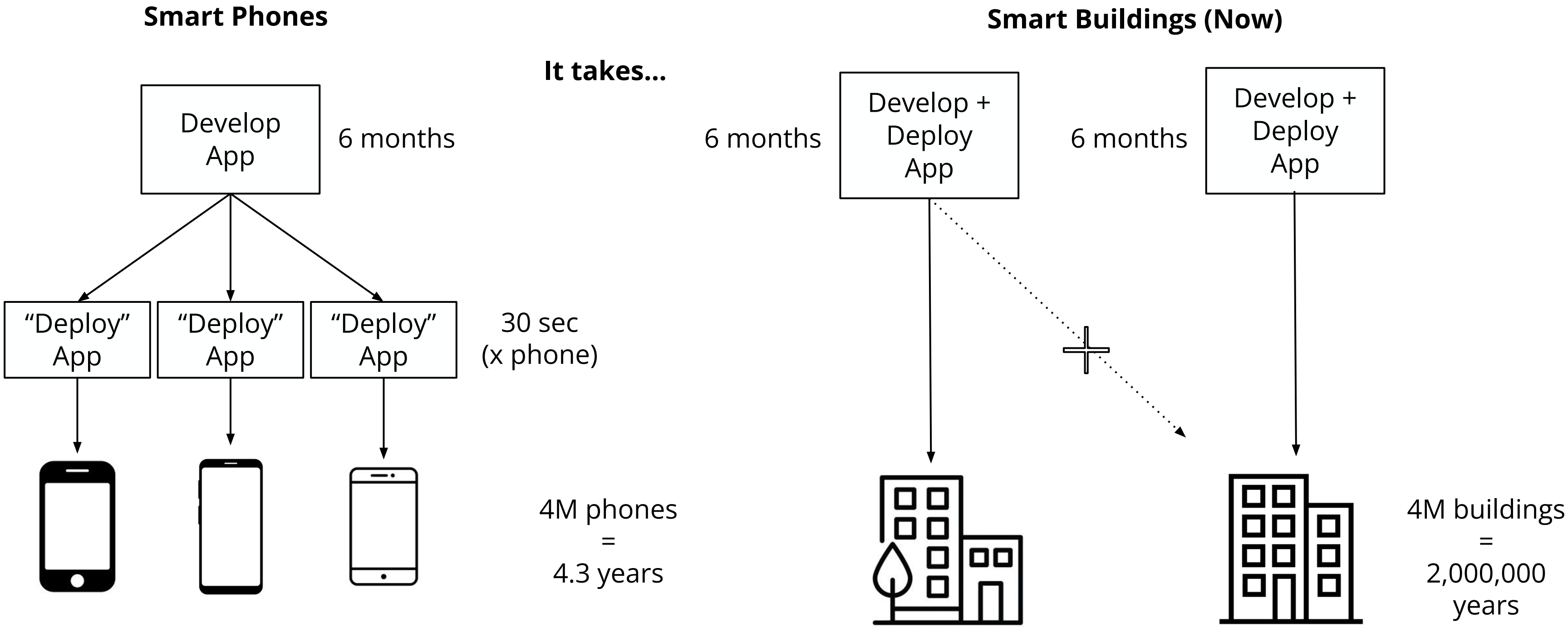
...and LBNL Data Warehouse





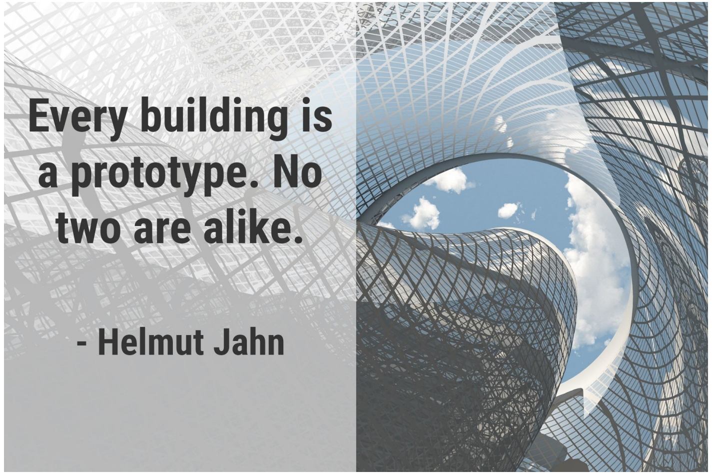
Pritoni et al. (2018). *Towards a Scalable Model for Smart Buildings.*
https://escholarship.org/uc/item/5b7966hh

The ideal goal is to write “portable” applications



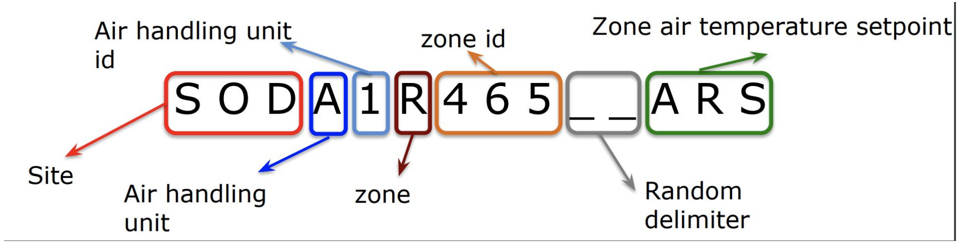
Current practice is not scalable!

Common problems



- Multitude of equipment vendors: different capabilities, features
- Custom-designed systems and use cases
- Every retrofit project is a "one-off"
- Things changes over time

- No common representation for "metadata":
  - Building systems described by informal and ad-hoc labels
  - Not standardized
  - Error-riddled
  - Requires a human to interpret (not machine-readable)
  - Not scalable



Manufacturer's' specified "recommended" names

- Used to facilitate the creation of graphics or control sequences
- Example:

VAV2-10.OCCCMIN	Occupied Min Air Flow
VAV2-10.OCCINPUT	Occuppied Input
VAV1-3.CPIDP	Cooling Command
VVT-2.ZONEDMD	Zone Demand
VVT-2.UNOCDB	Unoccupied Deadband
VVT-2.OCCDB	Occupied Deadband
AHU-2.OAD-O	Outside Air Damper Output
AHU-2.SFVFD-A	Supply Fan VFD Alarm
AHU-2.BLDG-P	Building Pressure
AHU-1.CRM-T	Room Temperature
AHU-1.VVTZN-T	VVT Zone Temp
AHU-1.DAT-WSP	Discharge Air Temperature Setpoint
AHU-2.FLTR-S	Filter Status
AHU-2.EF2-A	EF-2 Alarm
AHU-2.EF2-C	EF-2 Command
AHU-2.EF2-S	EF-2 Status

Examples of Names for **Discharge Air Pressure Sensors**

BAS Implementation 1	BAS Implementation 2	BAS Implementation 3
ACAD.AHU1.Supply Air Pressure	15 AHU 1 SA PRESS	30_ahu-001/dstpr
BJ1.AHU1_2.SSP	015-AHU-008.DA1-P	30_bl-023_024/statc_press
GIEDT.AHU.AHU1.SSP1	AHU00150.SA4-SP1	33_ahu-01/stat_press
GHA.AHU1.FAN SSP	70_BL184.DS-P	59-ahu_001/control_pressure
BRIG.SF1A.SUP STATIC	77 AHU 7 SA DUCT PRESSURE	59-ahu-004/da_stat_press
GBSF.AHU3.SPD	86 BL5-DP	
CHEM.AH2N.DUCT STATIC	90_BL4-5.DUCT-DP	

- Issues with these conventions:
  - vary by manufacturer
  - vary by software version
  - not enforced in the field (by technicians) - vary between and within buildings
  - hard to update (label used as ID for the point)

Point Labels

- Can we interpret them and put them in a flat table ?

Point Label
ZONE.AHU01.RM1-2603B.Zone Air Temperature

Equipment Type	Upstream Equipment	Equipment Name	Sensor Type
ZONE (VAV)	AHU01	RM1-2603B	Zone Air Temp Sensor

- How about these ones?

AHU.AHU01.Return Air Temperature -> no upstream equipment

AHU.AHU01.SF.Start Stop -> component of equipment (Fan)

ZONE.AHU01.RM1-2603B.Zone Air Temperature 2 -> more than one sensor of the same type for the same zone

- We need a more flexible data structure

Project Haystack v3

An Open Source initiative to streamline working with IoT Data Source: https://project-haystack.org/

“We standardize semantic data models and web services with the goal of making it easier to unlock value from the vast quantity of data being generated by the smart devices that permeate our homes, buildings, factories, and cities.”

In a nutshell:

- It replaces point names with semi-structured TAGs to describe the data
- It provides an “official” dictionary of TAGs (but custom TAGs can be used)
- TAGs can describe relationships between equipment via references

Example:

BAS Point Name: CARYTOWN.FLOOR4.AHU-4.VAV.ZONE.TEMP

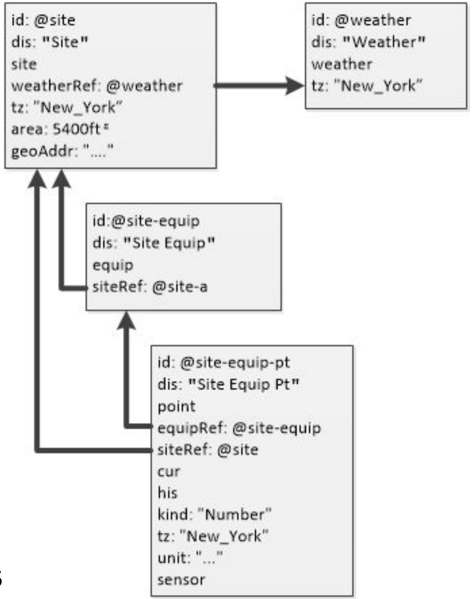
id:	150a3c6e-bef0ee0e
dis:	zn3-wwf14
sensor:	✓
air:	✓
temp:	✓
unit:	°F
curVal:	77.60 °F
equipRef:	Carytown AHU-4
siteRef:	Carytown
tz:	New_York
zone:	✓
vav:	✓
floor:	4
scheduleRef:	occSchedule-1

Project Haystack v3: Summary

Project Haystack

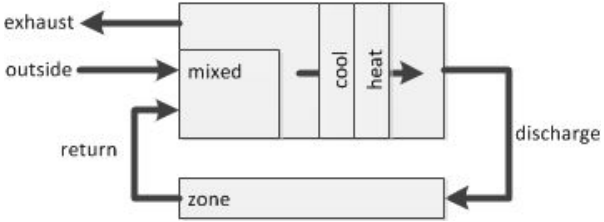
Advantages

- Open source schema (backed by industry partners)
- Intuitive to use by domain experts and technicians
- Relatively large user base (compared to other schemas)



Limitations and Issues

- Limited to built-up HVAC, meters, lighting (Building Operation)
- Lack of precise definitions of terms and best practice -> prone to “dialects”
- Lack of formal structure (TAG composition rules) -> hard to validate models
- Does not describe equipment layout (except for abstract refs)



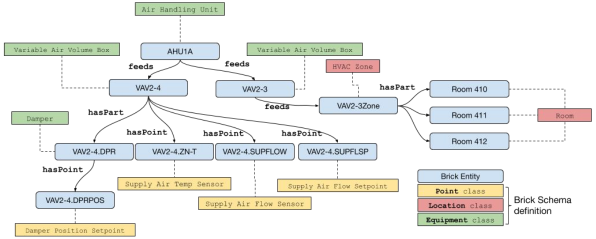
Bergmann et al. (2020). *Semantic Interoperability to Enable Smart, Grid-Interactive Efficient Buildings.* https://doi.org/10.20357/B7S304

Brick Schema

Brick

"Brick is a unified semantic representation of different resources in buildings and their systems. Brick enables software applications which are portable among buildings."

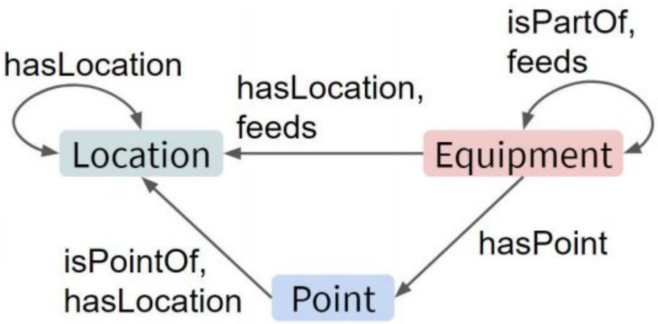
- Started in 2015 as academic project between universities (UCB, UCLA, CMU, UVA, USD, UCSD, IBM)
- Goal: support creation of portable, data-driven building analytics (and control)
- Uses flexible directed graphs to represent entities and their relationships (W3C RDF)
- In addition to tags, it can express higher-order abstractions such as classes and their relationships
- Recently backed by a industrial consortium
- Out of Scope: geometry, physical connectors (ducts, etc), physics, controls
- In Scope: HVAC, lighting, metering



Source: https://brickschema.org

Brick: Main Concepts

- Three main concepts, each the root of their own **class hierarchy**
- **Classes** provide definition, organization to **entities**
- **Entities** are the physical, logical and virtual “things”
- **Relationships** dictate how entities correspond and relate to each other



ENERGY TECHNOLOGIES AREA

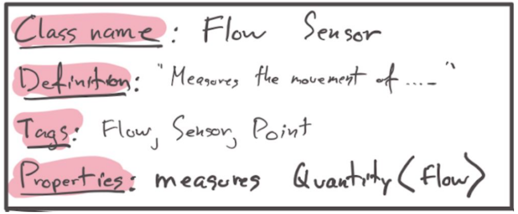
Source: https://brickschema.org & Fierro (2020). Brick presentation to ASHRAE 223p

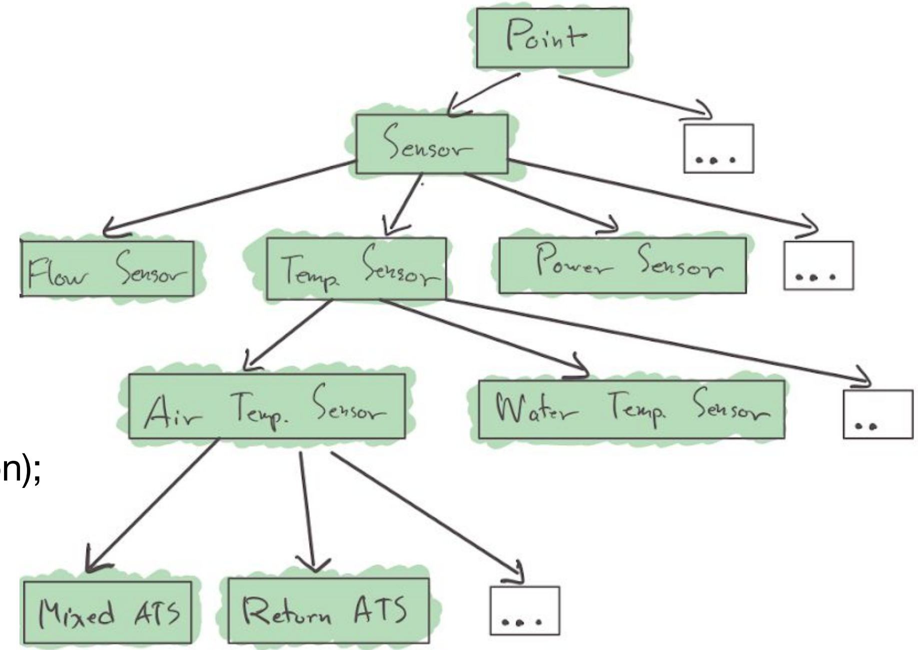
Example of Brick Classes: Point

A source of (digital) telemetry; 6 “flavors” defined in Brick

https://brickschema.org/ontology/1.2/classes/Point

- Sensor
- Command
- Setpoint
- Status
- Alarm
- Parameter





Subset of **Point** hierarchy

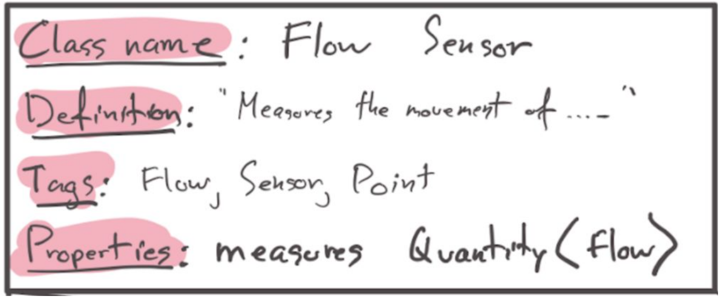
- Generic classes closer to top (partial information); more specific/useful closer to bottom

Source: https://brickschema.org & Fierro (2020). Brick presentation to ASHRAE 223p

Example of Brick Classes: Point (2)

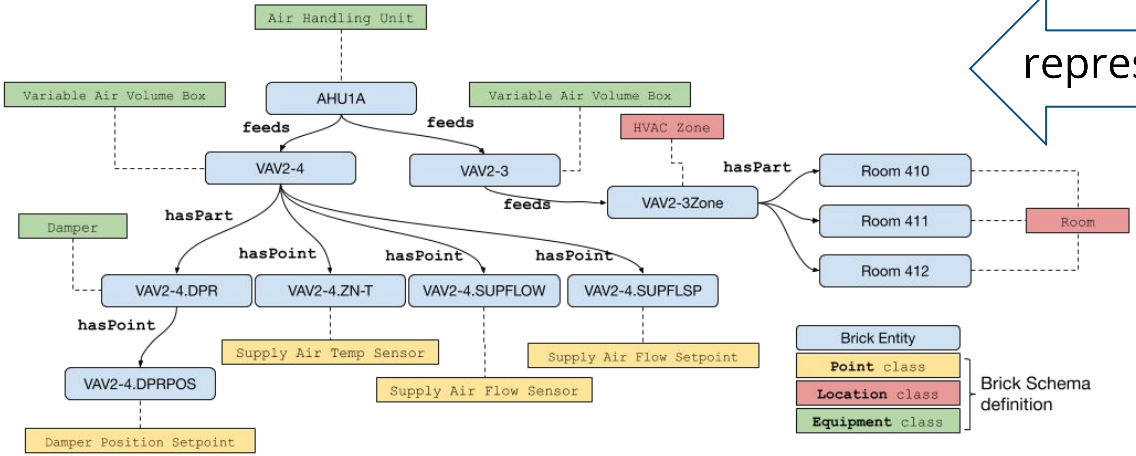
Breaking down the definition:

- **Class name**: standard concept name
- **Definition**: textual, human-readable definition (e.g. from ASHRAE dictionary)
- **Tags**: set of equivalent tags
- Tags ←→ Class and Class ←→ Tags translation process performed by a reasoner
- **Properties**: parameterization; set of additional properties and values that differentiates this class from its parent/siblings



Source: https://brickschema.org & Fierro (2020). Brick presentation to ASHRAE 223p

An example of a Brick Model



represents

Source: https://brickschema.org

Brick - Summary

Advantages

- Open source schema (backed by a new industry consortium)
- More structured than Haystack v3
- Relatively large user base (compared to other schemas)

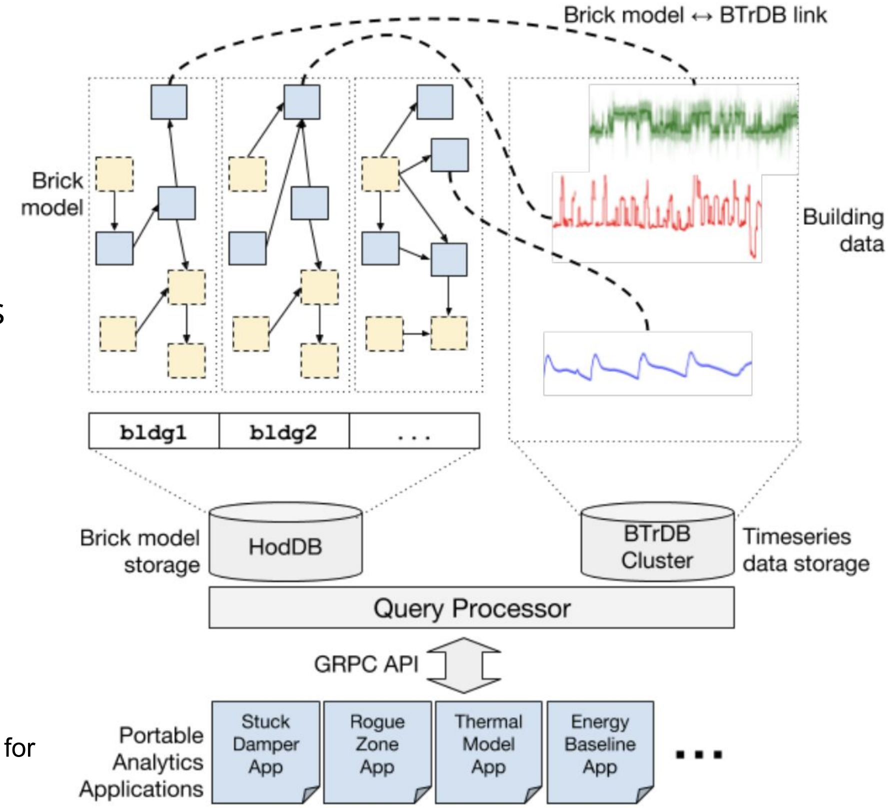
Limitations and Issues

- Limited to built-up HVAC, meters, lighting (Building Operation)
- Still in early development and with little real-building deployments
- RDF representation is hard to understand by humans (no adequate viz tools)
- Does not describe equipment layout (except for abstract feed relationships)

Bergmann et al. (2020). *Semantic Interoperability to Enable Smart, Grid-Interactive Efficient Buildings.* https://doi.org/10.20357/B7S304

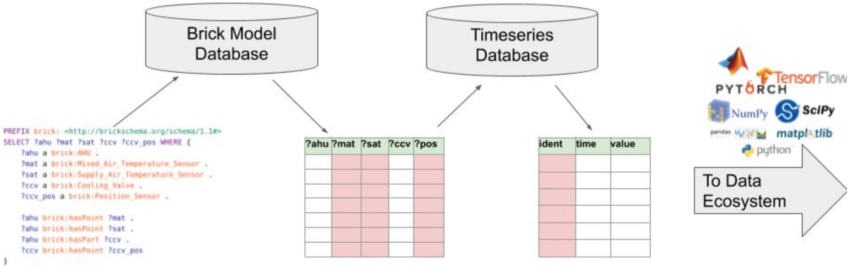
We developed a proof of concept platform: Mortar

- Open testbed for portable building analytics[7]
- Sensor data from more than 100 buildings
- All buildings in the testbed are described using Brick
- Used to demonstrate portable applications



Fierro et al. (2019). Mortar: An Open Testbed for Portable Building Analytics.
https://dl.acm.org/doi/abs/10.1145/3366375

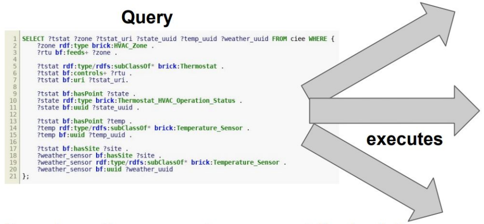
Mortar: developing applications

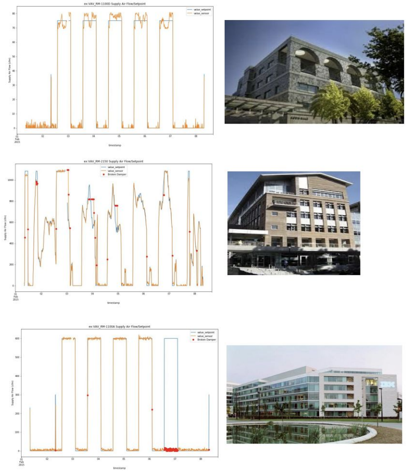


Express data requirements using Brick queries

Project Brick model into table of results for target building

Use identifiers in query results to fetch relevant timeseries data





Queries allow apps to account for building heterogeneity and **customize their operation** to each building.

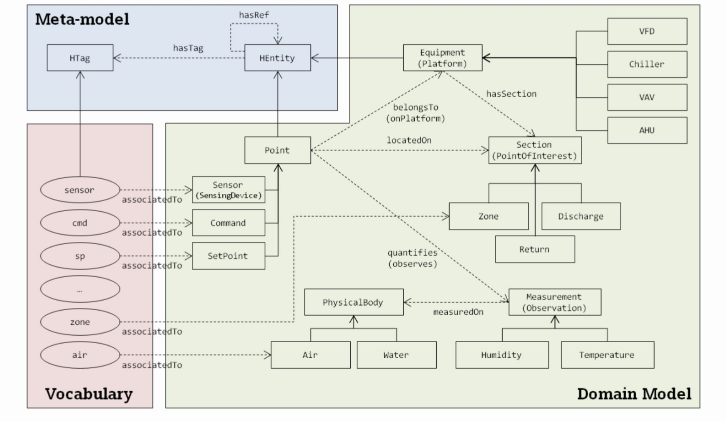
This is called **application portability**

Category	Application	Brick LOC	App LOC	# sites	% coverage
Measurement, Verification & Baselining	Baseline Calculation	3	120	33	37%
	EUI Calculation	10	100	7	8%
	HVAC Energy Disaggregation	14	124	14	16%
	Thermal Model Identification	17	339	17	19%
Fault Detection & Diagnosis	Rogue Zone Temperature	15	104	56	62%
	Rogue Zone Airflow	7	98	3	3%
	Baseline Deviation	3	204	14	16%
	Stuck Damper Detection	8	91	30	33%
	Obscured/Broken Lighting Detection	11	100	2	2%
Advanced Sensing	Virtual Coil Meter	14	150	60	67%
	Chilled Water Loop Total Electrical Consumption	17	160	15	17%

Fierro et al. (2019). Mortar: An Open Testbed for Portable Building Analytics. https://dl.acm.org/doi/abs/10.1145/3366375

Project Haystack Upgrade

Haystack Tagging Ontology   Download   HTO



http://www.vcharpenay.link/hto/

Project Haystack (v4)

- Created as reaction to Brick
- Backward compatible with Haystack v3
- Some elements of an ontology
  - Formal Vocabulary
  - Taxonomy
  - More complete relationships
  - RDF encoding
- Not widely deployed in the field yet

https://project-haystack.org/doc/index

ASHRAE 223p standard (reboot)

28 Feb 2018 ATLANTA, BERKLEY, CA and RICHMOND, VA

ASHRAE's BACnet Committee, Project Haystack and Brick Schema Collaborating to Provide Unified Data Semantic Modeling Solution

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ATLANTA, BERKLEY, Calif. and RICHMOND, Va. (Feb. 28, 2018) – The ASHRAE BACnet committee, Project Haystack and the Brick initiative announced they are actively collaborating to integrate Haystack tagging and Brick data modeling concepts into the new proposed ASHRAE Standard 223P for semantic tagging of building data.

ASHRAE 223p standard (new TPS)

Title: Semantic Data Model for Analytics and Automation Applications in Buildings

Purpose: The purpose of this standard is to formally define knowledge concepts and a methodology to apply them to create interoperable, machine-readable semantic models for representing building system information for analytics, automation, and control.

Scope: This standard provides a way to apply Semantic Web standards to the creation of models that represent building system components, their relationships in various contexts, and associated data. [...]

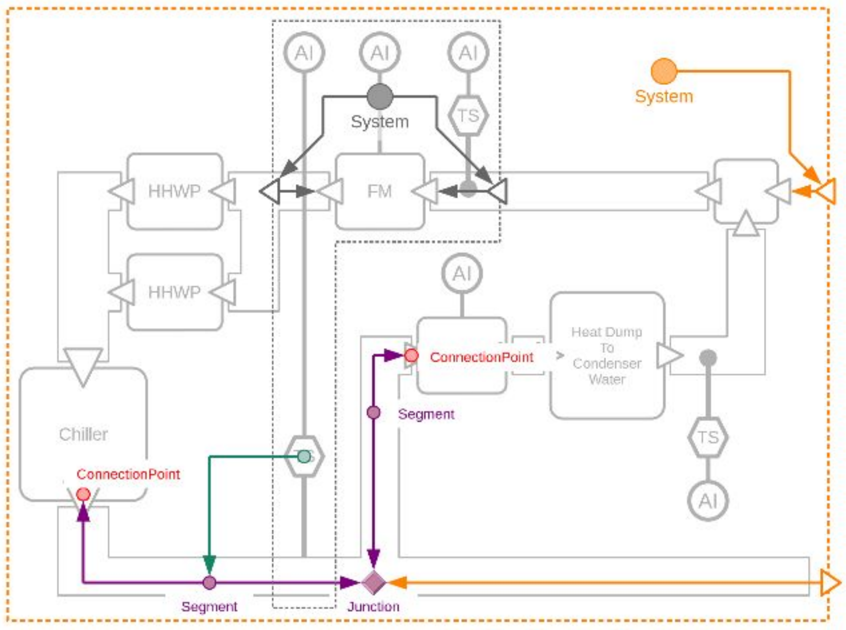
Applications targeted:

- automated fault detection and diagnostics,
- control system configuration,
- building system commissioning,
- digital twins,
- optimization of energy use,
- energy audits, and
- smart grid interactions.

- Semantic Web:
- Resource Description Framework (RDF)
  - machine- readable language to characterize things and their relationships in graph structure.
- ~~Web Ontology Language (OWL)~~
- Shapes Constraint Language (SHACL)
  - defines restrictions and enable conformance checking

ASHRAE 223p standard (Modeling Concepts 1)

- Standardized way of mapping the devices, connections, junctions, segments, systems, and properties.
- The model is about topology and composition, not geometry
- More detailed than Haystack and Brick

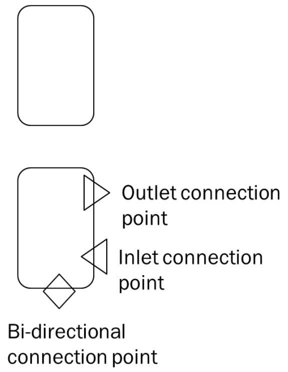


ASHRAE 223p committee. Working documents

ASHRAE 223p standard (Modeling Concepts 2)

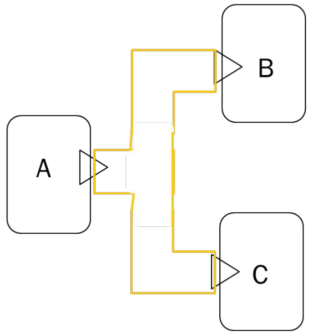
Device – A tangible object designed to accomplish a specific task

- Devices may contain other devices
- Devices may have **ConnectionPoints**
- ConnectionPoints are typed by substance (e.g., air, water)
- Ex: a Fan



Connection – A logical representation of a physical connection between devices

- A connection has at least one **inlet** and one **outlet**
- Ex: a Duct, Pipe, Wire

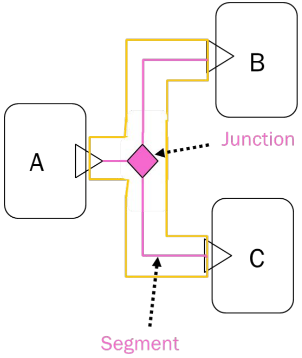


ASHRAE 223p committee. Working documents

ASHRAE 223p standard (Modeling Concepts 3)

Junction – A representation of the place where a physical connection has a branch

- Ex: a “T” section (junction) in a Duct

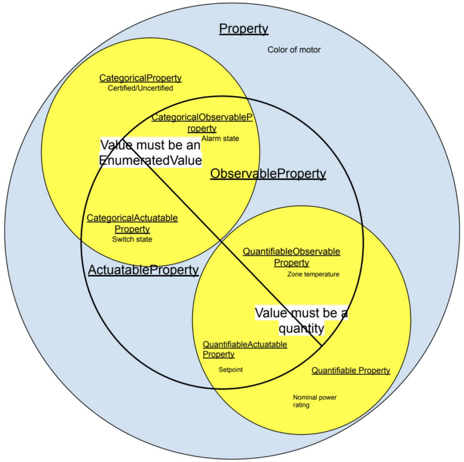


Segment – A representation of one portion of a connection that branches Segments must link a connection point to a junction or a junction to another junction

- Ex: a section of a Duct

Properties – an attribute, quality, or characteristic of a feature of interest. They can be associated with Devices, ConnectionPoints, Connections, and maybe some other things

- Ex: nameplate capacity, zone temperature

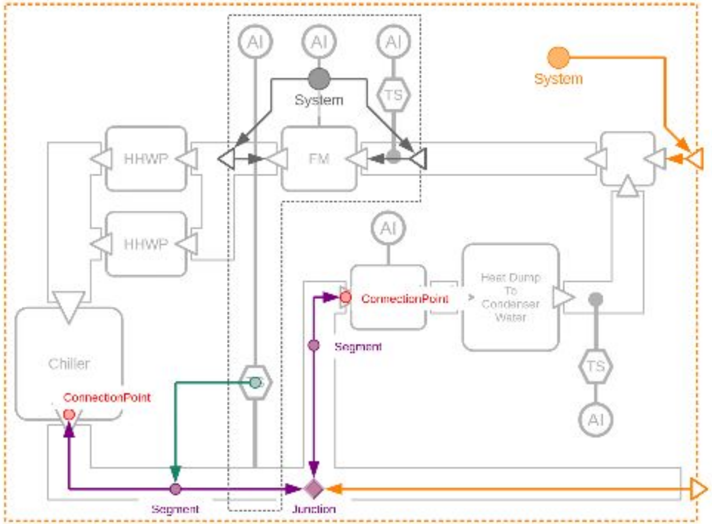


ASHRAE 223p committee. Working documents

ASHRAE 223p standard (Modeling Concepts 4)

System – A collection of connected devices or other systems

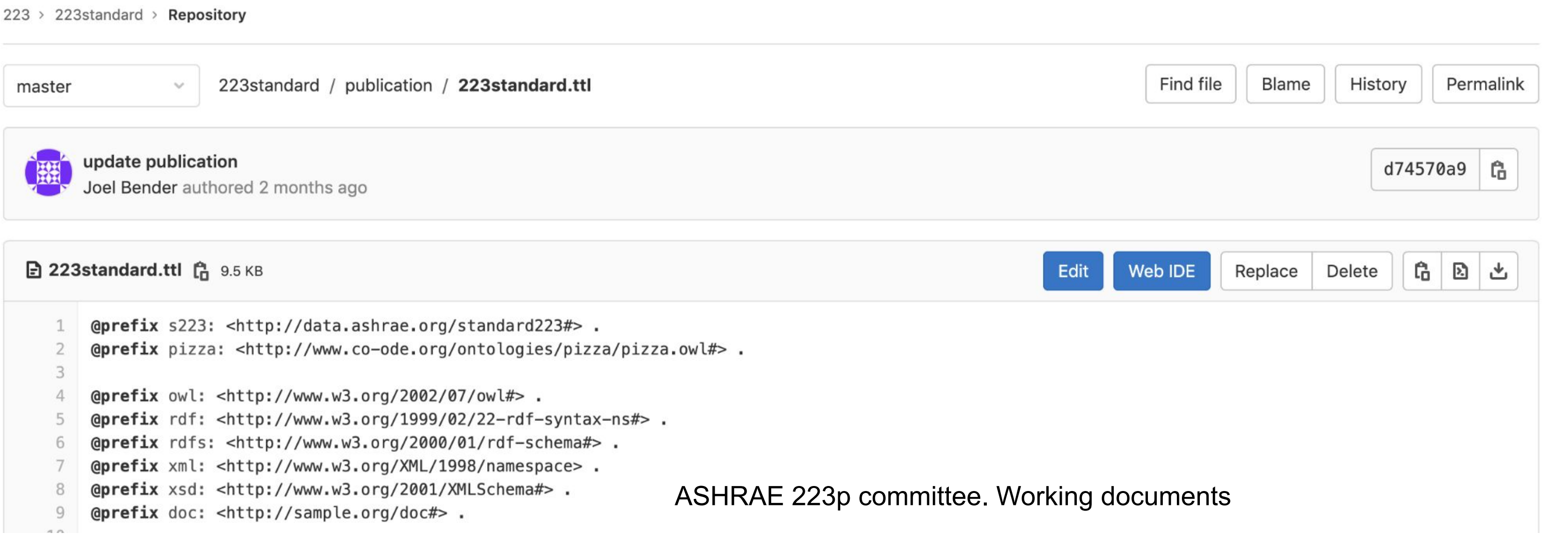
- Systems are logical constructs meant to be understandable by the application domain.
- A modeler can <u>choose</u> to represent something as a device or a system.
- Systems may have **SystemConnectionPoints**
- Systems can be associated through SystemConnectionPoints and the necessary Connections can automatically be generated
- Ex: a Chiller



ASHRAE 223p standard (Modeling Concepts 5)

Other concepts covered (skipped here):

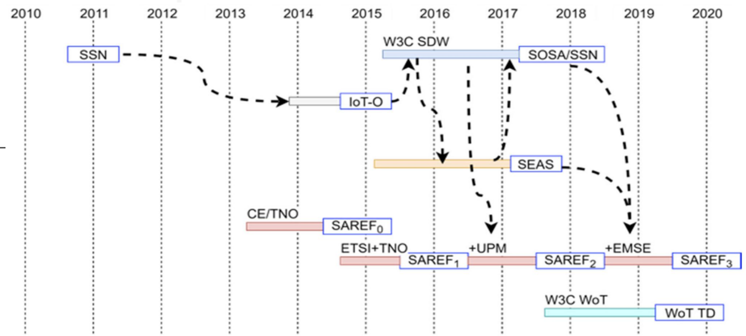
- **Domains:** to distinguish different disciplinary perspectives like Electrical, HVAC, Security ...
- **Physical Spaces – Domain Spaces:** covering rooms and zones and their overlap
- **Sensors**: can measure a location and be located in another one
- **Aspects/Roles/Functions/Setpoints:** under development



ASHRAE 223p committee. Working documents

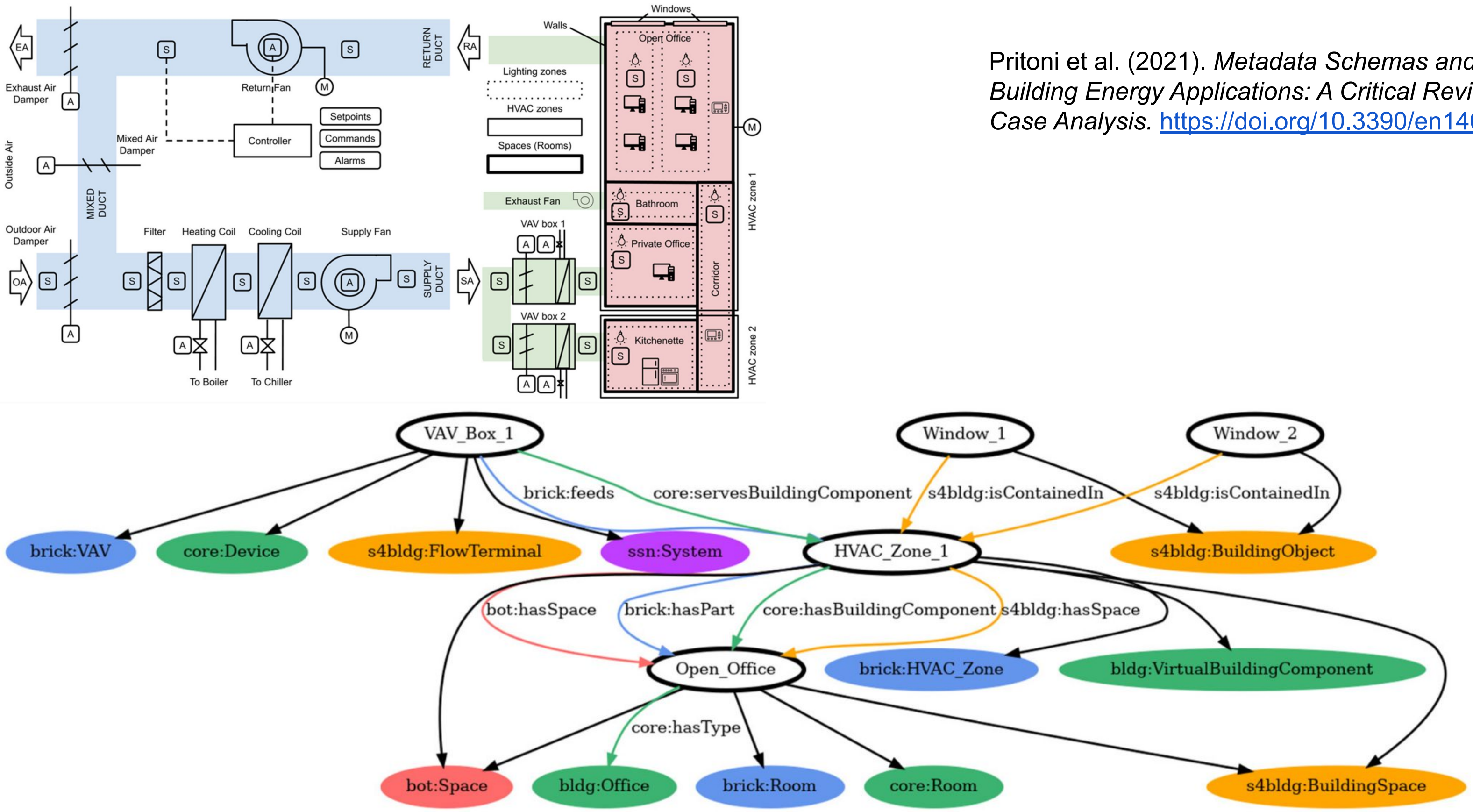
Landscape in 2021

Phase of the Building Life Cycle	Group	Schemas (Year Created, [Reference])
Design and energy modeling	-	Industry Foundation Classes (IFC) (2013, [76]) Green Building XML (gbXML) (2000, [77]) ifcOWL (2016, [78]) Tubes (2020, [79]) SimModel Ontology (2014, [80]) EnergyADE (2014, [81])
Operations	Sensor networks, Internet of Things (IoT), and smart homes	Semantic Sensor Network/Sensor, Observation, Sample, and Actuator (SSN/SOSA) (2011, [82]) Web Thing Model (WoT) (2015, [83]) oneM2M BaseOntology's (2016, [84]) One Data Model (OneDM) (2018, [85]) Smart Energy Aware Systems (SEAS) (2016, [86]) ThinkHome (2011, [87]) Building Ontology for Ambient Intelligence (BOnSAI) (2012, [88]) DogOnt (2008, [89]) Ontology of Smart Building (SBOnto) (2017, [90]) Smart Applications REFerence (SAREF) (2014, [91])
	Commercial building automation and monitoring	Project Haystack 3 (2014, [92]) BASont (2012, [90])Project Haystack 4 (2019, [93]) Haystack Tagging Ontology (HTO) (2016, [94]) Brick Schema (2016, [95]) Google Digital Building Ontology (2020, [96]) Semantic BMS ontology (SBMS) (2016, [97]) CTRLont (2017, [97]) Green Button (2011, [98]) RealEstateCore (REC) (2017, [99]) Building Topology Ontology (BOT) (2019, [100]) Building Automation and Control Systems (BACS) (2017, [101]) Knowledge Model for City (KM4City) (2014, [102]) EM-KPI Ontology (2017, [103])
	Grid-interactive efficient building (GEB) applications	Facility Smart Grid Information Model (2017, [104]) RESPOND (2020, [105])
	Occupants and behavior	DNAs Framework (obXML) (2015, [106]) Occupancy Profile (OP) Ontology (2020, [107]) Onto-SB: Human Profile Ontology for Energy Efficiency in Smart Building (2018, [90]) OnCom (2019, [108])
	Asset management and audits	Building Energy Data Exchange Specification (BEDES) (2014, [109]) Virtual Buildings Information System (VBIS) (2020, [19]) Ontology of Property Management (OPM) (2018, [110])



Pritoni et al. (2021). *Metadata Schemas and Ontologies for Building Energy Applications: A Critical Review and Use Case Analysis.* https://doi.org/10.3390/en14072024

Landscape in 2021

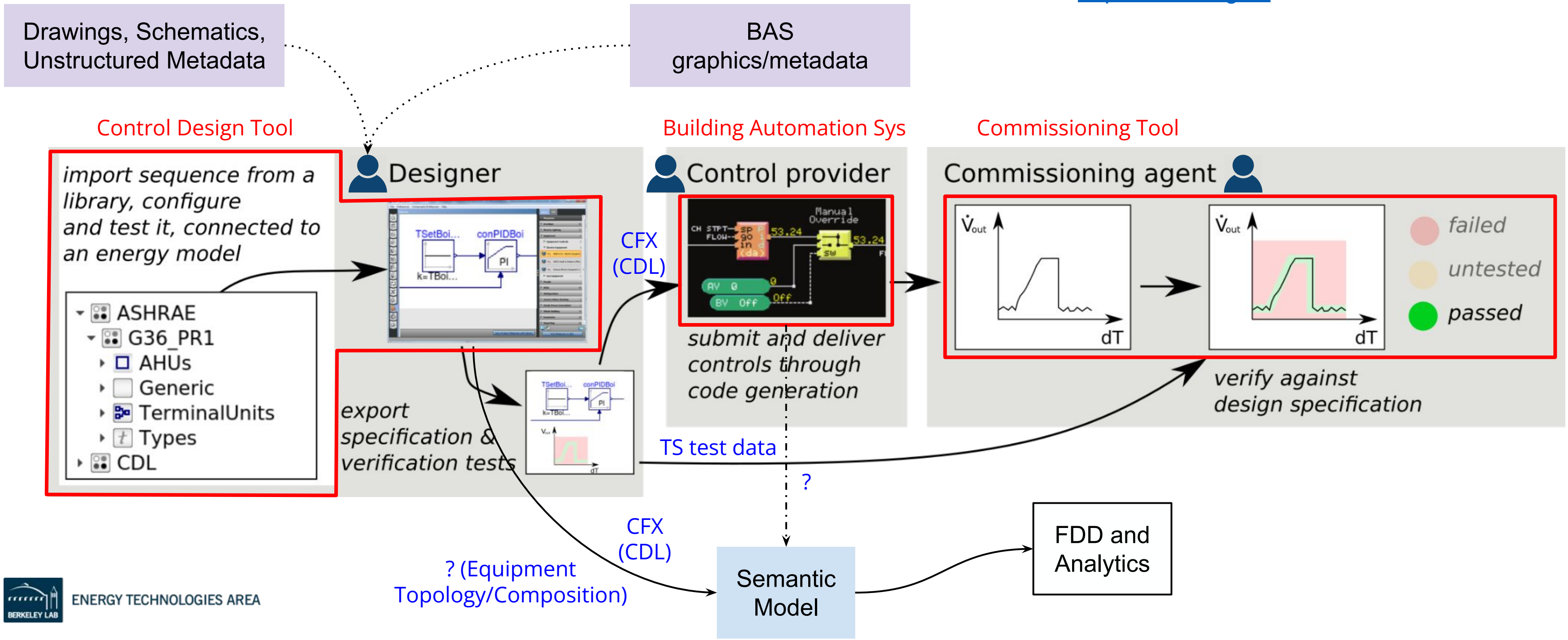


Pritoni et al. (2021). *Metadata Schemas and Ontologies for Building Energy Applications: A Critical Review and Use Case Analysis.* https://doi.org/10.3390/en14072024

Workflow 1a: Control Delivery + FDD AutoConfiguration

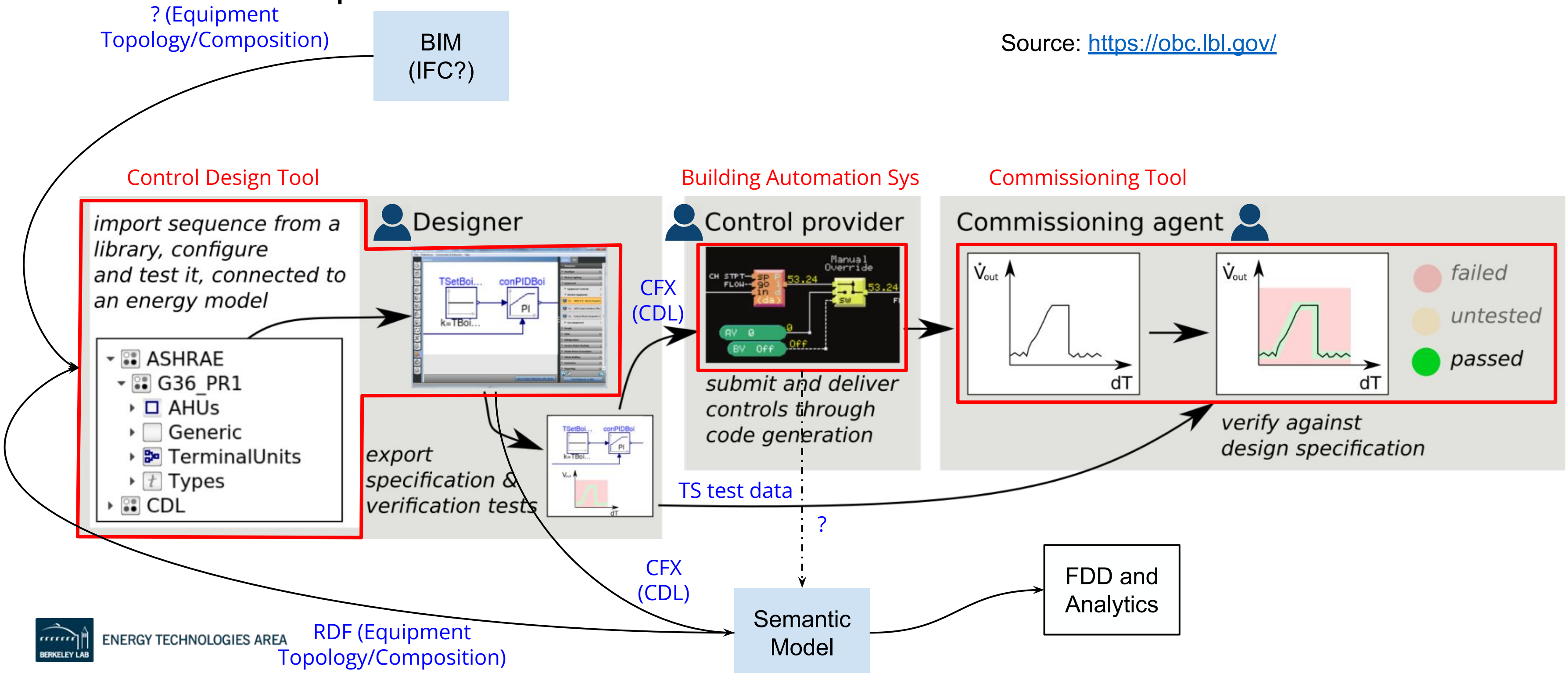
- Existing Building, Existing BAS, No Other Semantic Models, Upgrade Control Sequence+Commision

Source: https://obc.lbl.gov/



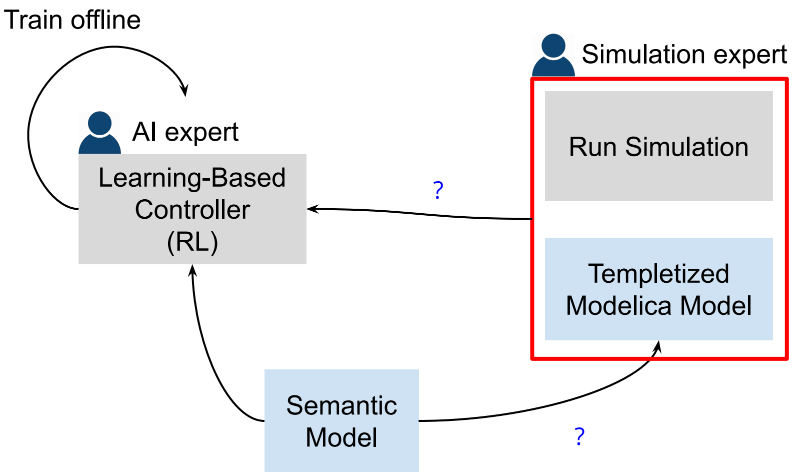
Workflow 1b: Control Delivery + FDD AutoConfiguration

- Existing Building, Existing BAS, Existing Semantic Models, Upgrade Control Sequence+Commision



Workflow 2: Bootstrapping Learning-Based Controls

- Existing Building, Existing BAS, Existing Semantic Model, No Modelica Model, Bootstrapping Learning-Based Algorithm



Ontologies do not solve all the problems

- "Ontologies are formal, explicit specification of a shared conceptualization"
  - Different stakeholders may have different mental models for the same thing (different conceptualizations) -> different modeling needs (representations)
- We expected standardization, but…
  - Creating an "instance" of a building is still a design (subjective) process
  - I can end-up with alternative models of the same building
- To take full advantage of the data models we should write applications differently
  - Apps need to be written more generally to cover multiple alternative models (a "platform")
- We need to remember that this need to move from PhDs to practitioners
  - Tools are still scarce and not user-friendly
  - New workflows are still unclear
- We need to consider the lifecycle of these models and how they get updated and synchronized

Summary and final remarks

- Several parallel initiatives have recently emerged to standardize building metadata
- Each one has different scope, application to building lifecycle and use cases
- Efforts are mostly disconnected but discussion between groups has started
- Modelica-based models can play a role in this emerging ecosystem
- Still very little market adoption and even less stock footprint
- Data lifecycle and impacts on current workflows needs to be studied further

Thank you!

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