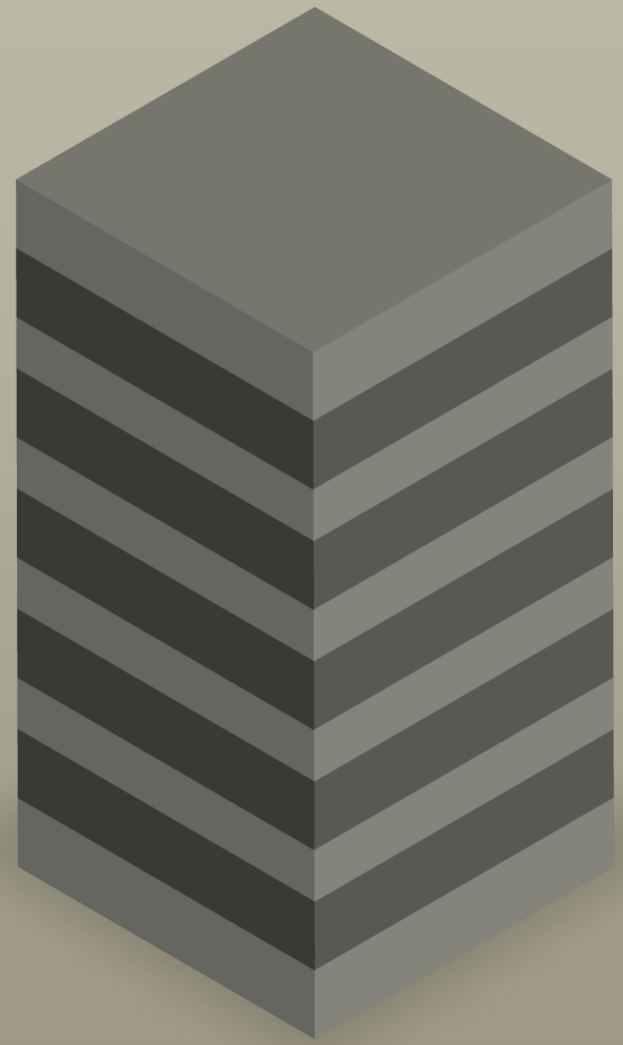
Enabling Large-Scale Data Integrity Checks for Building Automation and Control Systems

Maria Husmann – Siemens Smart Infrastructure

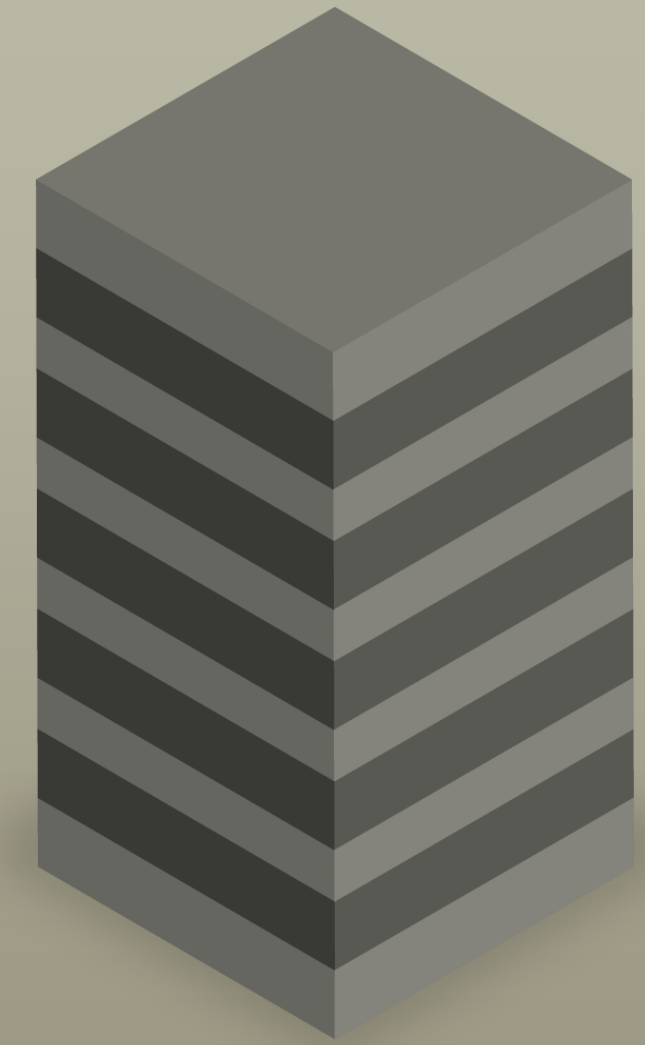
SIEMENS

“The Swiss buildings stock consumes approximately 100 TWh, i.e. 45 per cent of the total end energy demand in Switzerland. Buildings also account for about one third of Switzerland’s CO2 emissions.”



Swiss Federal Office of Energy: https://www.bfe.admin.ch/bfe/en/home/efficiency/buildings.html

*“Buildings and construction together account for **36%** of global final energy use and **39%** of energy-related carbon dioxide (CO2) emissions when upstream power generation is included.”*



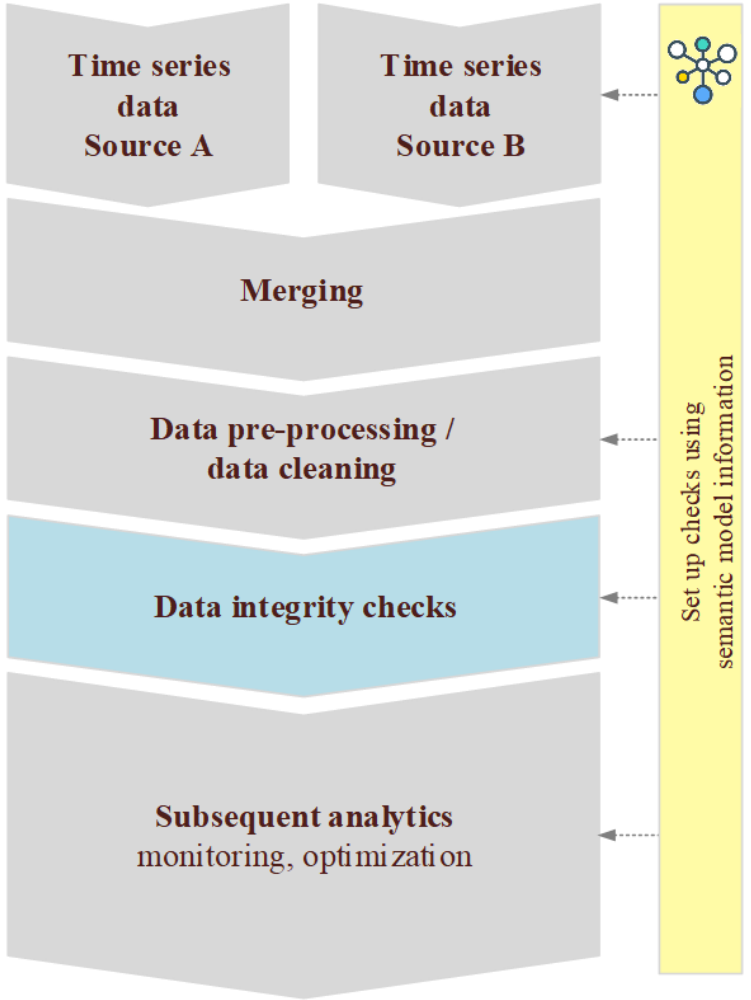
United Nations Environment Programme Global Status Report 2017:
https://www.worldgbc.org/sites/default/files/UNEP%20188_GABC_en%20%28web%29.pdf

Building automation systems

Data integrity and plausibility checks

Motivation

- **Data analytics such as fault detection & diagnostics (FDD)** methods are essential for the energy-efficient and comfortable operation of buildings
- Most of these **analytics functions require reliable (time series) data** which is often critical in building automation projects
- Data integrity and plausibility checks are one way to **increase data quality and reliability**
- Analytics methods – including data integrity checks and data processing – in general can be significantly improved by **combining time series data and semantic model information**



SIEMENS

Project partners

Joint project with Lucerne University of Applied Sciences (HSLU) and Pre-Development at Siemens Smart Infrastructure Building Products

Resulted in a publication at CLIMA 2022:

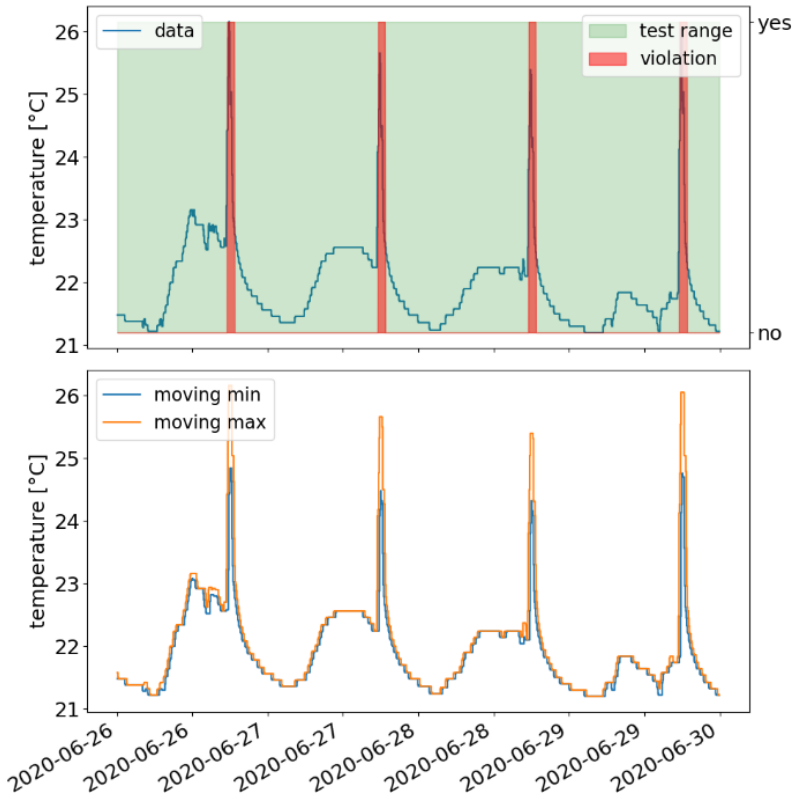
“Data Integrity Checks for Building Automation and Control Systems”

Available at https://proceedings.open.tudelft.nl/clima2022/article/view/271

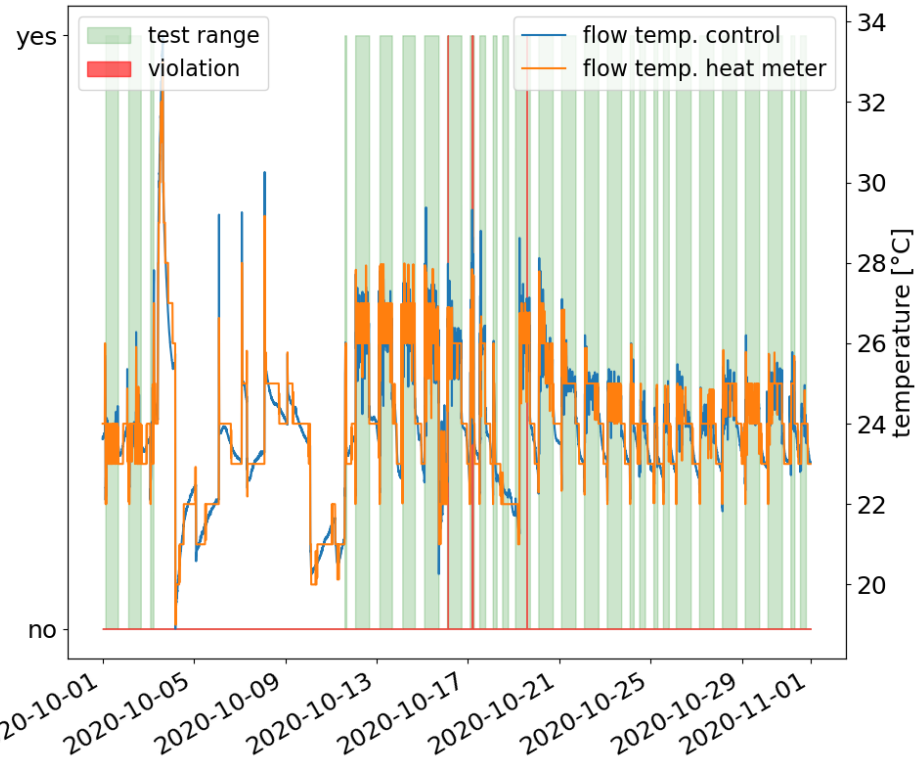
Main Contributors:

- Reto Marek, HSLU: HVAC domain specialist, software engineer
- Andreas Melillo, HSLU: physicist, data scientist
- Markus Gwerder, Siemens: HVAC domain specialist, electrical engineer
- Maria Husmann, Siemens: computer scientist, semantic modelling expert

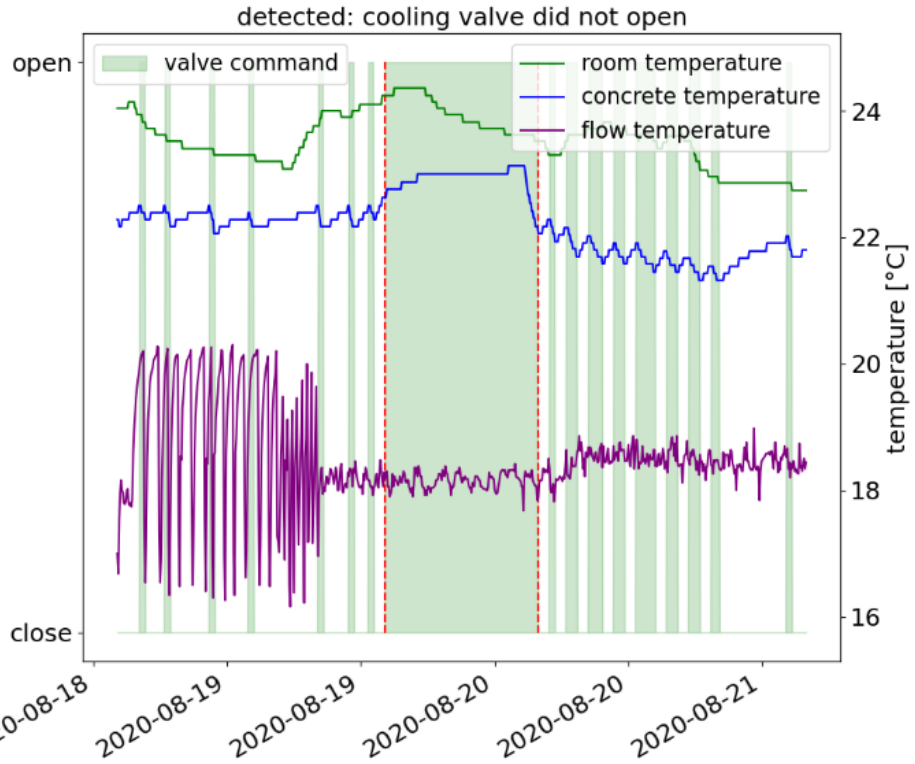
Integrity and plausibility check examples

Type of check	Collection	Real world example
Single signal checks Single signal checks are applied to individual time series. These checks include detection of long-term drifts in signals, maximum or minimum slopes, positive or negative peaks, daily/weekly cycles, dependency on solar position...	• **Measurement spike detection (e.g., room temperature)** • Sensor drift detection (e.g., room air quality) • Daily/weekly periodicity in certain measurements (e.g., outside air temperature, solar radiation, outside brightness, room air quality, room temperature …) • Measurement reset detection indicating leakage (e.g., hot water, fresh water) • Measurements affected by the sun react on sunrise/sunset (e.g., solar radiation, outside brightness, PV power) • …	Room temperature spike detection (reason for spikes: solar radiation on sensor) 

Integrity and plausibility check examples

Type of check	Collection	Real world example
Signal similarity checks Signal similarity checks test whether two time series are similar at certain points / ranges in time	• **Similar time series of return temperature for control and heat meter (when fluid is circulating)** • Similar time series shapes of solar radiation and electrical power of PV plants • Similar time series of temperature/humidity before and after inactive air treatment aggregate • Similar time series "outside air temperature measured by building automation" and "meteorological service provider reference station outside air temperature" • …	Heat meter flow temperature and control flow temperature signals are similar (important fault to identify: configuration/addressing error) 

Integrity and plausibility check examples

Type of check	Collection	Real world example
Reaction checks Signal reaction checks test whether a time series shows the expected response to an event	• **Concrete temperature reacts to heating (cooling) valve position change if heat (cold) is provided** • Room temperature reacts to radiator valve position change if heat is provided • Room air quality reacts to room presence detection • Room brightness reacts to light control command / intensity variation • Airflow meter measurement reacts to fan control command / modulation change • Heat meter measurement reacts to pump control change • Flow temperature of heating / cooling distribution system reacts to pump control command and valve position change • …	Concrete core temperature does not react on valve command (reason: sporadic commanding error / software bug) 

The challenge:
Finding the right input points for each integrity check

47	dev612:positive-integer-value_5	B_01'0G1'10G_04_02'RHvacCoo'TabsCtl'TiOnMin
48	dev602:analog-value_446	B_01'0G1'10G_05_01'RHvacCoo'TabsCtl'TOaDsgn
49	dev206:analog-value_388	B_01'EG'RS_EG_05_03'HVAC'Tabs'HReq
50	dev202:analog-output_0	B_01'EG'RS_EG_04_03'TabsVlvPosC
51	dev801:analog-value_456	B_01'0G1'10G_01_01'RHvacCoo'TabsCtl'TOaEff
52	dev207:analog-value_467	B_01'EG'EG_05_04'RHvacCoo'TabsCtl'SpTConHi
53	dev1213:analog-value_461	B_01'0G2'20G_06_02'RHvacCoo'TabsCtl'SpTConDsgn
54	dev203:positive-integer-value_6	B_01'EG'EG_04_04'RHvacCoo'TabsCtl'TiOffMin
55	dev201:multi-state-value_140	B_01'EG'EG_04_02'RHvacCoo'TabsCtl'OpMod
56	dev204:binary-value_146	B_01'EG'EG_05_01'RHvacCoo'TabsCtl'EnH
57	dev203:analog-value_469	B_01'EG'EG_04_04'RHvacCoo'TabsCtl'SpTConMin
58	dev803:analog-value_447	B_01'0G1'10G_01_03'RHvacCoo'TabsCtl'TOaTabs
59	dev105:analog-value_461	B_01'EG'EG_02_04'RHvacCoo'TabsCtl'SpTConDsgn
60	dev607:binary-value_146	B_01'0G1'10G_05_06'RHvacCoo'TabsCtl'EnH

Aspern TZ2

Showing results from 1 to 1,000 of 13,383. Query took 0.1s, minutes ago.

SIEMENS

Past approaches: Focused on points

- Point names parsing is brittle
- Little relationship information is available (e.g. no connections to primary plants)
- Building structure hierarchy it not always apparent.

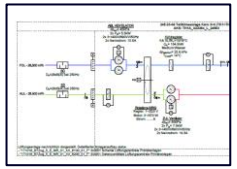
Aspern TZ2

```
B_01'0G1'RS_10G_02_03'SenDev'TR
B_01'0G1'10G_02_03'RHvacCoo'SpTRDtr'SpTR
```

Theilerstrasse 1a

```
B2'R'Flr06'R614s1'SenDev'TR
B2'R'Flr06'R614'RHvacCoo'SpTRDtr'SpTR
```

Building automation lifecycle



Bid → Plan → Engineer → Commission → Operate

Tenders, BIM data, schematics

Status	Name	Description	Segment usage	Device
Filter	Filter	Filter	Filter	Filter
	B2	Buerogebaeude		
	R	Raum		
	Flr00	Erdgeschoss		
	Flr01	1.Obergeschoss		
	Flr02	2.Obergeschoss		
	Flr03	3.Obergeschoss		
	Flr04	4.Obergeschoss		
	Flr05	5.Obergeschoss		
Device converted	ChangeOver TH1+4 PRO	Raum HLK Change Over TH1+4		AS1207 [PXC3.E75A-1]
Device converted	ChangeOver TH2 PRO	Raum HLK Change Over TH2		AS1214 [PXC3.E75A-1]
Device converted	ChangeOver TH3 PRO	Raum HLK Change Over TH3		AS1223 [PXC3.E75A-1]
Device converted	R508 PRO	Raum 508 Liftlobby		AS1207 [PXC3.E75A-1]
Device converted	R509 PRO	Raum 509 Meetingraum 2		AS1203 [PXC3.E72A-1]
Device converted	R509s1 PRO	HLK/Lgt/Bls R509s1	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s1Cdn PRO	HLK R509s1 Kondensationswächter	RSegm	AS1201 [PXC3.E72A-1]
Device converted	R509s2 PRO	HLK R509s2	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s3 PRO	HLK/Bls R509s3	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s4 PRO	HLK R509s4	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R510 PRO	Raum 510 Meetingraum 3		AS1203 [PXC3.E72A-1]
Device converted	R511 PRO	Raum 511 Meetingraum 4		AS1204 [PXC3.E72A-1]

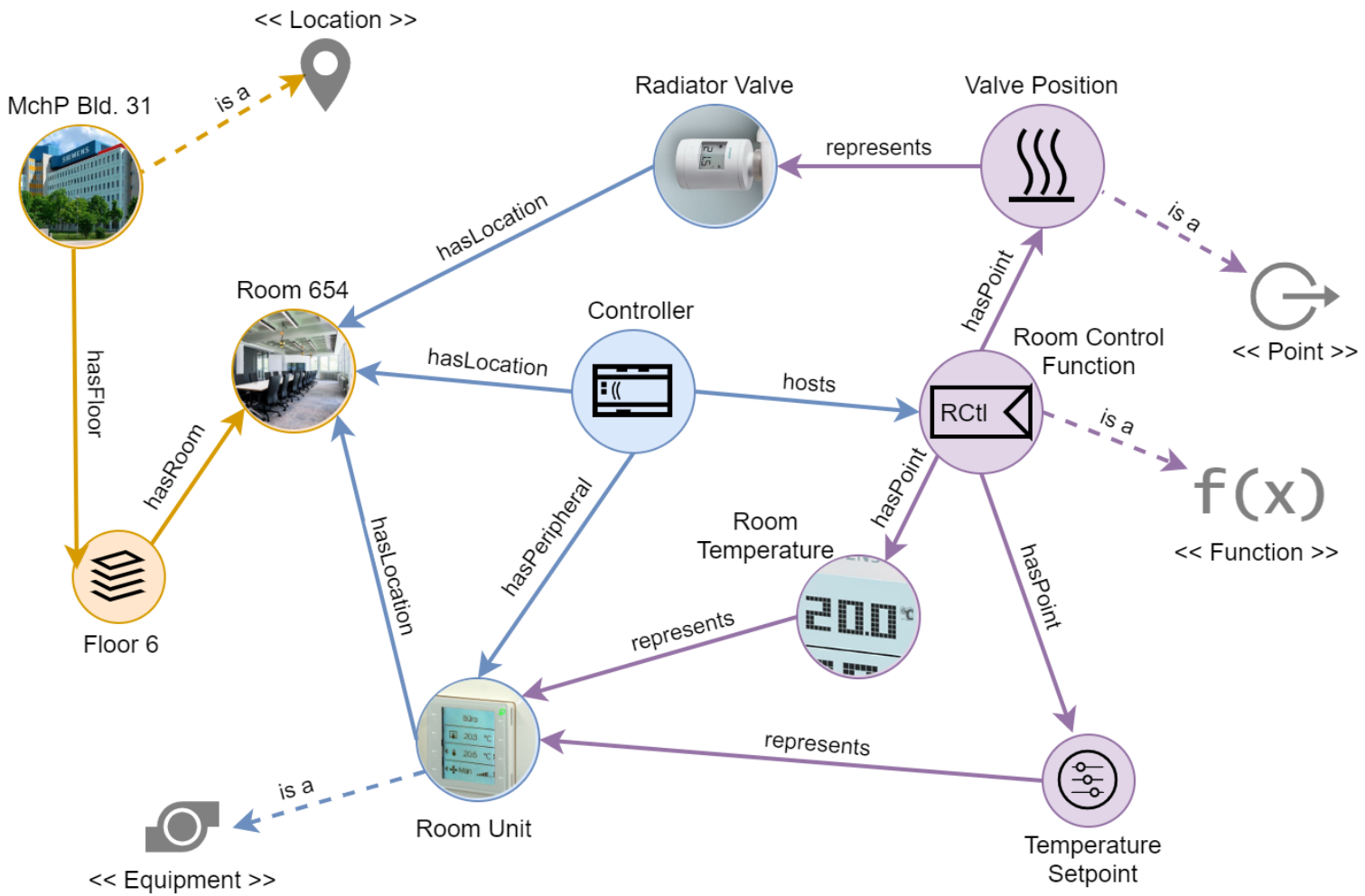
SIEMENS

Wealth of information in engineering tool

Status	Name	Description	Segment usage	Device
Filter	Filter	Filter	Filter	Filter
	B2	Buerogebaeude		
	R	Raum		
	Flr00	Erdgeschoss		
	Flr01	1.Obergeschoss		
	Flr02	2.Obergeschoss		
	Flr03	3.Obergeschoss		
	Flr04	4.Obergeschoss		
	Flr05	5.Obergeschoss		
Device converted	ChangeOver TH1+4 PRO	Raum HLK Change Over TH1+4		AS1207 [PXC3.E75A-1]
Device converted	ChangeOver TH2 PRO	Raum HLK Change Over TH2		AS1214 [PXC3.E75A-1]
Device converted	ChangeOver TH3 PRO	Raum HLK Change Over TH3		AS1223 [PXC3.E75A-1]
Device converted	R508 PRO	Raum 508 Liftlobby		AS1207 [PXC3.E75A-1]
Device converted	R509 PRO	Raum 509 Meetingraum 2		AS1203 [PXC3.E72A-1]
Device converted	R509s1 PRO	HLK/Lgt/Bls R509s1	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s1Cdn PRO	HLK R509s1 Kondensationswächter	RSegm	AS1201 [PXC3.E72A-1]
Device converted	R509s2 PRO	HLK R509s2	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s3 PRO	HLK/Bls R509s3	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R509s4 PRO	HLK R509s4	RSegm	AS1203 [PXC3.E72A-1]
Device converted	R510 PRO	Raum 510 Meetingraum 3		AS1203 [PXC3.E72A-1]
Device converted	R511 PRO	Raum 511 Meetingraum 4		AS1204 [PXC3.E72A-1]

SIEMENS

A building automation knowledge graph (simplified)



SIEMENS

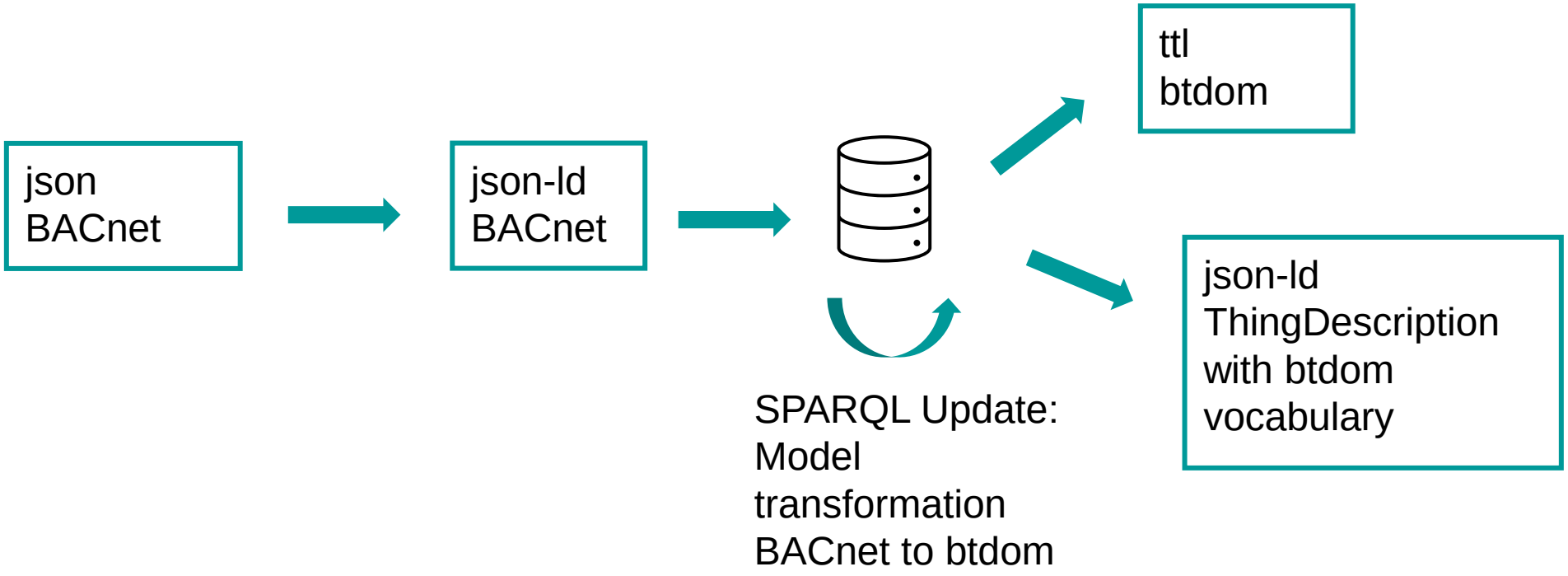
Getting instance data: Semantic export from engineering tool


```
{
  "@context": {
    "btas": "http://bt.schema.siemens.io/shared/btas#",
    "btzf": "http://bt.schema.siemens.io/shared/btzf#",
    "rdfs": "http://www.w3.org/2000/01/rdf-schema#"
  },
  "@graph": [
    {
      "btzf:concernsLocation": {
        "@id": "urn:abt:257b519a-b57b-4a4f-9c4a-f96028ef9672"
      },
      "btas:model": "DXR2.E18-1",
      "btas:serialNumber": "14000417F7",
      "@id": "urn:abt:00283636-fd73-4b37-9796-5b031d32ae09-02000193",
      "@type": [
        "btas:Device"
      ],
      "rdfs:comment": "Automation station 13",
      "rdfs:label": "AS_13"
    }
  ]
}
```


JSON-LD

SIEMENS

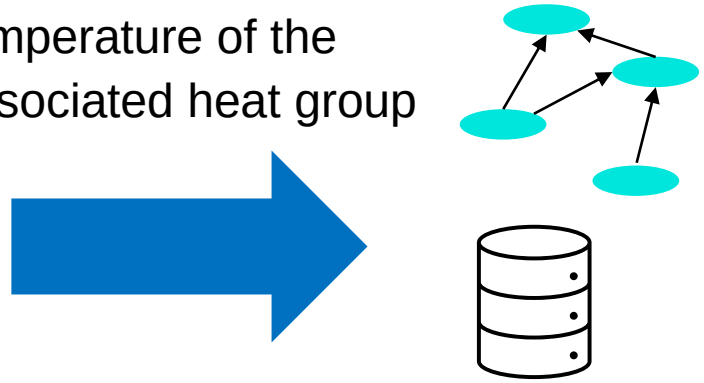
Getting instance data for brownfield buildings: network scan



SIEMENS

Data flow

Find all data points that represent valve positions, the measured room temperature value of the same room, and the operating status and flow temperature of the associated heat group

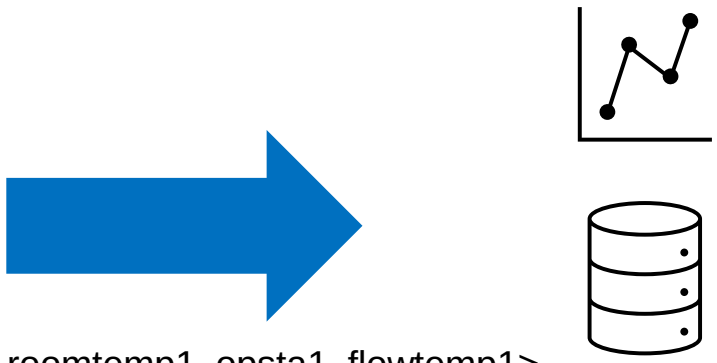


Graph database

GraphDB

<valve1, roomtemp1, opsta1, flowtemp1>
<valve2, roomtemp2, opsta2, flowtemp2>
…

Get values of the last 30 days for all points



Timeseries database

influxdb

Execute checks

python

Datasets

Building automation data from the research project “Aspern Smart City Research” (https://www.ascr.at/en/) in Vienna, Austria, as well as the Siemens Campus in Zug, Switzerland have been used

Student home (Aspern) for 300 students, ca. 11500 m²
0.8 Mio. triples
6500 data points

Office building (Aspern), ca. 8'000 m²
1 Mio. Triples
10’400 data points

Office and production buildings (Zug), ca. 35'000 m²
8.5 Mio. Triples
120’000 data points

Some results

- Temperature spikes between 7 and 8pm
  - Can lead to unnecessary cooling
  - Assumed cause: direct sunlight on sensor.
  - Verified manually by querying the graph: all affected rooms were facing west
- Valves that were not opening
  - Commanding error
  - Fixed by an update to the controller
- Implausible presence values
  - Very short presence detection in single rooms
  - Consistent with neighbour complaints about lights turning on at night
  - Fixed by replacing faulty presence sensors

Domain modelling community at Siemens Smart Infrastructure Building Products

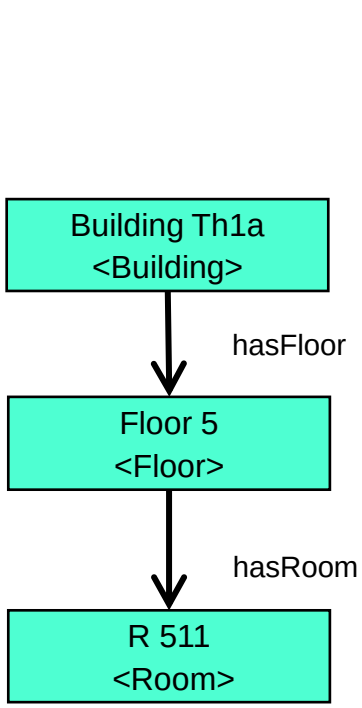
- Innersource publishing platform for ontologies
- ISO 15926-14 as upper ontology[1], includes contributions from Siemens colleagues
- Anyone can contribute, governed by a core team
- Support from semantic web experts from corporate technology

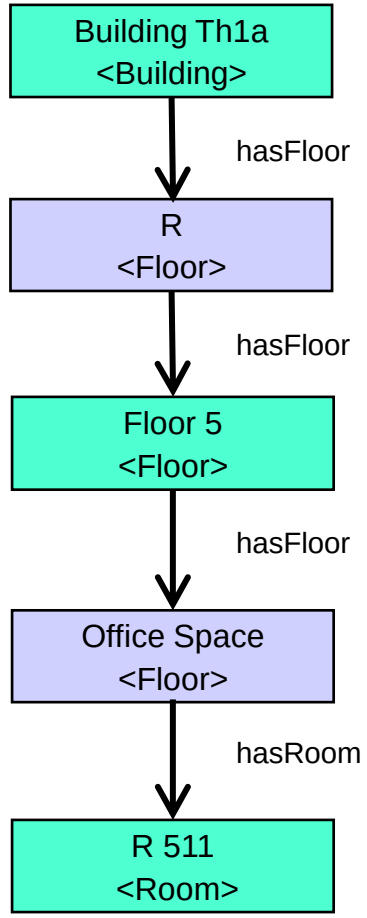
1) https://www.iso.org/standard/75949.html

SIEMENS

Challenge: data model and ontology mismatch

- Users in engineering tool abuse floor concept as general grouping mechanism
- The root cause are UX issues in the tool and engineering library
- Building hierarchy becomes unpredictable
- Upper ontology with transitive relationships to the rescue: Building =>* Room (only works for some use case)





SIEMENS

Challenge: Ontology evolution and instance data

- Ontologies (t-box) still evolving
- Different data sets of instance data (a-box) conforming to different versions of the ontology
- Queries fail when switching data sets
- Best practices are currently missing apart from versioning in the ontologies

Lessons learned

- Enforcing data quality vs getting no data
- Simple SPARQL queries vs complex ones that handle all possible cases
- Industry-wide ontologies needed for easy integration of 3rd party systems
  - Fragmented, but some consolidation in progress
- Non-ontologists can write SPARQL queries, but need support for complex queries
- Tooling in semantic web area has room for improvement.

Contact

Dr. Maria Husmann
Team Lead Web of Things
SI BP R&D PRD
Zug
Switzerland

E-mail firstname.lastname@siemens.com

Twitter @MariaHusmann

SIEMENS