“Ontologies to automate the configuration and deployment of monitoring services for building energy systems”

Hervé Pruvost

(Fraunhofer IIS/EAS)

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Presenter

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Education:

- Studied Mechanical and industrial engineering at Ecole Nationale Supérieure d'Arts et Métiers (ENSAM), Cluny & Paris, France.

Career path:

- 2 years at BNP Paribas Real Estate, Paris, France.
  - Development of office buildings real estate programs
- 6 years at Institute for Construction Informatics (Prof. Scherer) of the Technische Universität Dresden, Germany.
  - R&D in informatics for AEC/FM applications: risk management, process modeling, energy-efficient building design, stochastic
  - BIM, Linked Data, data modeling, risk modeling, SW dev.
- 6 years at Fraunhofer IIS/EAS, Dresden, Germany.
  - R&D, data engineering, data science for building automation
  - BIM, ontologies, IoT, SW dev.

Fraunhofer Gesellschaft

More than 70 years of application-oriented research for the benefit of business and society

76 institutes and research units

2.5 billion euros of contract research in 2021

Including more than 70% contracts from industry and research projects funded by the public sector

Around 30% of base funding by federal and state governments

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The Fraunhofer Institute for Integrated Circuits IIS -> EAS Division

Division Engineering of Adaptive Systems EAS in Dresden

Division
Engineering of Adaptive Systems EAS

Founded	1992
Employees	approx. 110
Budget	approx. 12.5 million €
Directors	Prof. Dr. Peter Schneider Dr. Wolfgang Felber

Fraunhofer IIS

Founded	1985
Employees	approx. 1,000
Budget	approx. 184 million €
Directors	Prof. Dr. Albert Heuberger Dr. Bernhard Grill

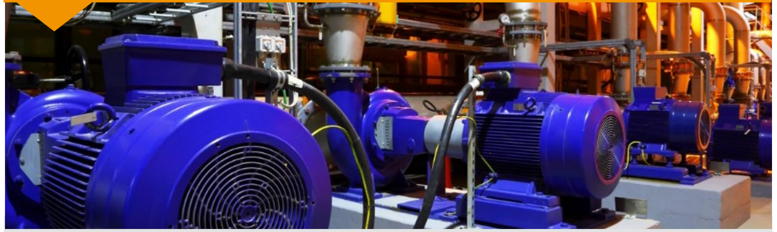
The Fraunhofer Institute for Integrated Circuits IIS -> EAS Division

Division Engineering of Adaptive Systems EAS in Dresden

Industrial Wireless Networks

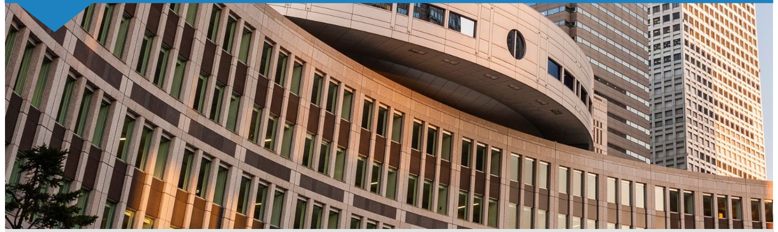
- Data stream Analysis to find faults and misconfigurations
- Management of wireless networks

Industrial Production



- Condition monitoring on machines and plants
- Predictive maintenance
- Optimization of production processes

Building Energy Systems

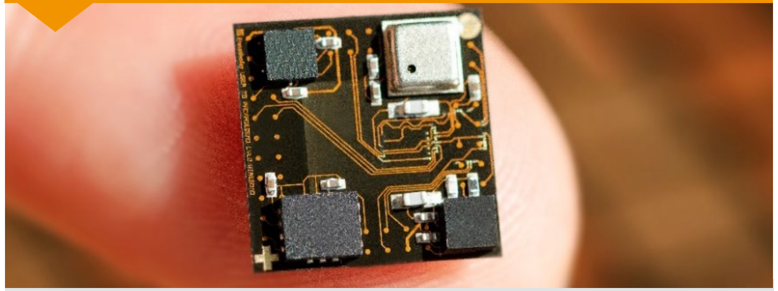


- Detection of faulty system configurations
- Optimization of energy distribution in complex energy systems
- Predictive control of energy systems

Industrial Image Processing

- Programmable Vision-System-on-Chip
- Reproduction of all processing steps from image acquisition and analysis to feature extraction on programmable hardware

Efficient electronics



- Miniaturization and energy saving for higher performance
- Combination of modern packaging technologies and design methods with the possibility to integrate different sensors

Intelligent sensors and actuators

- Universal Sensor Platform for IoT & AI systems
- Sensor/Actuator technologies integrated in machine tools

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Motivation:
Scalable monitoring services

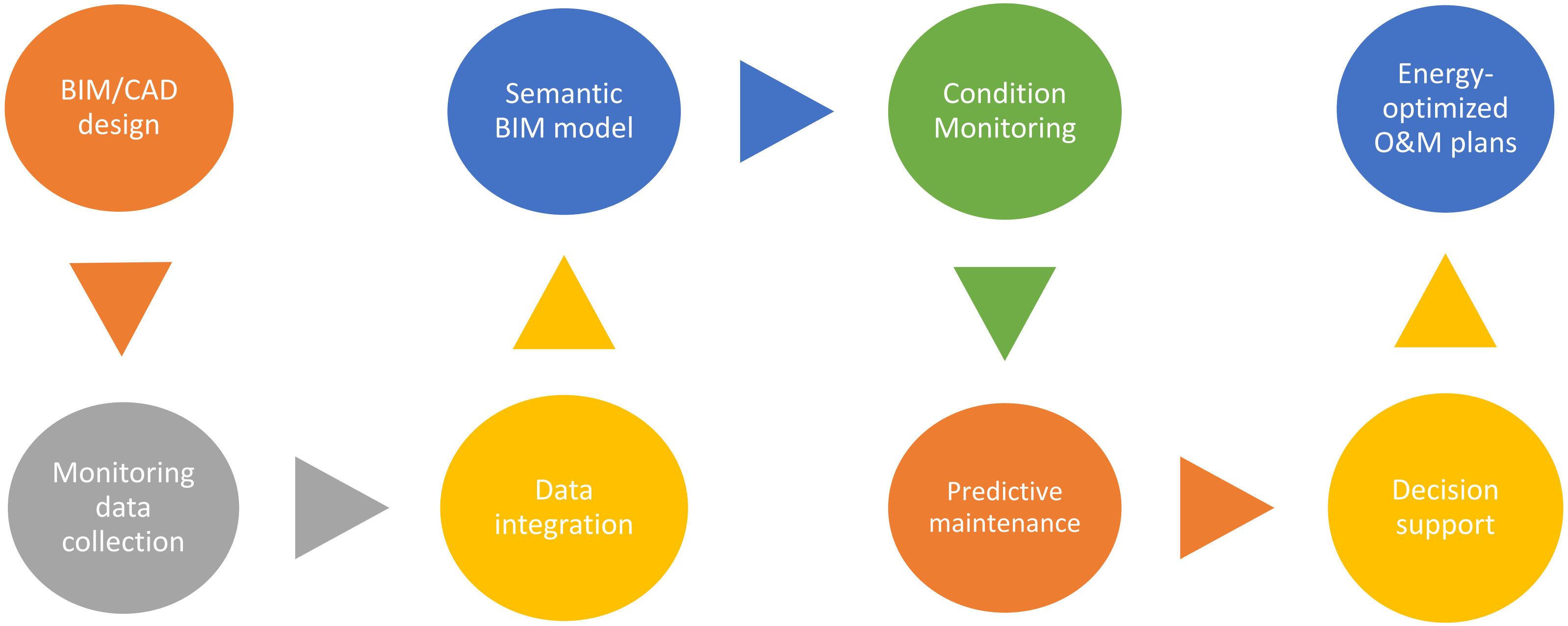
- Need to deploy monitoring and energy assistance systems in many buildings to target energy savings at a large scale
- Similar issues in energy systems leading to energy waste. Similarities between HVAC systems but every building remain different and unique

Different automation systems and vendors:

Modbus, ZWAVE, CODA, COHERENT TECHNOLOGIES, homematic IP, LUMEL, php, TECHNISCHE ALTERNATIVE GEBÄUDETECHNIK INTELLIGENT GEREGELT, CIRCUTOR, FIBARO, EVERSPRING, MCO HOME, QUBINO WIRELESS SMART HOME, NEO Coolcam, NETATMO, MySQL, SIEMENS, VICIONE

Digital Workflow for automated building monitoring and control

- Building monitoring and control is the result of a long process starting from the design of a building
- Is there a way to automate this process in a digitalized building lifecycle?



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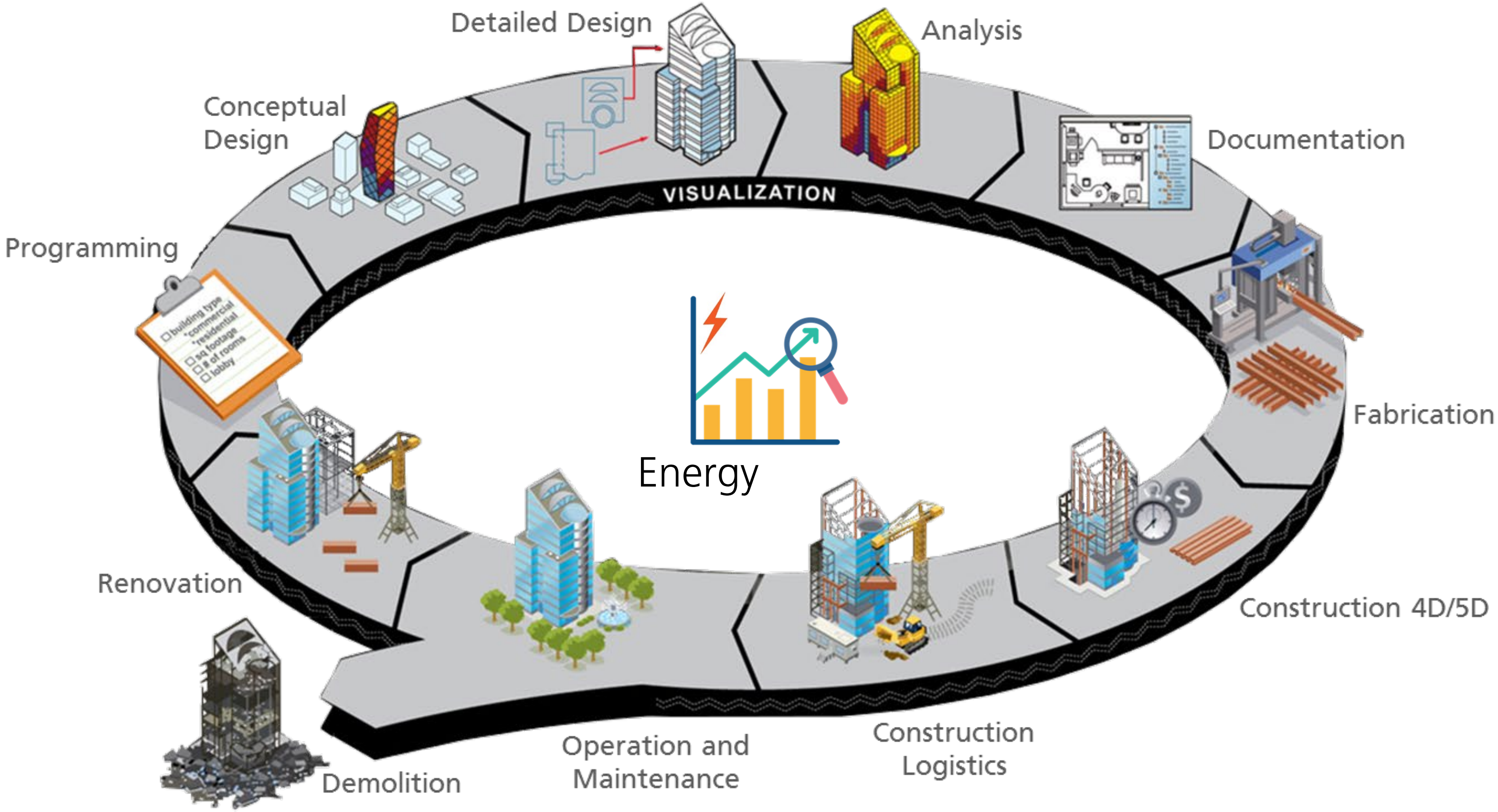
Building Life Cycle

Much information is generated during the whole building life cycle in which much resource is consumed and wasted



Quelle: http://buildipedia.com/aec-pros/design-news/the-daily-life-of-building-information-modeling-bim

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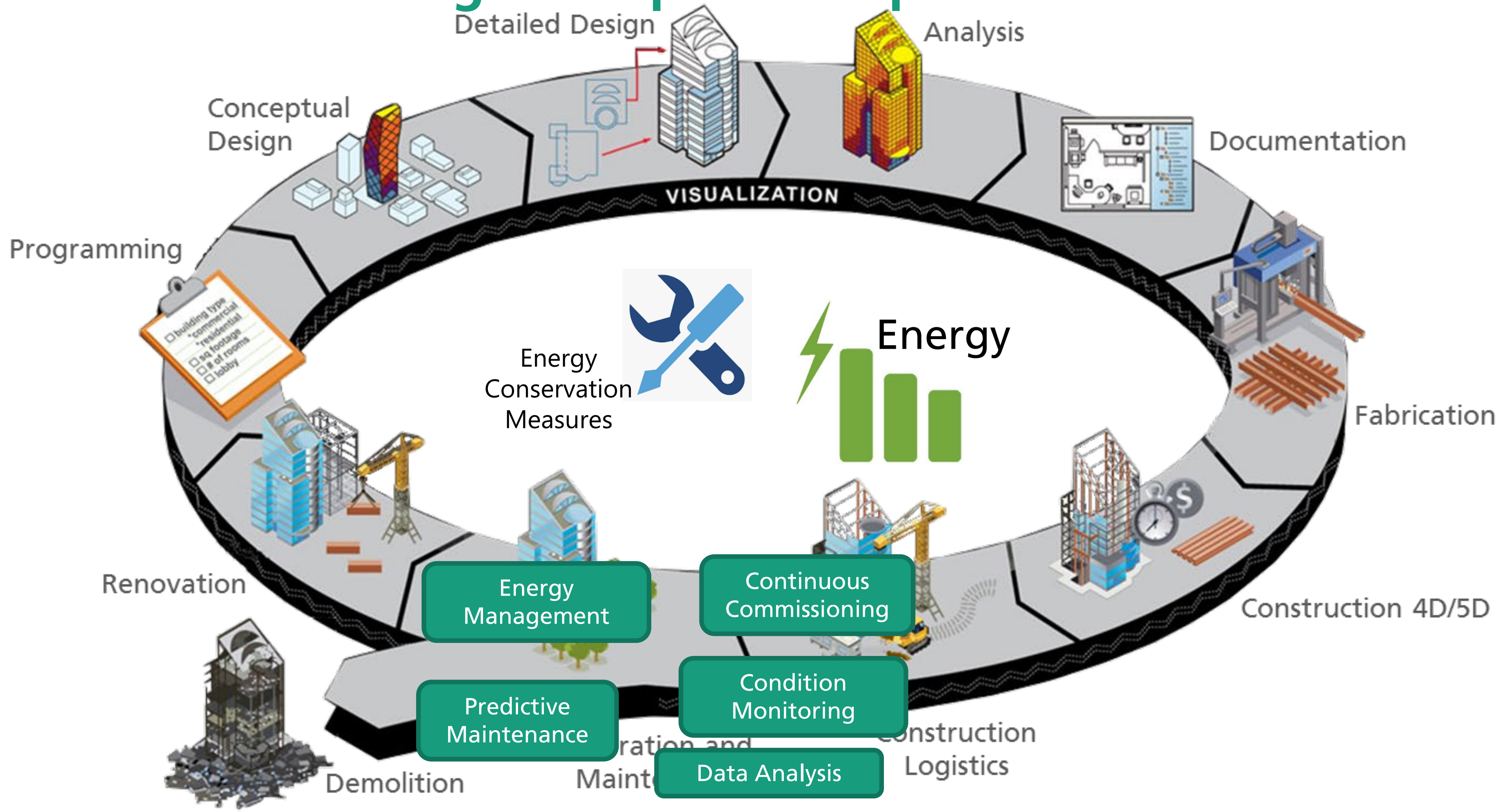
Building Life Cycle

How to reuse this information for systematic and automatic energy waste mitigation in commissioning and operation phase?



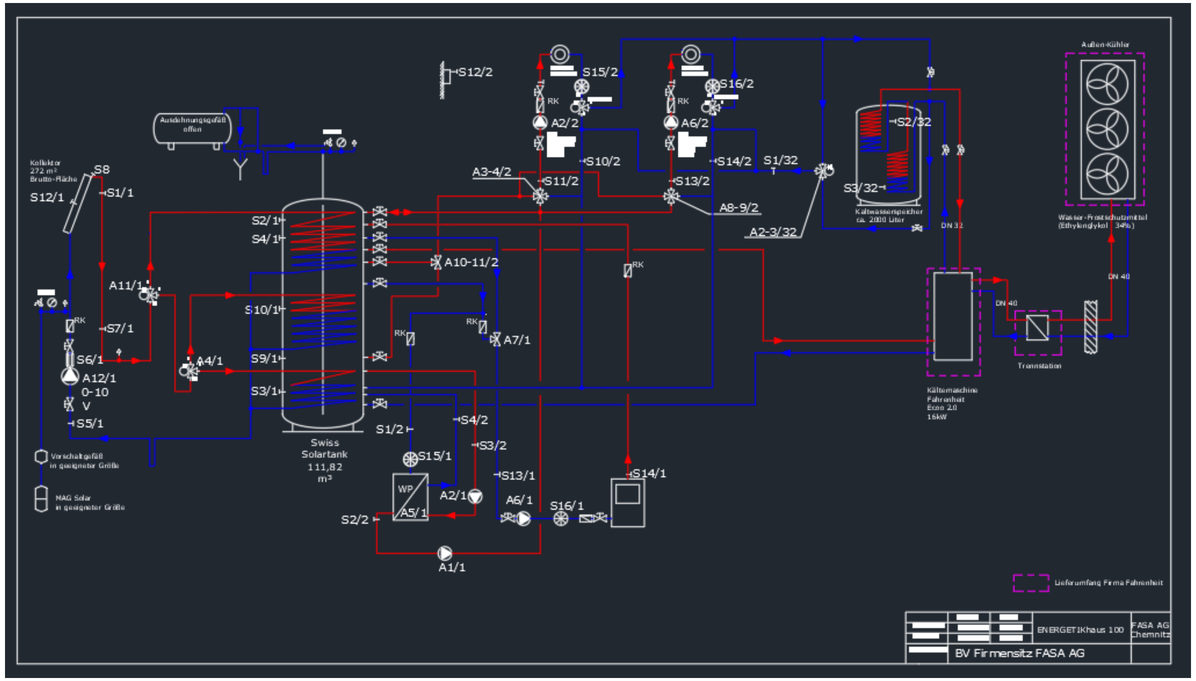
Quelle: http://buildipedia.com/aec-pros/design-news/the-daily-life-of-building-information-modeling-bim

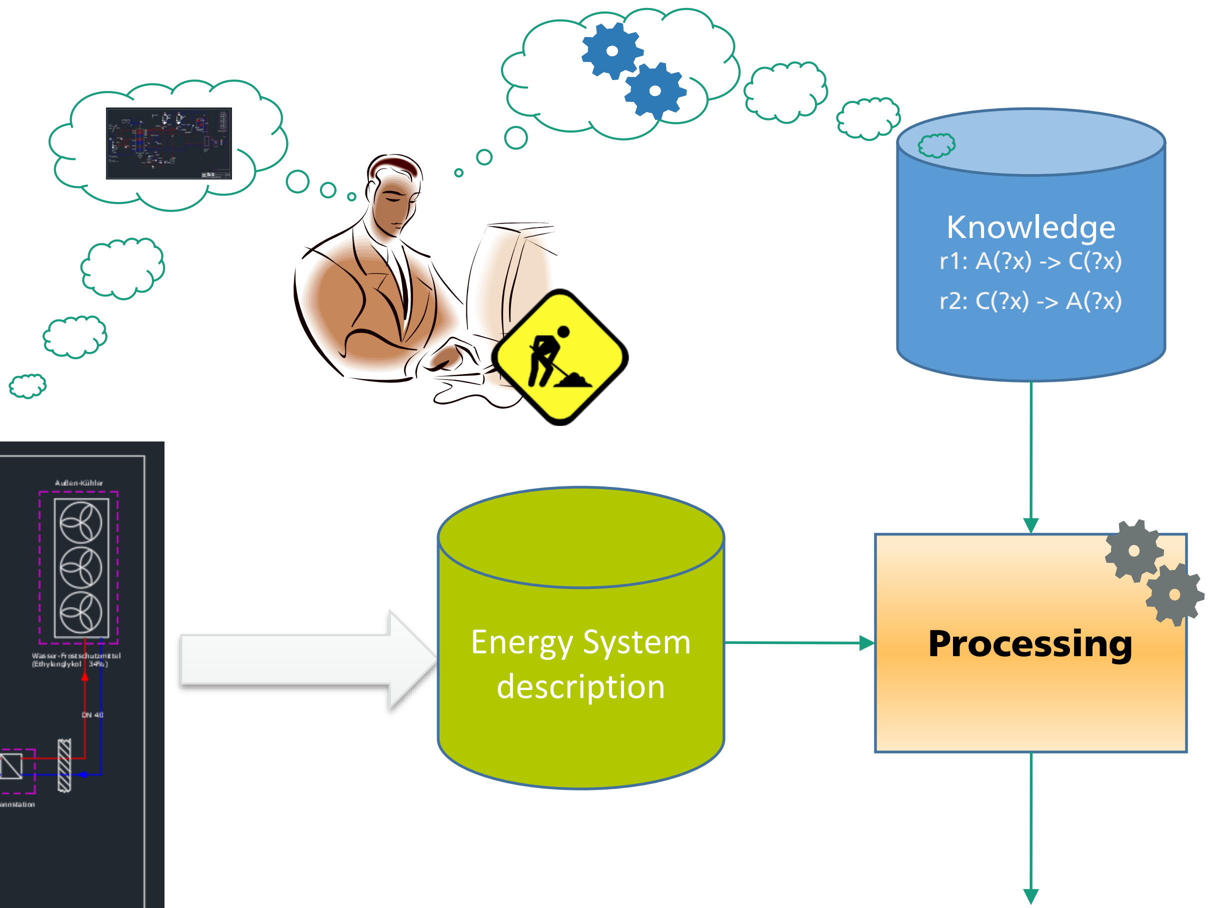
Methodology: Automation…

Of the Design and Deployment of Energy System Monitoring and BACS systems

By Emulating the reasoning of a human technical expert

For Characterizing the current energy system and prescribing applicable monitoring functions





1. Identification of Energy Risks
2. Selection of Monitoring tasks and Control functions (deployable in a BMS or in a parallel system)
3. Selection of energy-optimized control strategies and energy conservation measures
4. Extraction of required and available data points

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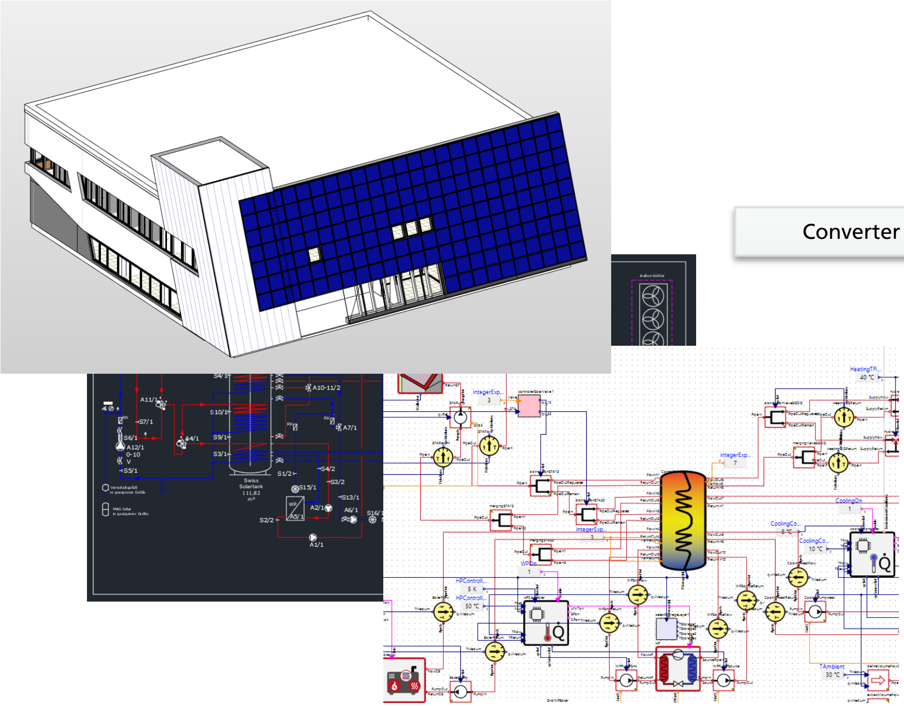
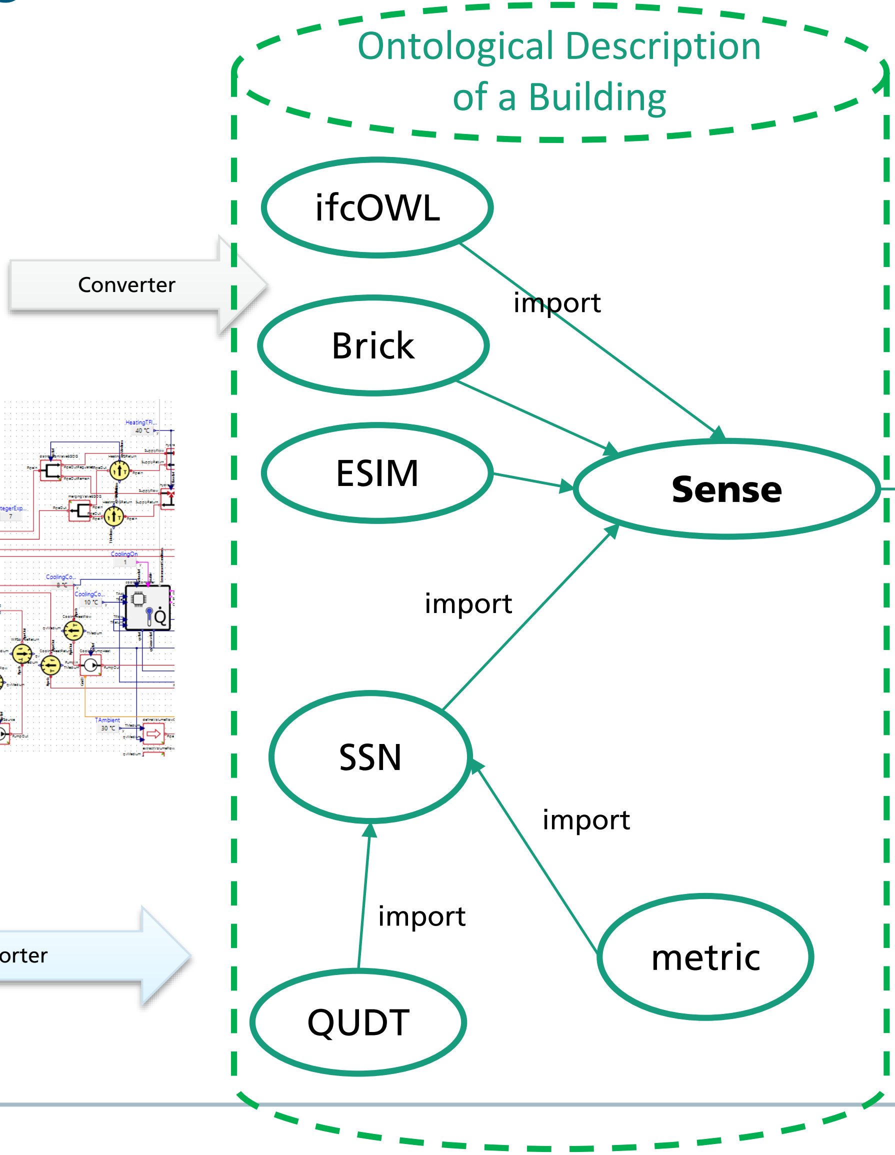
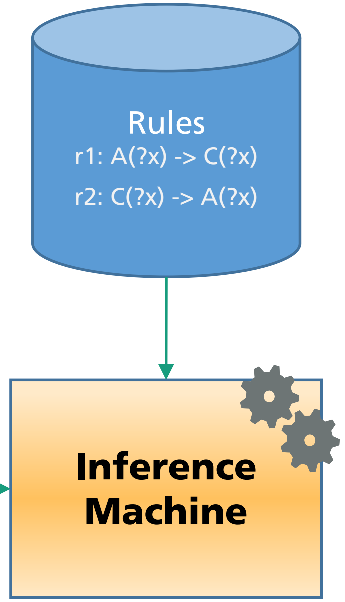
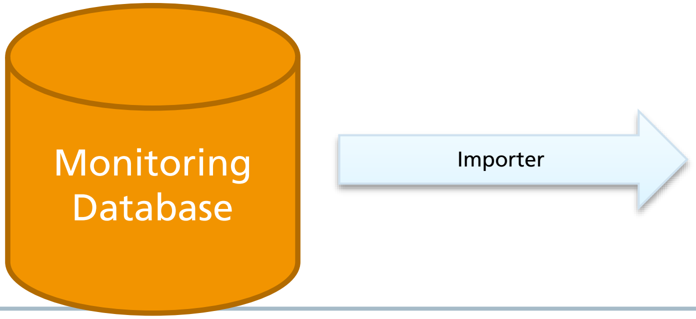
Metadata sources for system description and ontology population: 3 options









Metadata sources:

1. Sensors database of an existing data acquisition system (database-driven workflow).
2. an existing metadata model made available from a graph database (digitalized workflow)
3. a BIM model gained from CAD design (digitalized BIM workflow) -> BIM2BMS (BIM2FDD, BIM2BACS)

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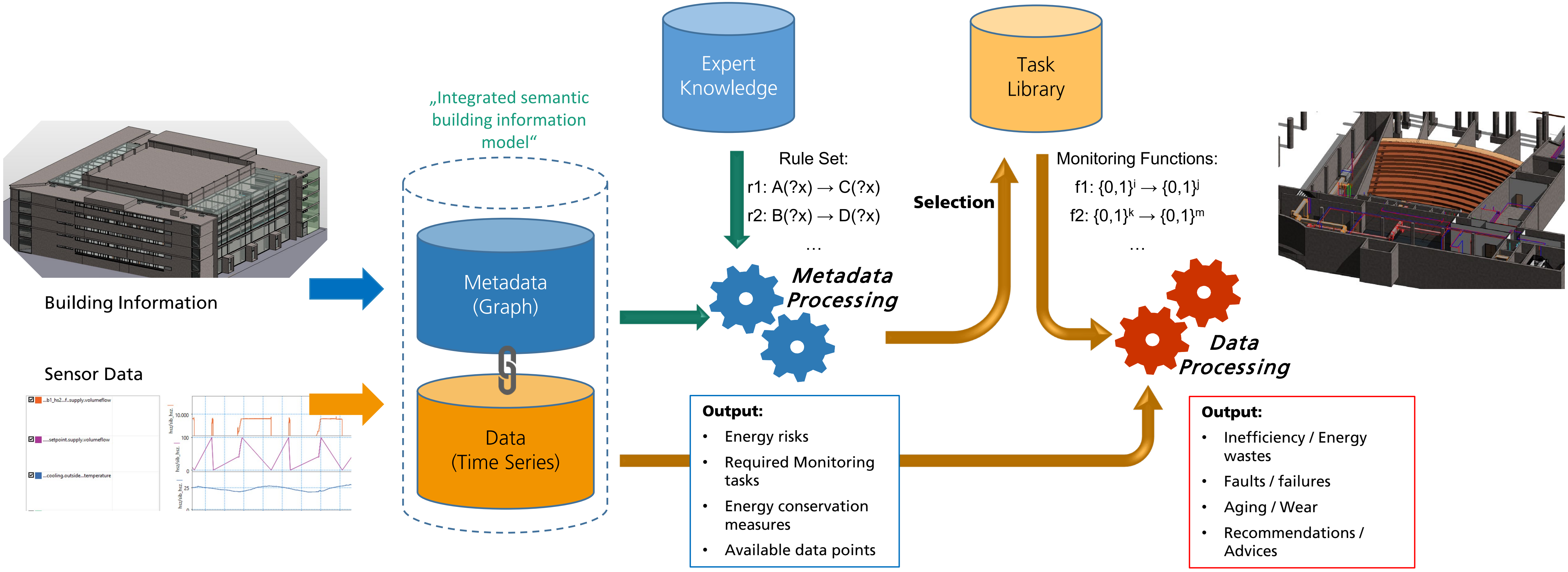
Workflow for automated building energy system monitoring

Overall Goal -> Automated configuration and execution of monitoring functions (e.g. FDD)



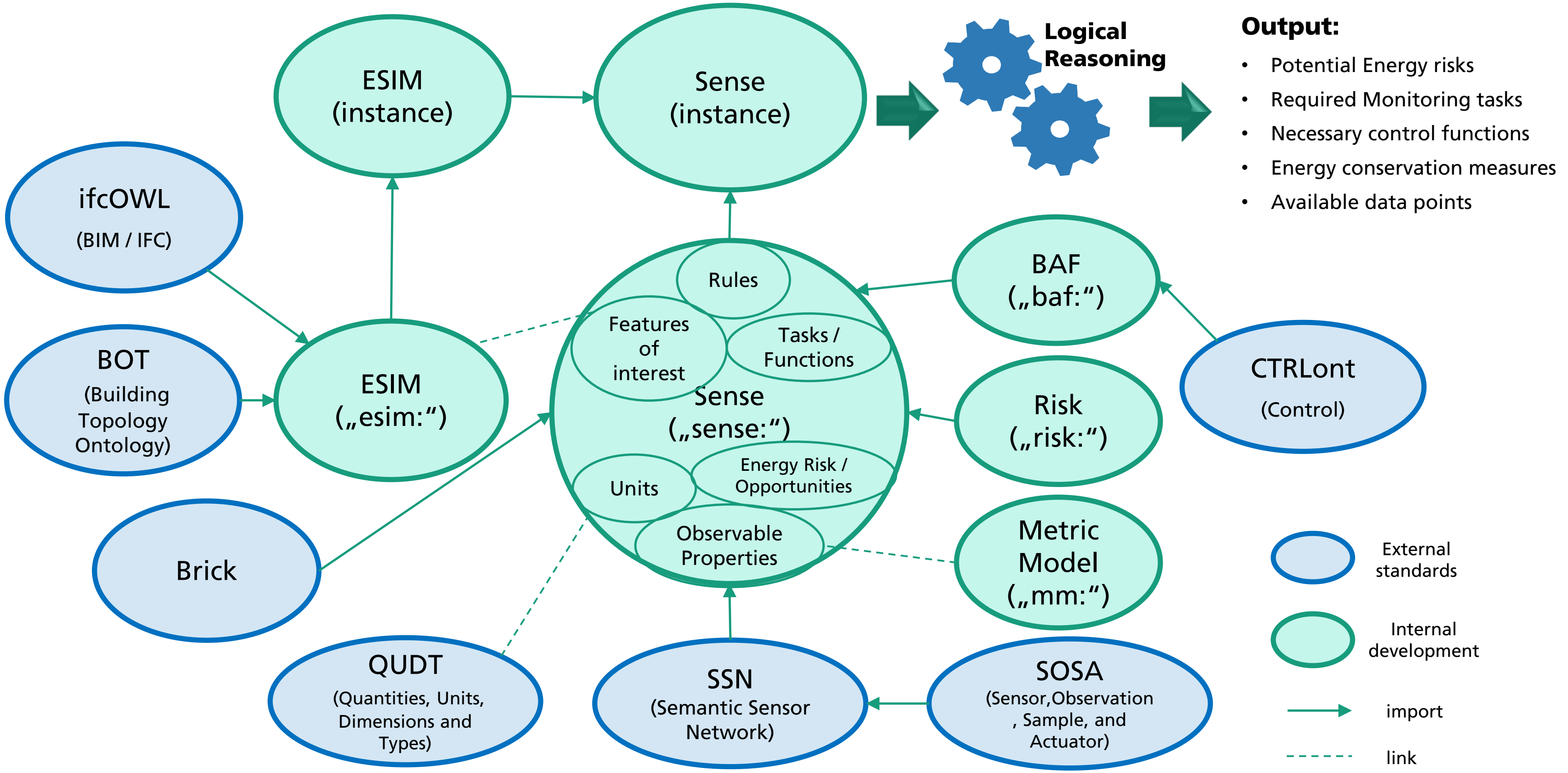
Data processing level: monitoring use cases

For checking energy waste and prescribing energy conservation measures

- Energy conservation measures (ECM) are potential actions a building user, facility manager or a controller can perform on the overall energy system to save energy
- ECM formalized as conceptual rules in the knowledge base (meta data processing step) and implemented as monitoring functions performing analyses on measurement time series (data processing step)
- Defined at different Levels of Monitoring (LoM) and Levels of Control (LoC):
  - Building
  - Zone
  - Room
  - Component
  - Subsystem
- For a specific building, applicable ECMs depend on available building information and monitoring data

ECM1	**save cooling energy**
ECM1-1	save cooling energy by optimizing solar gain
ECM1-2	save cooling energy when facility not occupied
ECM1-3	save cooling energy by better matching energy and comfort needs
ECM1-4	save cooling energy avoiding HVAC operating errors
ECM1-5	save cooling energy avoiding wastes through openings
ECM1-9	save cooling energy avoiding wear of components
ECM1-10	save cooling energy fixing broken components
ECM2	**save heating energy**
ECM2-1	save heating energy by optimizing solar gain
ECM2-2	save heating energy when facility not occupied
ECM2-3	save heating energy by better matching energy and comfort needs
ECM2-4	save heating energy avoiding HVAC operating errors
ECM2-5	save heating energy avoiding wastes through openings
ECM2-9	save heating energy avoiding wear of components
ECM2-10	save heating energy fixing broken components
ECM3	**save lighting energy**
ECM3-6	save lighting energy turning off lights when space unoccupied
ECM3-7	save lighting energy optimizing natural light income
ECM3-9	save lighting energy avoiding wear of components
ECM3-10	save lighting energy fixing broken components
ECM4	**save electrical energy**
ECM4-8	save electrical energy turning appliances down when room unoccupied
ECM4-9	save electrical energy avoiding wear of components
ECM4-10	save electrical energy fixing broken components

Metadata processing level: Ontology System of descriptive and prescriptive ontologies



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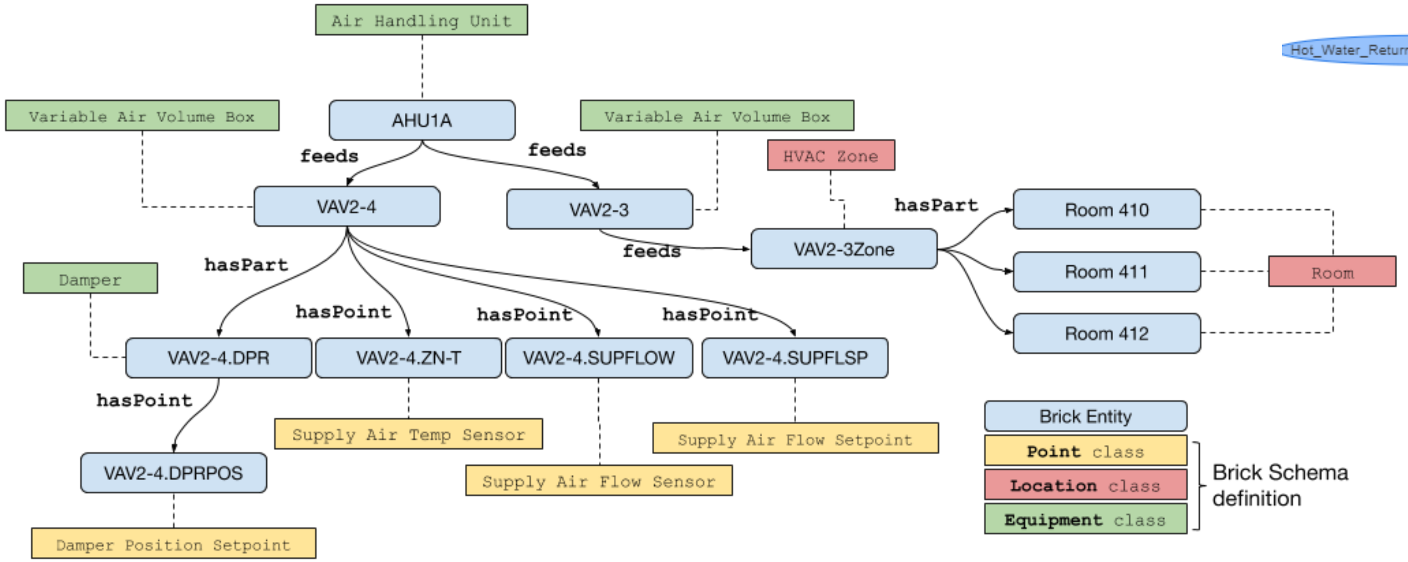
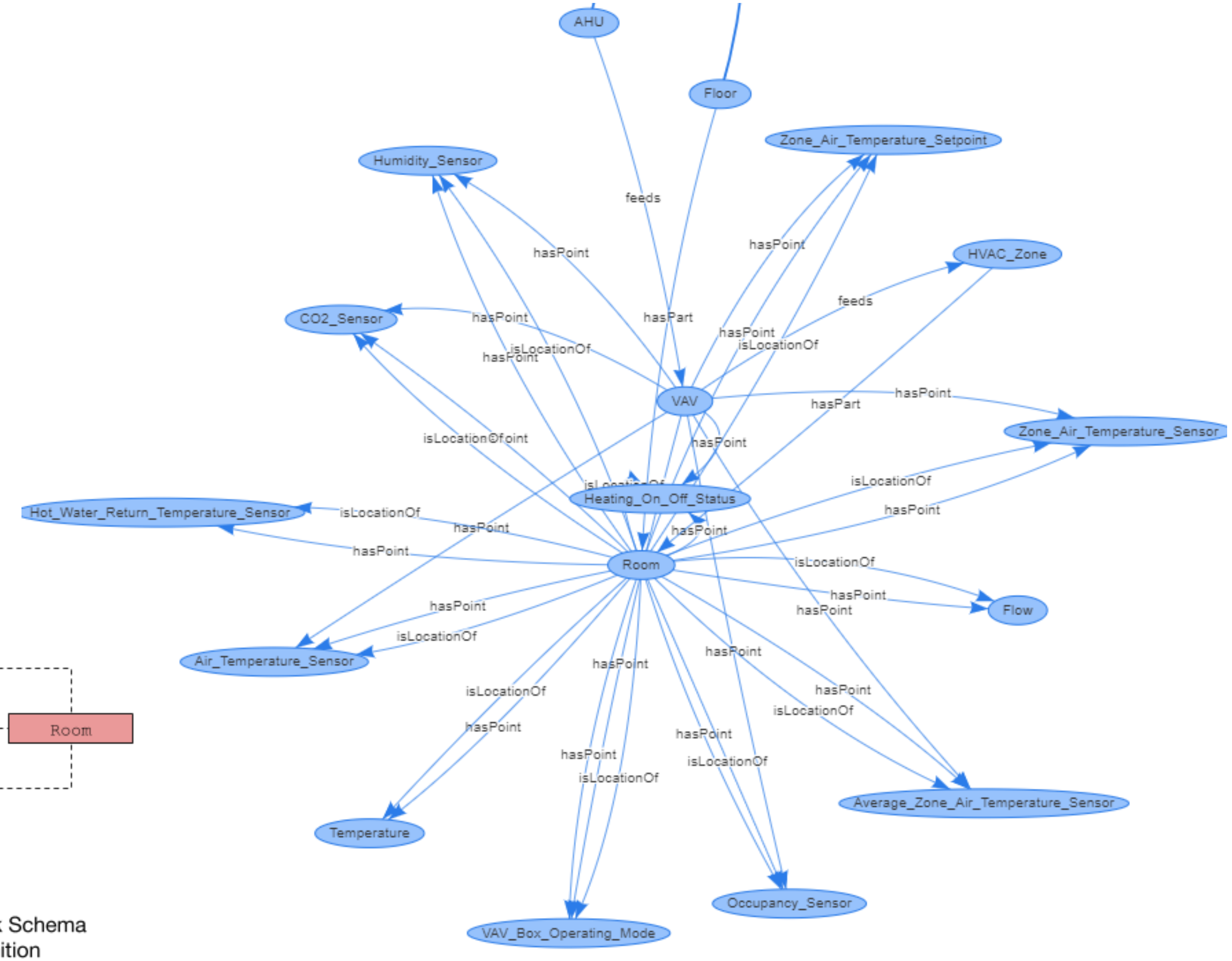
„Brick“ Schema

- open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them.
- extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together.





Source: https://brickschema.org/

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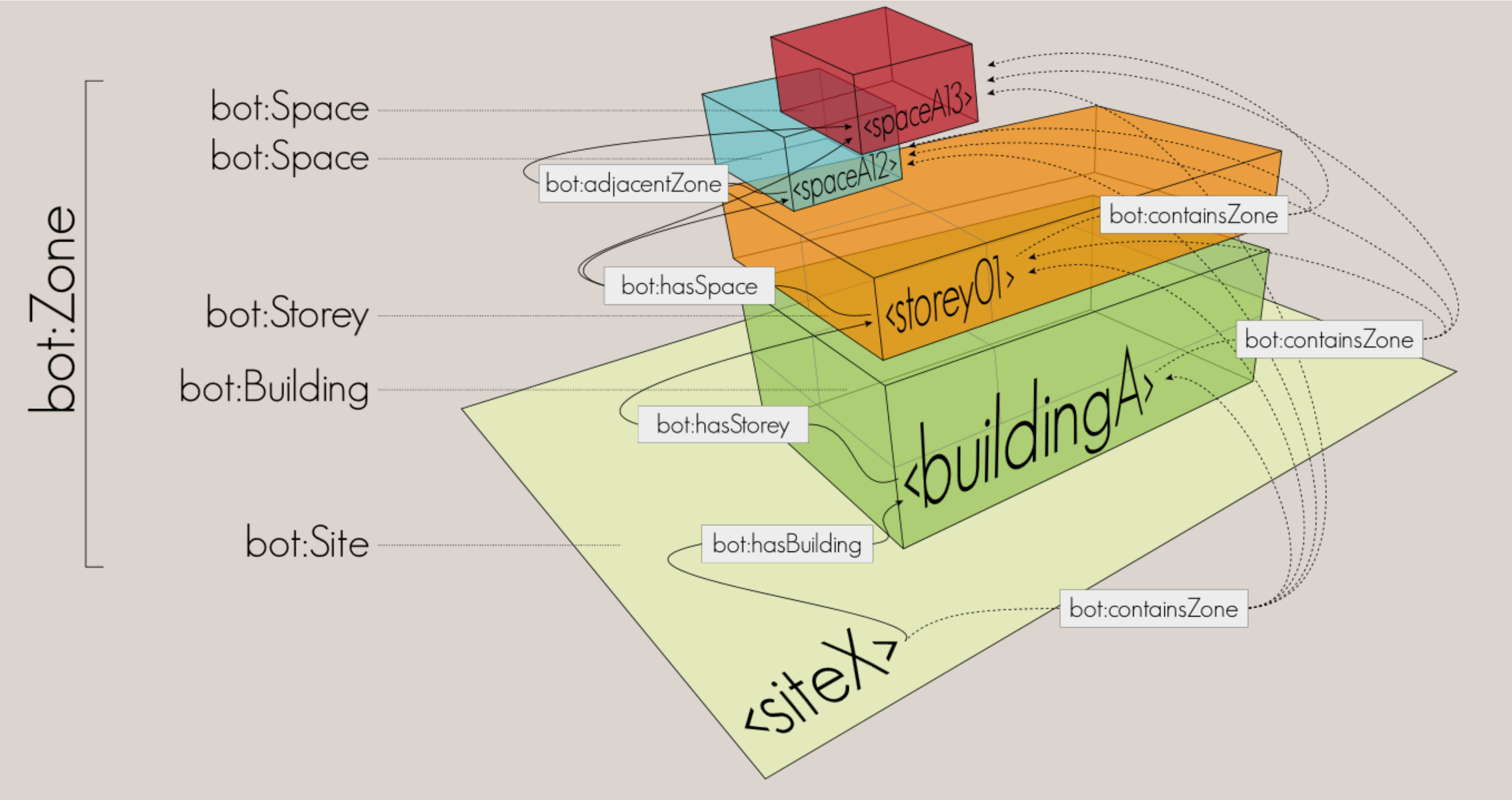
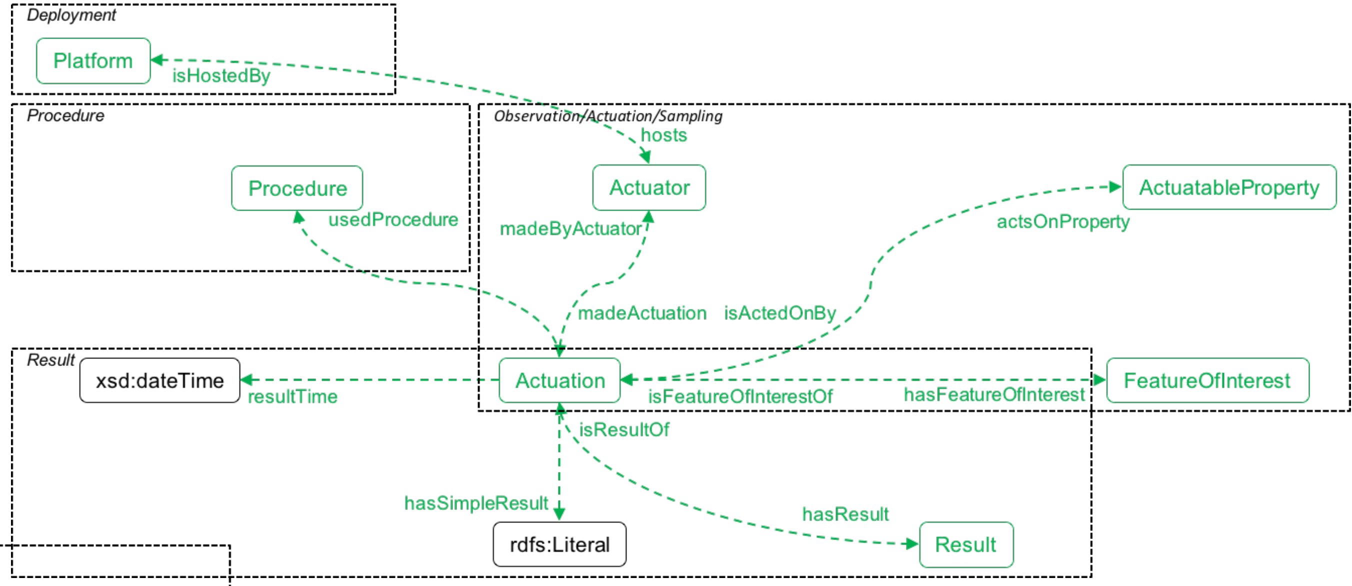
bot:Zone - “Matryoshka”- style nesting

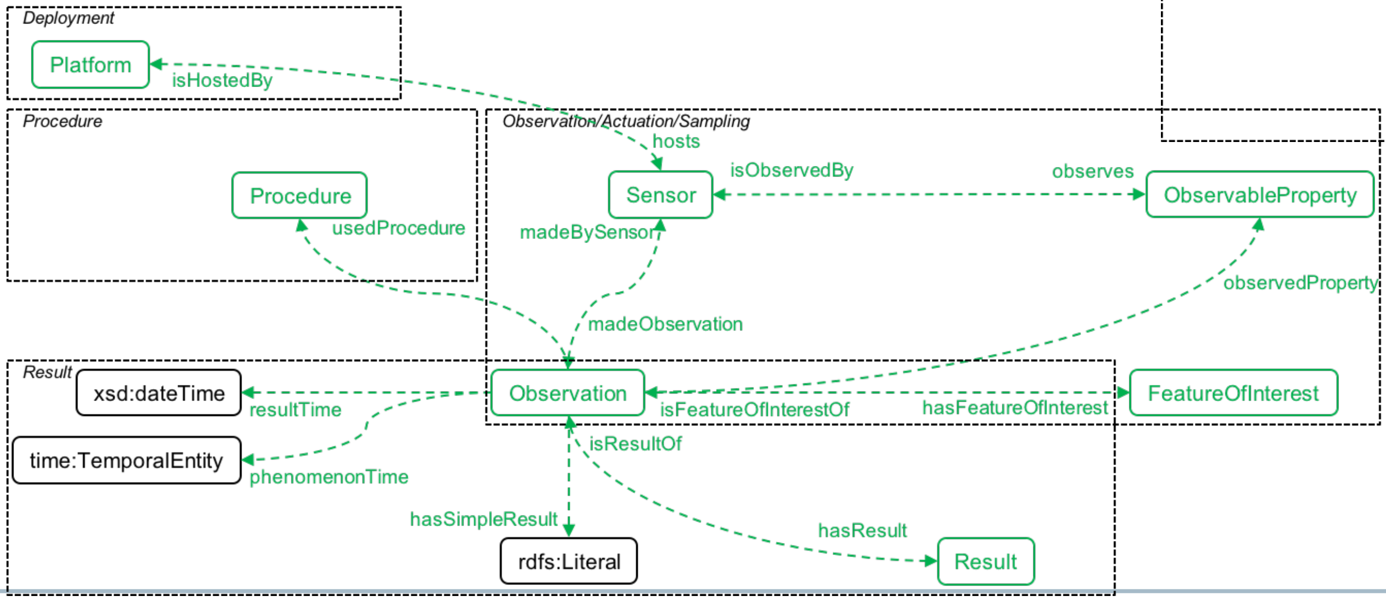


Source: http://www.semantic-web-journal.net/content/bot-building-topology-ontology-w3c-linked-building-data-group-0

SSN: Semantic Sensor Network

- The **Semantic Sensor Network (SSN)** ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators.
- SSN follows a horizontal and vertical modularization architecture by including a lightweight but self-contained core ontology called **SOSA (Sensor, Observation, Sample, and Actuator)** for its elementary classes and properties.

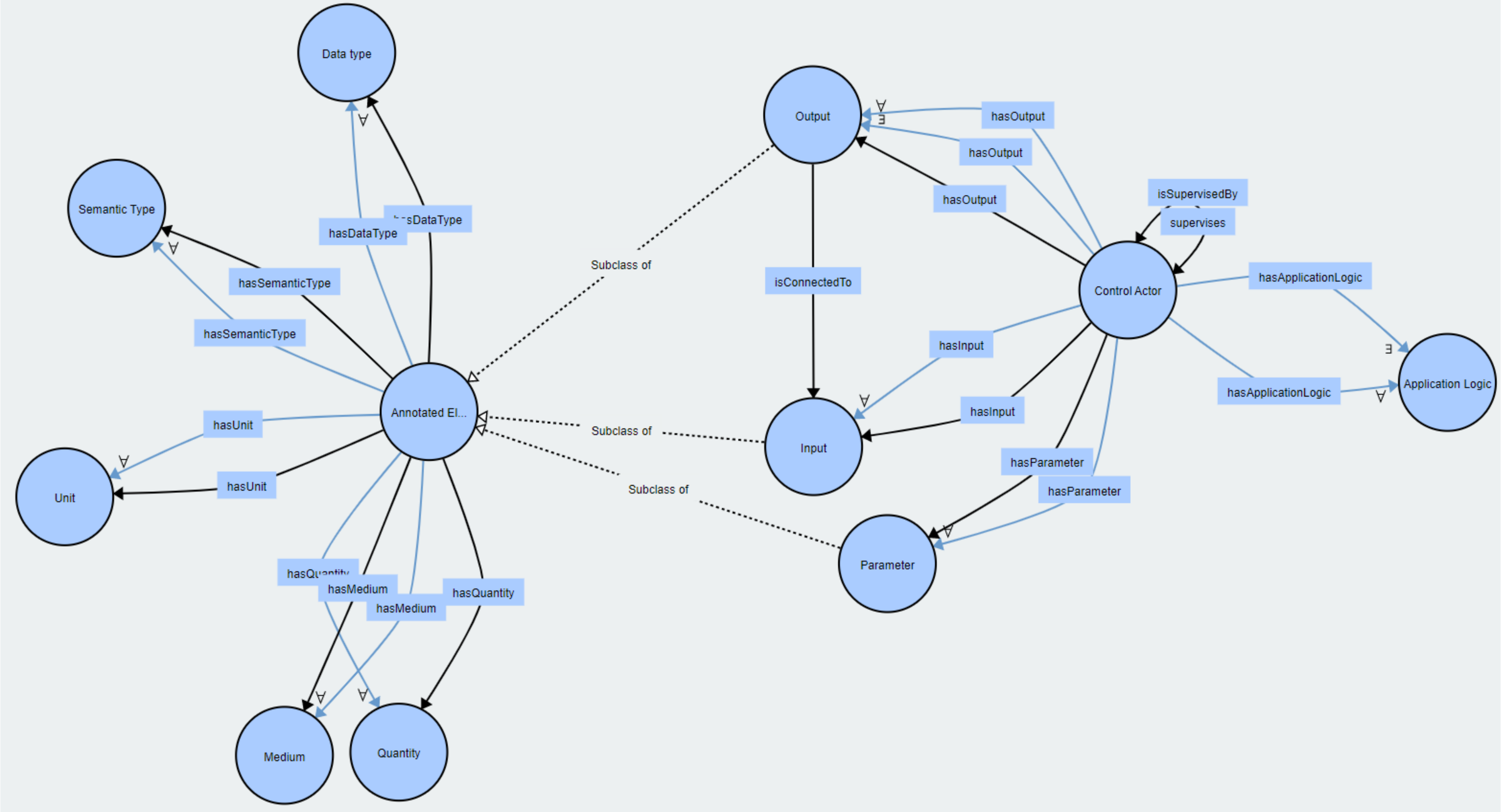




Source: https://www.w3.org/TR/vocab-ssn/

CTRLont:

- Several abstract concepts:
  - Functions
  - I / O
  - Parameters
  - Application logic
  - …



Source: https://w3id.org/ibp/CTRLont

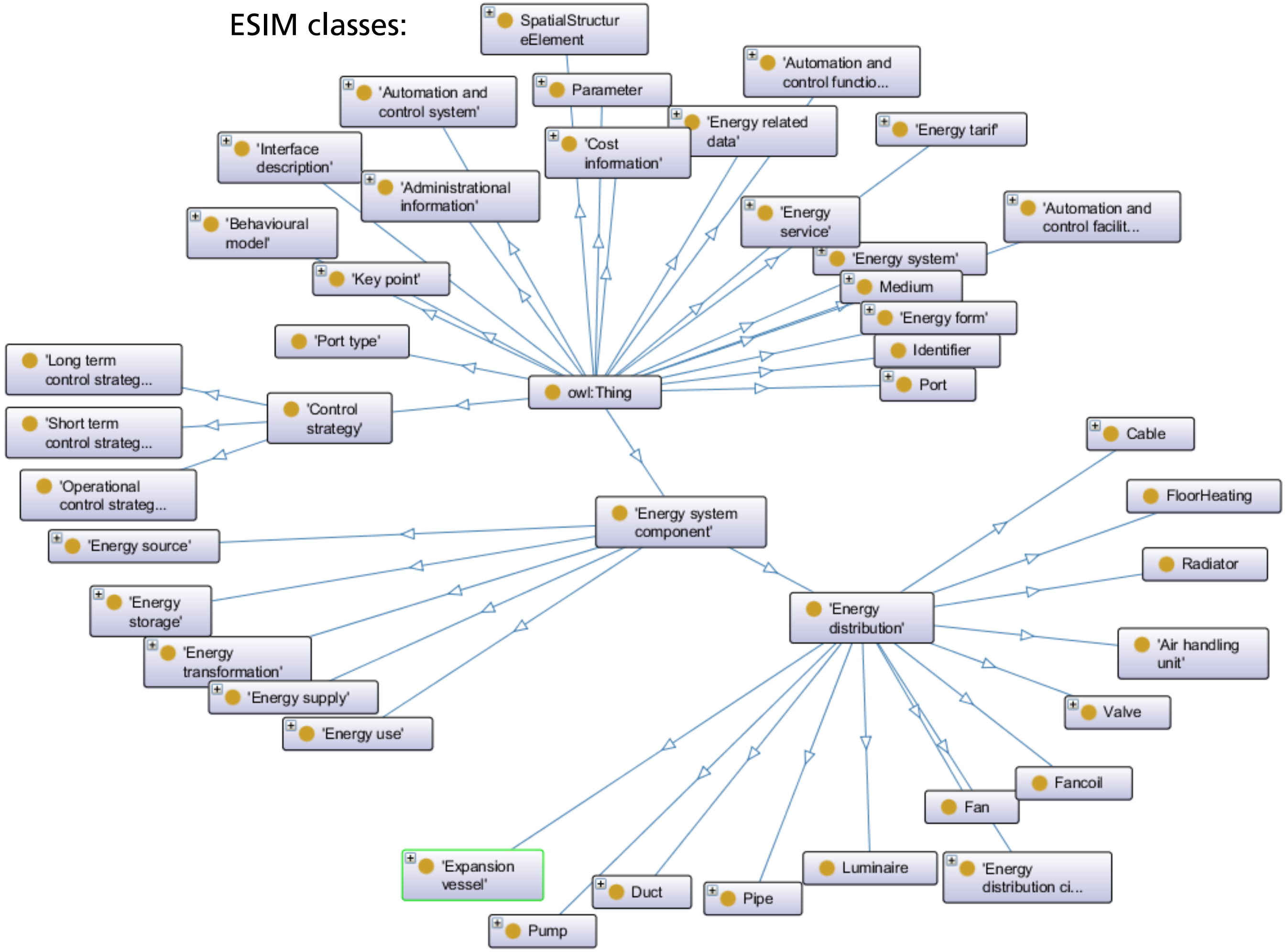
ESIM: Energy System Information Model

Energy System Information Model (ESIM) is a domain specific model that **provides information of the urban and building energy system including the automation and control systems**. It comprises **functional, structural and physical descriptions of the systems** as master data and additional **operational data**.

```
@prefix : <http://www.eas.iis.fraunhofer.de/dc/esim-instance#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix esim: <http://org.fhg.iis.eas.eee.esim/ESIMonto#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@base <http://www.eas.iis.fraunhofer.de/dc/esim-instance> .

<http://www.eas.iis.fraunhofer.de/dc/esim-instance> rdf:type owl:Ontology ;
                                                     owl:imports <http://org.fhg.iis.eas.eee.esim/ESIMonto> ;
                                                     owl:versionInfo "Created with TopBraid Composer" .

#################################################################
#    Individuals
#################################################################

###  http://www.eas.iis.fraunhofer.de/dc/esim-instance#BoilerPump
:BoilerPump rdf:type owl:NamedIndividual ,
                     esim:Pump .


###  http://www.eas.iis.fraunhofer.de/dc/esim-instance#CombiStorage
:CombiStorage rdf:type owl:NamedIndividual ,
                       esim:HotWaterTank ;
              rdfs:label "HotWaterTank_FASA" .
```

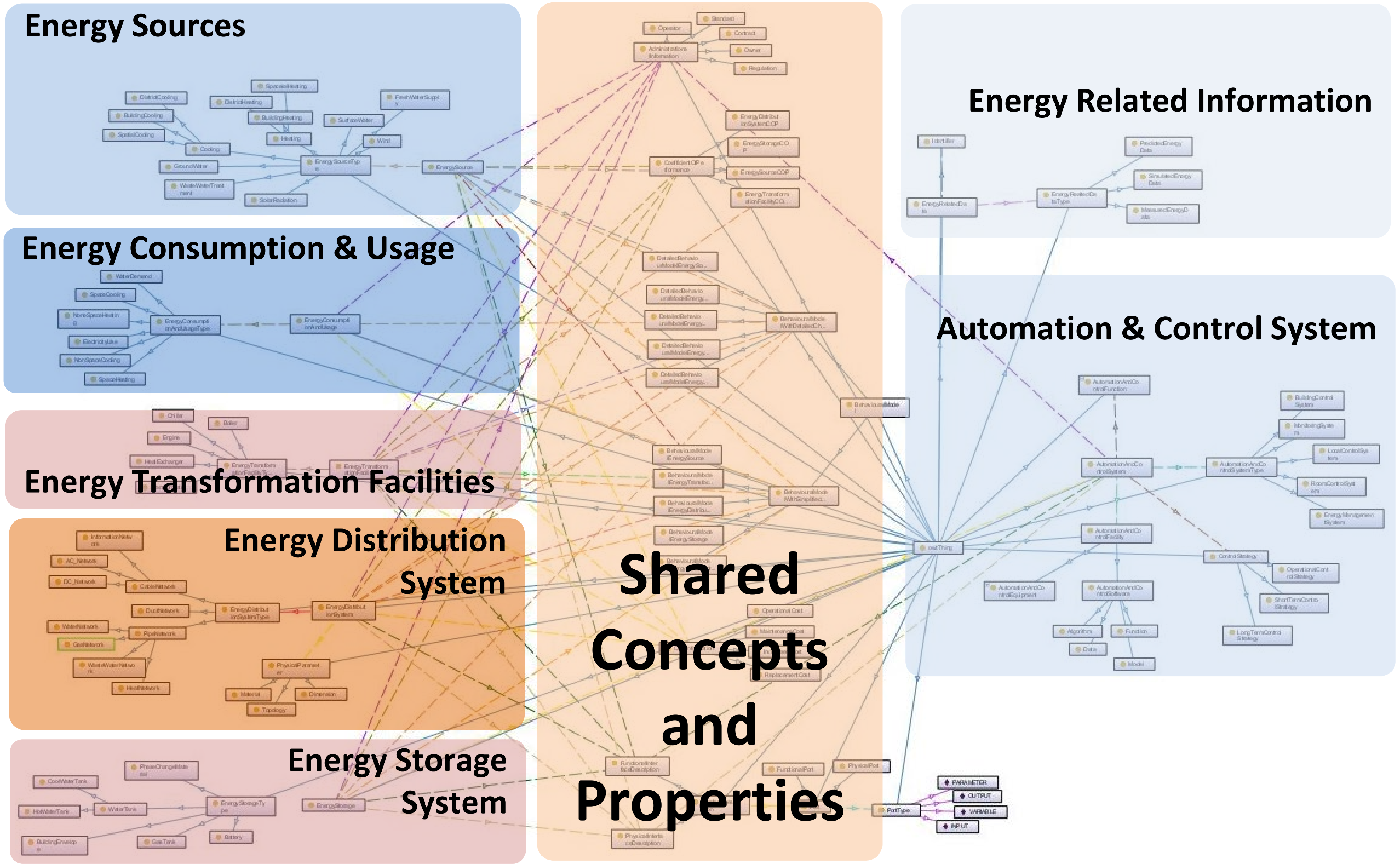
RDF serialization

ESIM classes:



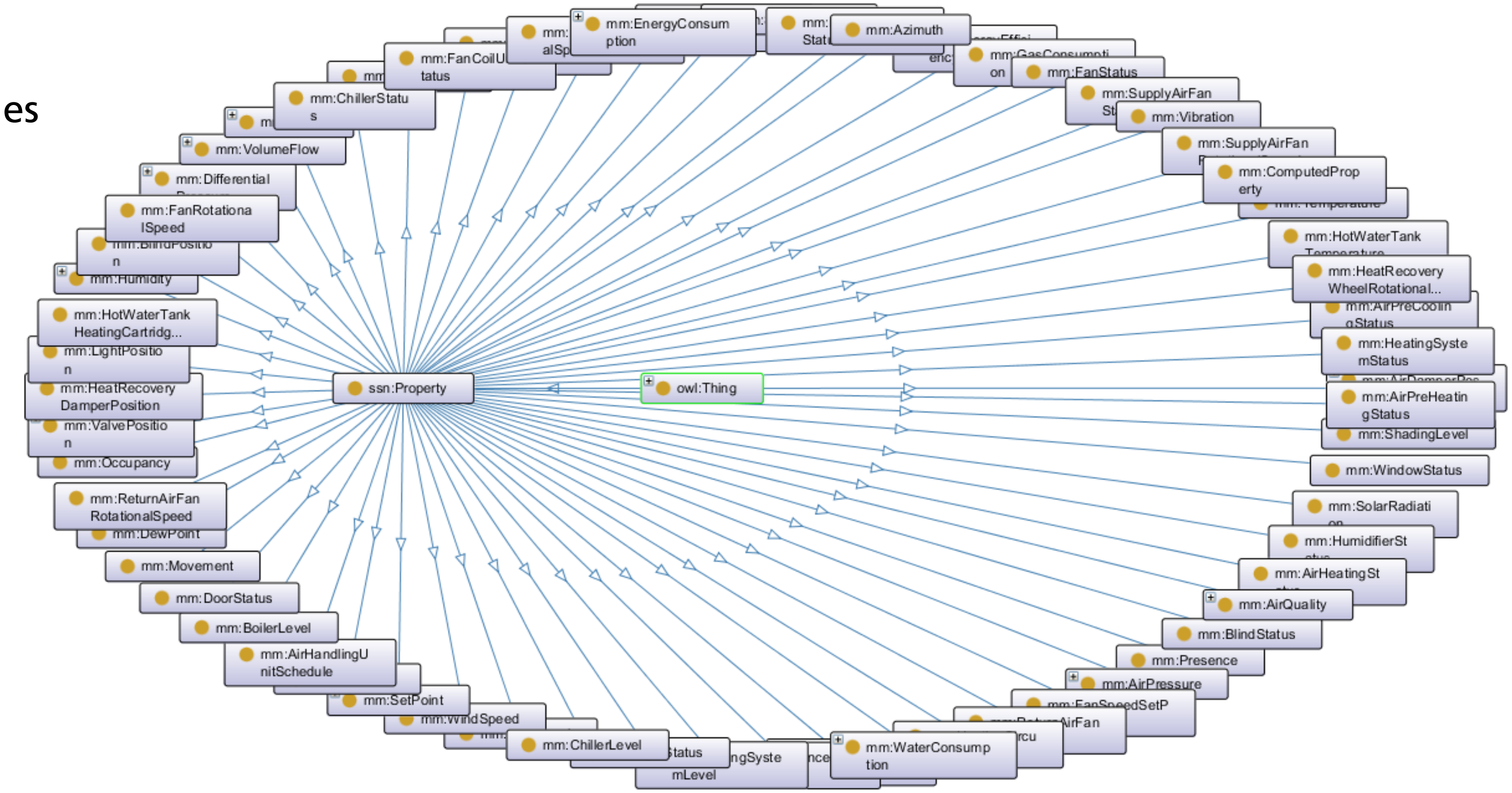
ESIM ontology

Main concepts



MM: Metric Model

- Set of metrics for engineering quantities
- Emcompasses BACS data points
- Complements SSN, QUDT, Brick…



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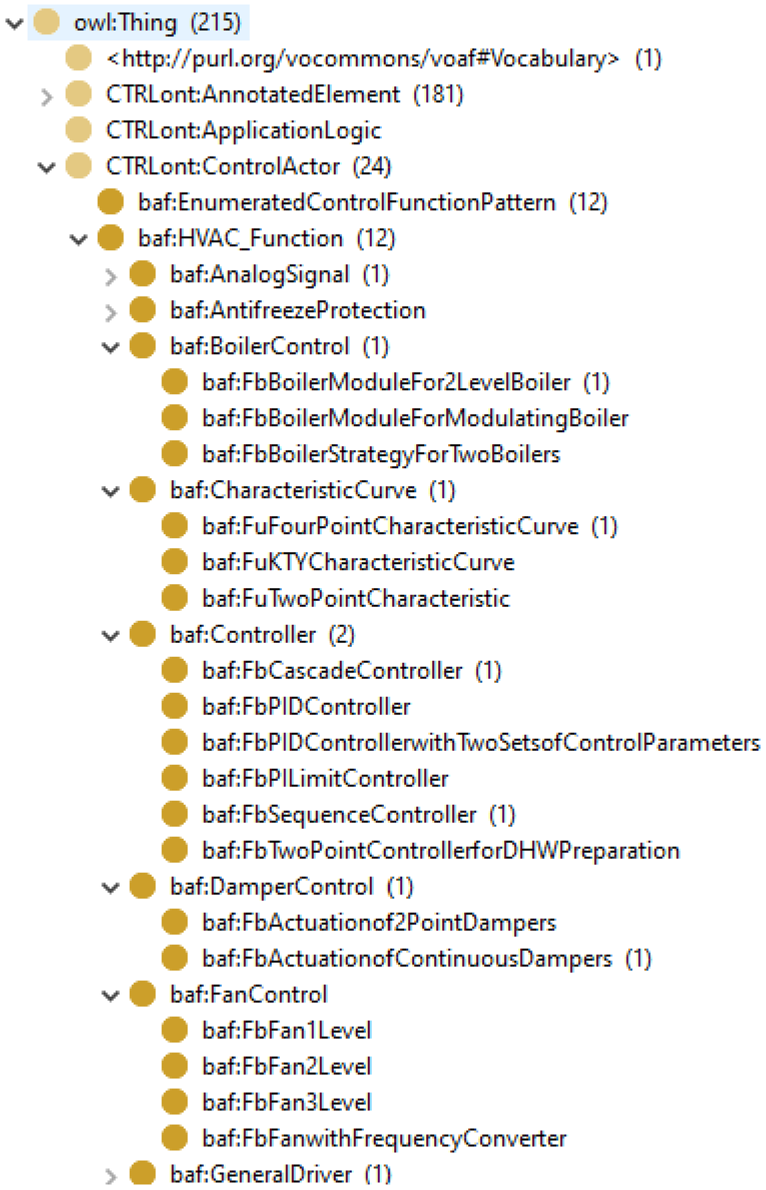
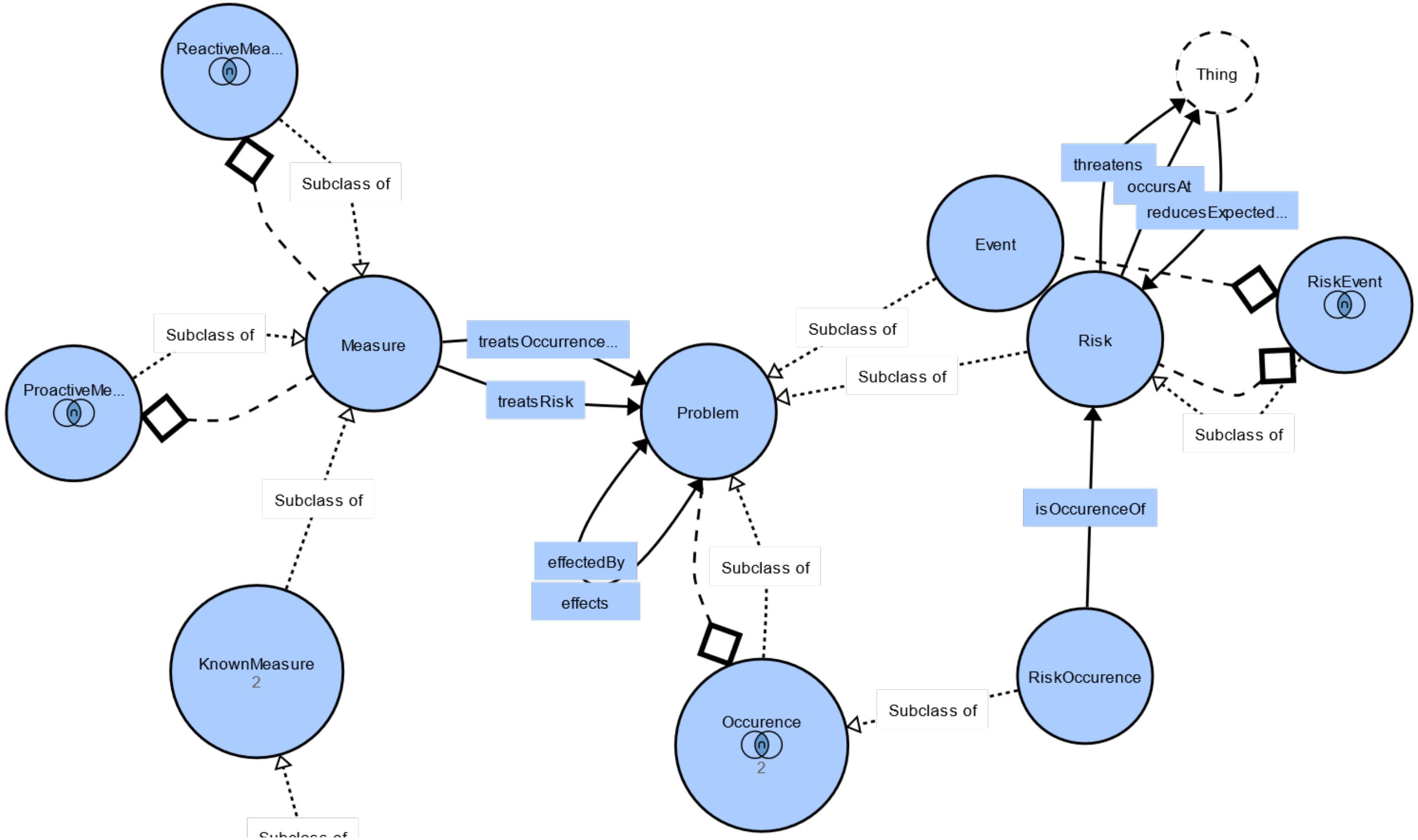
BAF: Building Automation Functions

- BACS functions ontology:
    - Reuse of abstract concepts from CTRLont ontology (Fraunhofer IBP)
    - Catalogue of generic function blocs used by BACS designers
    - For the automatic selection and configuration of function blocs incl. dependencies and parameters.



RISK: Risk ontology

- RISK ontology:
  - Formalizes concepts from the field of risk management
  - Catalogue of risks, issues and faults that can occur within the buildin lifecycle
  - Provides concepts for FDD



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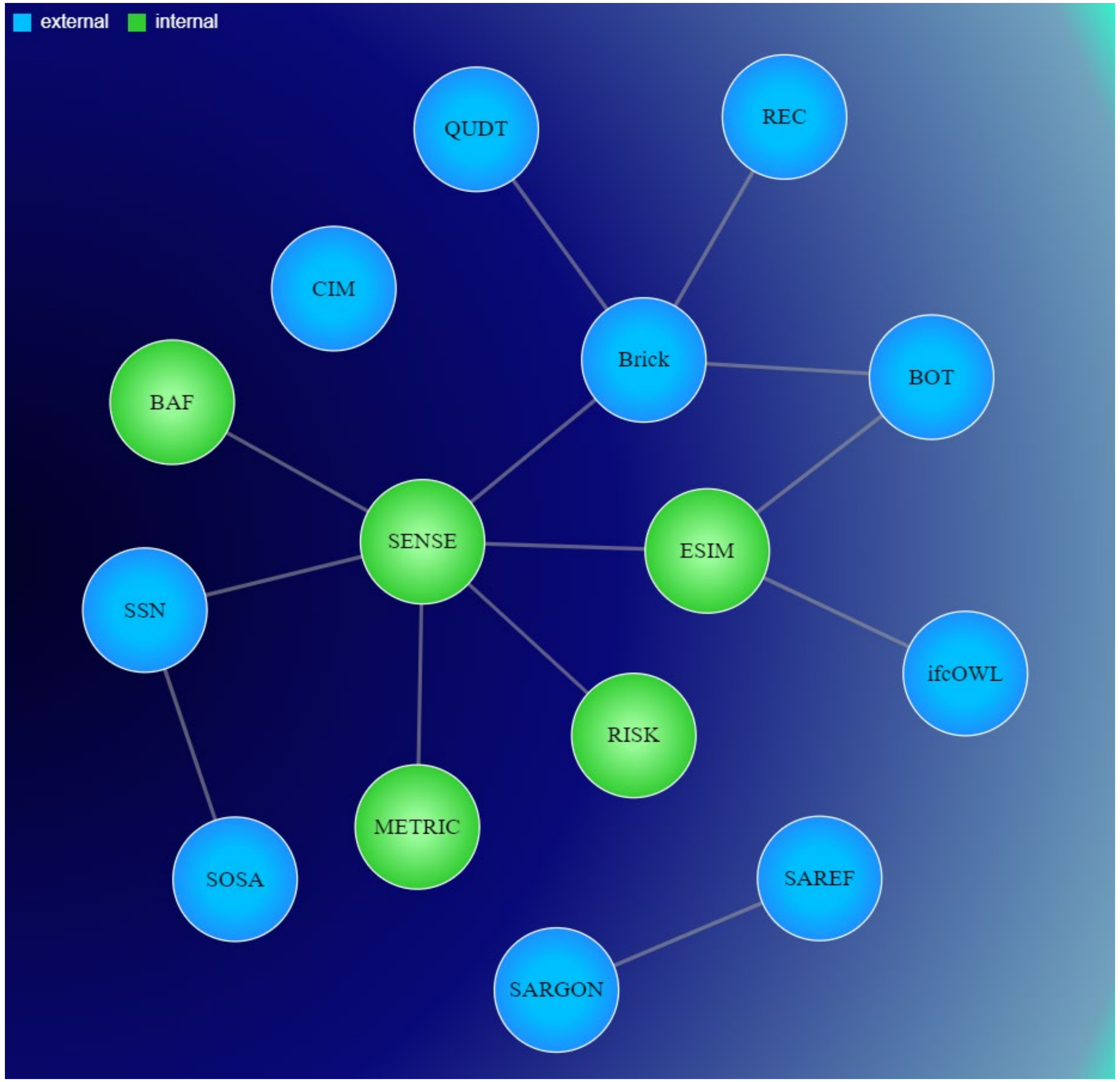
Ontologies schemas online

- Ontologies from the SENSE Composition:
  - Metric Model (MM): https://w3id.org/mm
  - Risk (RISK): https://w3id.org/risk
  - Building Automation Functions (BAF): https://w3id.org/baf
  - Energy System Information Model (ESIM): https://w3id.org/esim



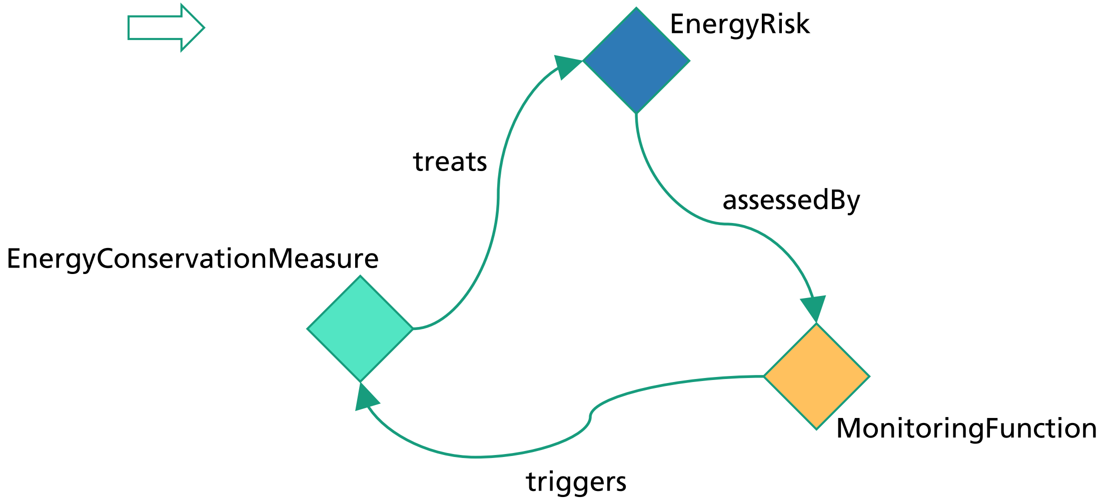
SENSE ontology for system characterization through semantic reasoning

Use of a Risk paradigm

- risk:Problem (32)
  - risk:Event
  - risk:Occurence (2)
    - risk:RiskOccurence
  - risk:Risk (30)
    - risk:CertificationRisk
    - risk:ConstructionRisk
    - risk:CostRisk
    - risk:DesignRisk (1)
    - risk:EnergyRisk (24)
    - risk:GeotechnicalRisk (4)
    - risk:LegalRisk (1)
    - risk:ReliabilityRisk
    - risk:RiskEvent

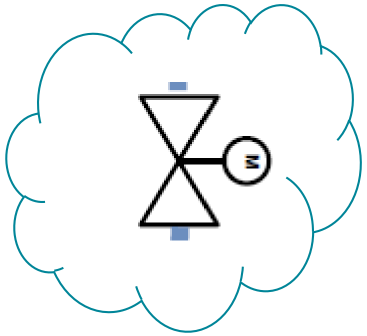
- sosa:Procedure
  - risk:Measure
    - risk:KnownMeasure
      - risk:GeotechnicalMeasure
      - so:EnergyConservationMeasure
        - so:CoolingEnergySavingMeasure
        - so:ElectricalEnergySavingMeasure
        - so:EnumeratedEnergyConservationMeasure
        - so:HeatingEnergySavingMeasure
        - so:LightingEnergySavingMeasure
    - risk:ProactiveMeasure
    - risk:ReactiveMeasure

- risk:WastingEnergyThroughOpenings
- risk:UnusedLights
- risk:UnusedHeatingEnergy
- risk:UnusedCoolingEnergy
- risk:UnusedAppliances
- risk:SupplyAirTemperature_TooLow
- risk:SupplyAirTemperature_TooHigh
- risk:SupplyAirPressure_TooLow
- risk:SupplyAirPressure_TooHigh
- risk:SupplyAirHumidity_TooLow
- risk:SupplyAirHumidity_TooHigh
- risk:SpaceUndercooling
- risk:SpaceOverheating
- risk:SimultaneousAirHeatingAndAirCooling
- risk:SimulatenousAirCoolingAndRadiantHeating
- risk:OverheatingThroughSolarGain
- risk:HeatRecoveryUsedButNotVentilated
- risk:HeatRecoveryUnused
- risk:HeatRecoveryInefficientlyUsed
- risk:AirSuppliedButNotReturned
- risk:AirReturnedButNotSupplied
- risk:AirHumidifiedButNotVentilated
- risk:AirHeatedButNotVentilated
- risk:AirCooledButNotVentilated



SENSE ontology for system characterization through semantic reasoning
Use of logical axioms and rules

- Formalizing knowledge of HVAC expert for characterizing systems from their topology:



Preliminary fact:

- data point of a valve as a valve position

SENSE ontology for system characterization through semantic reasoning

Use of logical axioms and rules

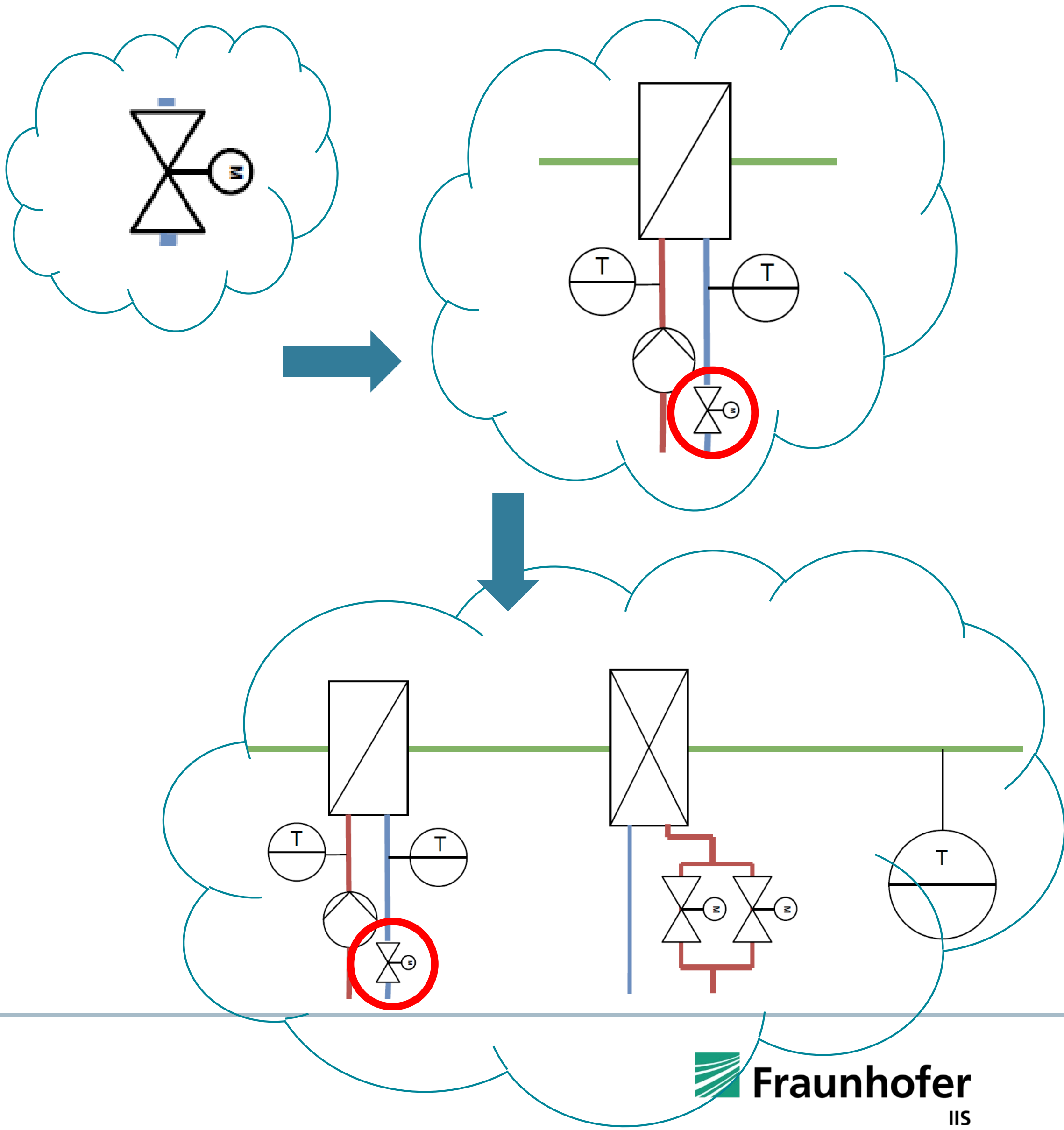
- Formalizing knowledge of HVAC expert for characterizing systems from their topology:

Preliminary fact:

- data point of a valve as a valve position

System characterization:

- valve regulates flow in a heating coil ?
- heating coil is installed on same circuit as cooling coil ?
- or both are part of same air handling unit ?
- temperature sensor installed between cooling coil and air distribution box ?
- …



SENSE ontology for system characterization through semantic reasoning

Use of logical axioms and rules

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System characterization:

- valve regulates flow in a heating coil ?
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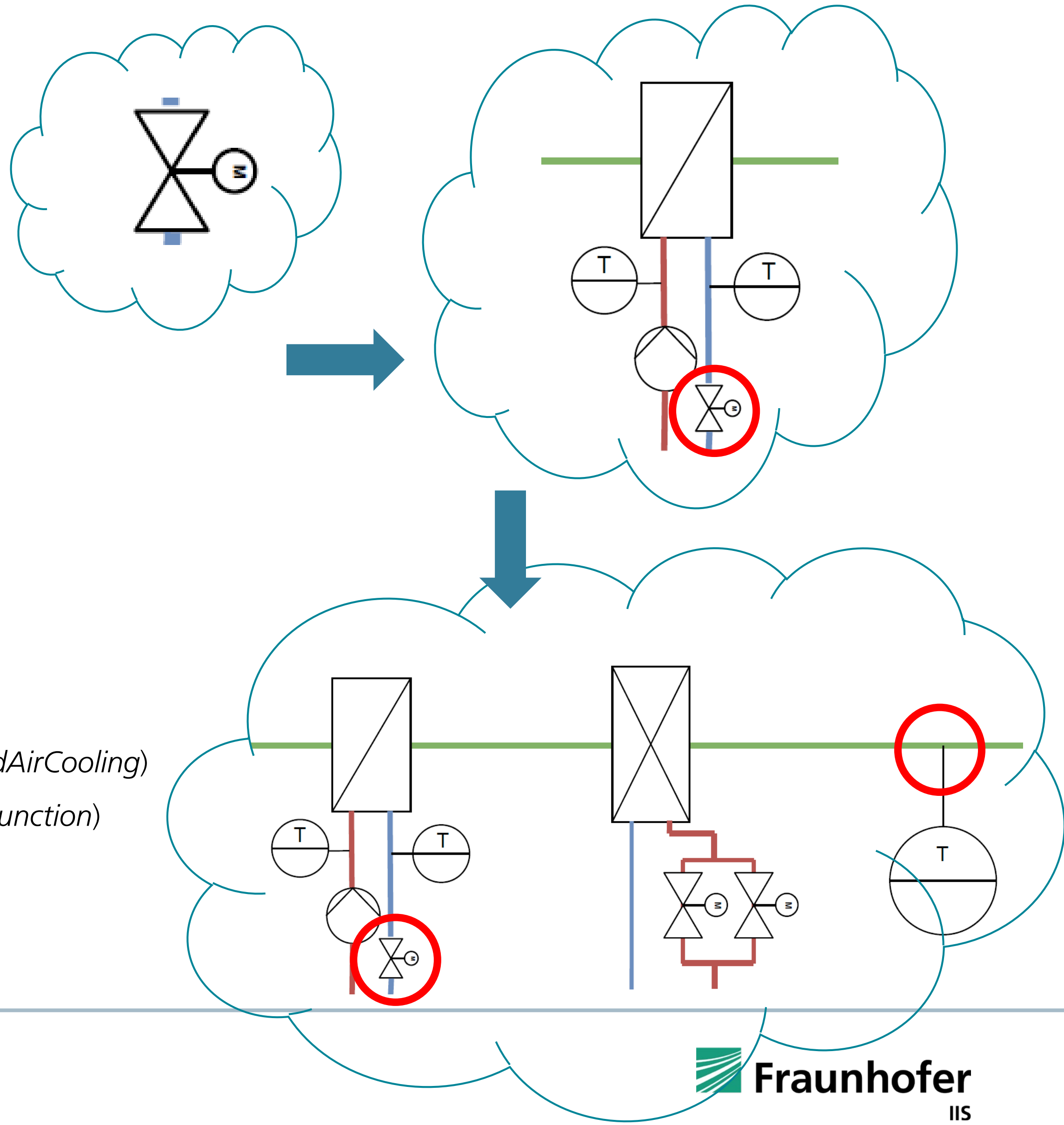
- temperature sensor installed between cooling coil and air distribution box ?
- …

Infered fact:

- data point is a heating coil valve position (*mm:HeatingCoilValvePosition*)
- AHU has a risk of simoultaneous air heating and cooling (*risk:SimultaneousAirHeatingAndAirCooling*)
- data point can be used to assess occurence of this risk during operation (*baf:MonitoringFunction*)
- temperature sensor measures supply air temperature (*mm:SupplyAirTemperature*)
- data point can be used to regulate temperature data point
- …



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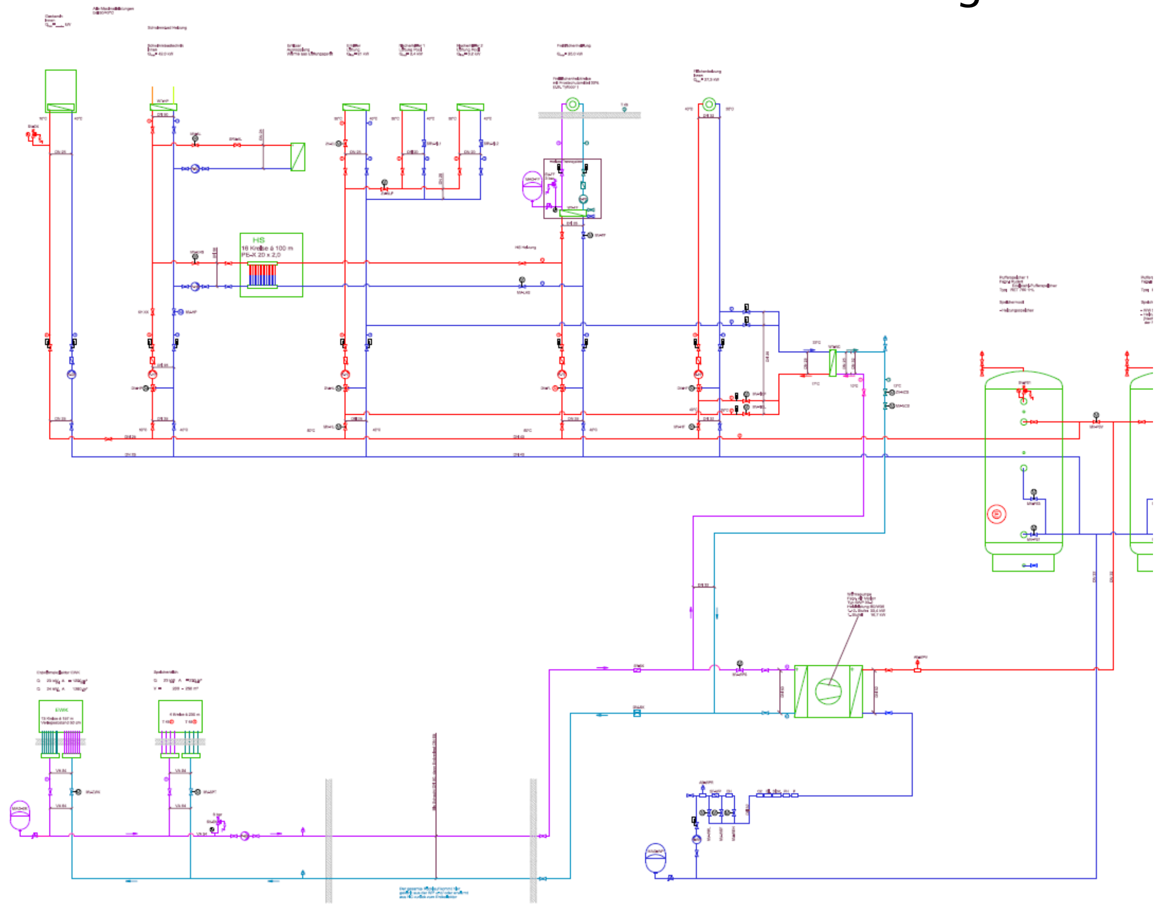
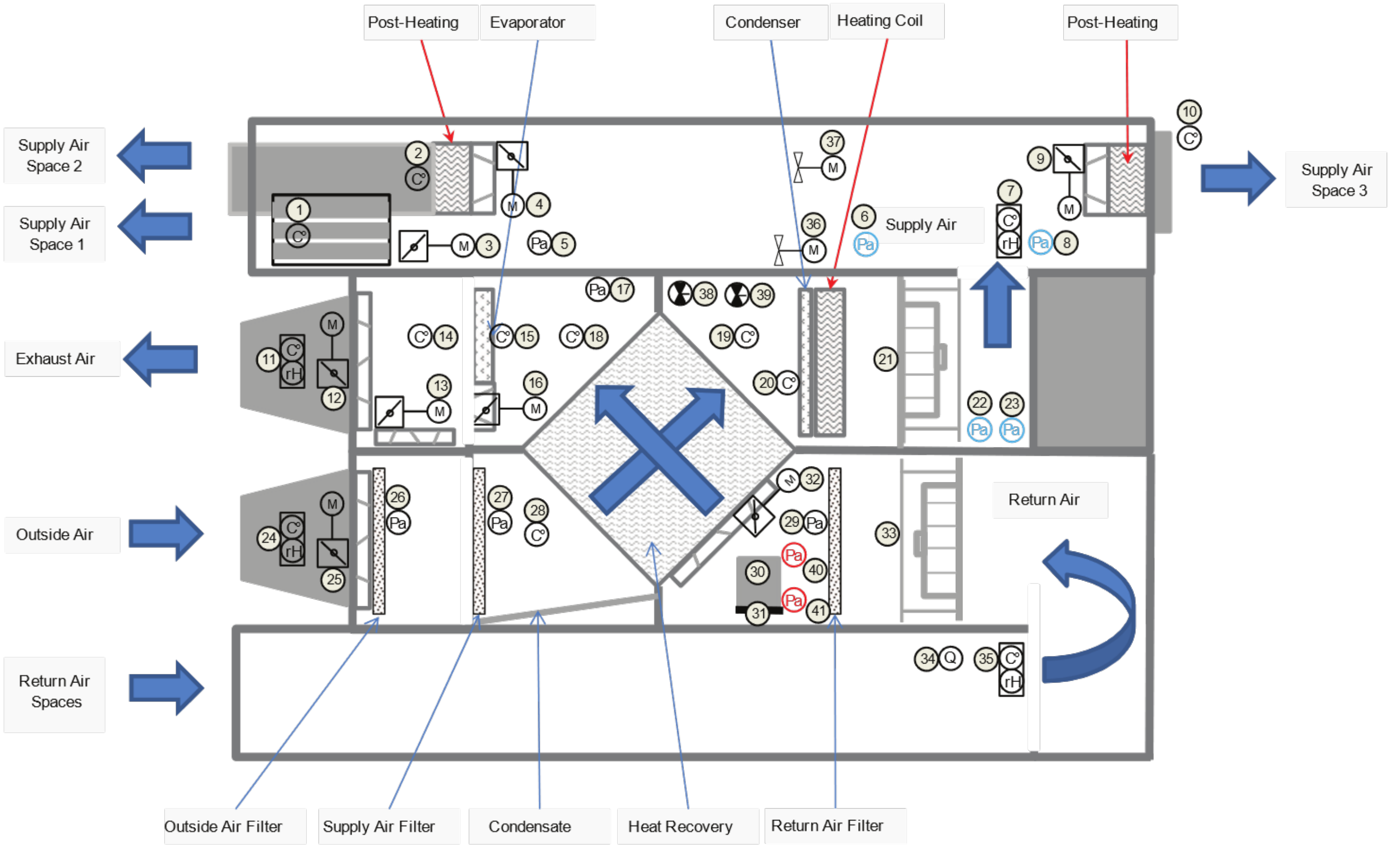
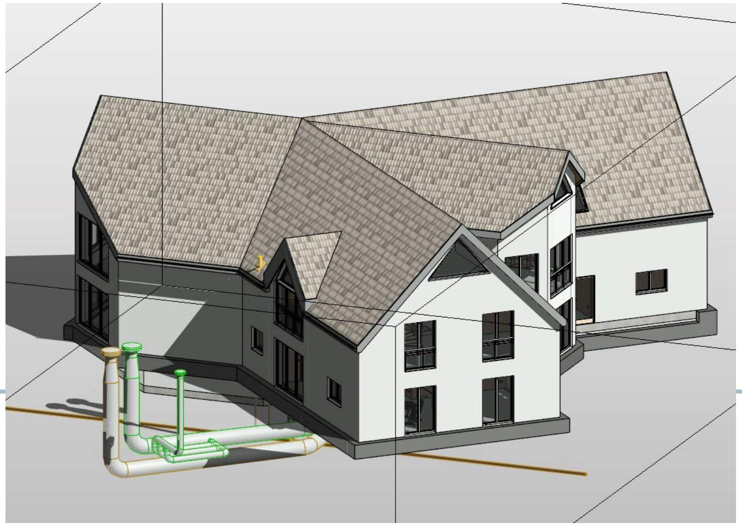
Case example

Available design information:

- P&I diagramms
- Case of an air handling unit

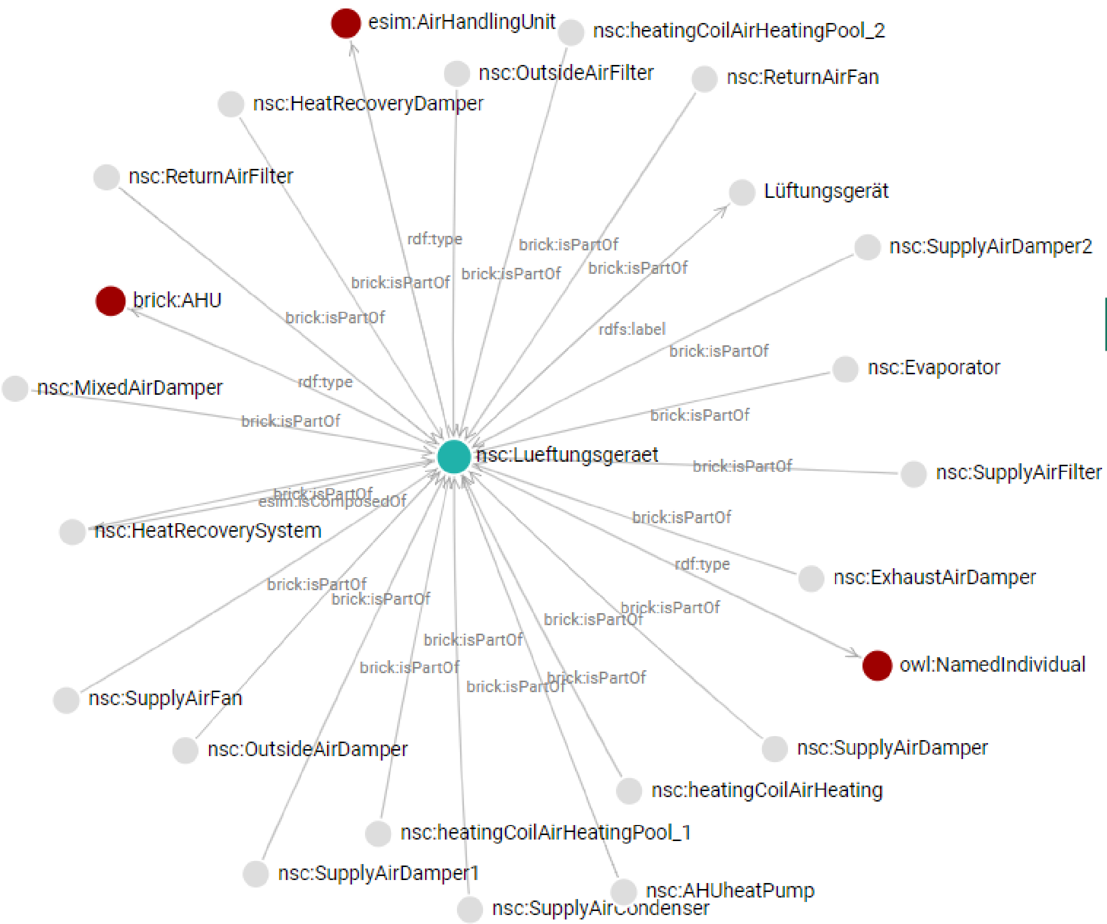


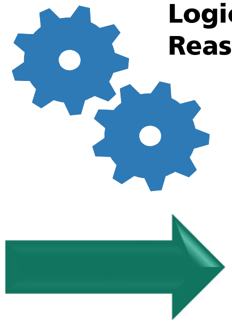




Semantic reasoning for one air handling unit

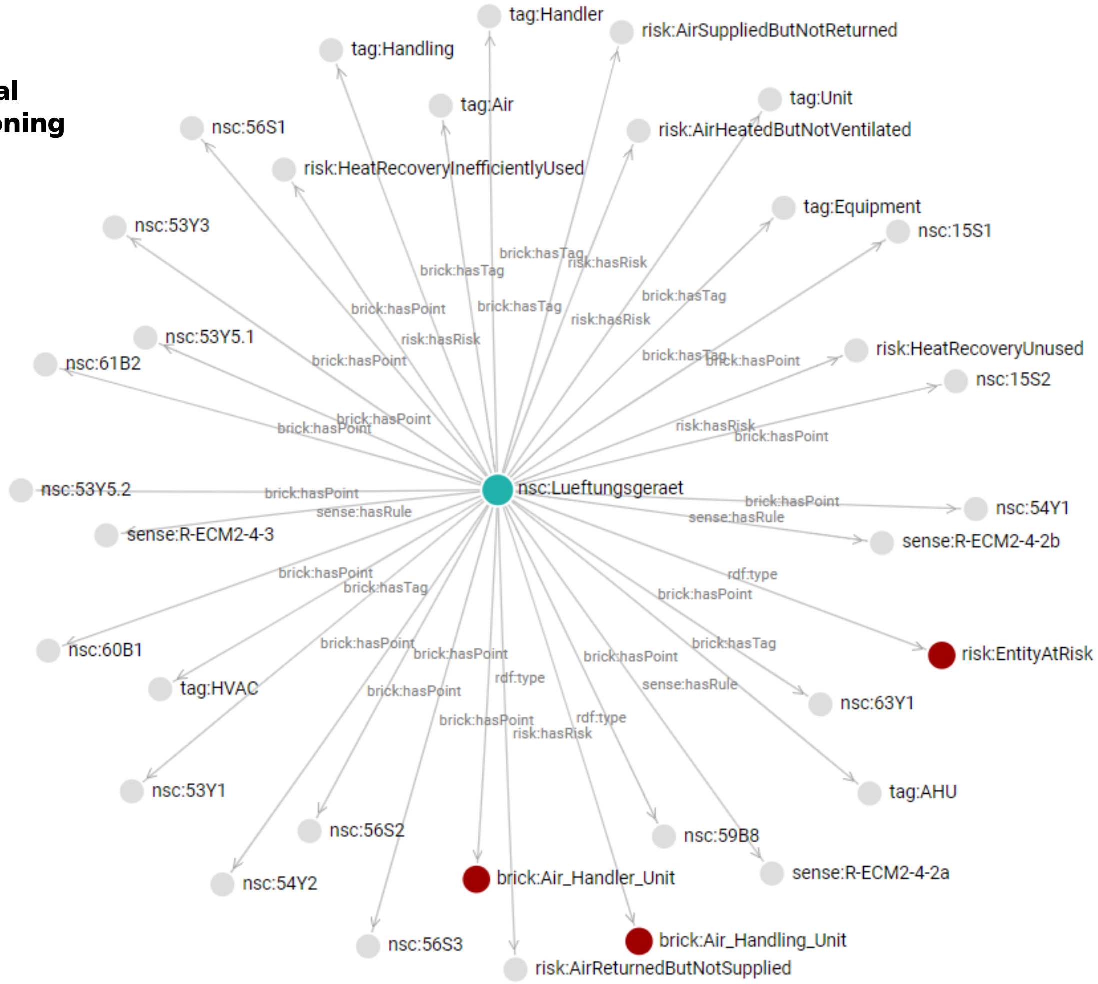
Asserted facts





Logical Reasoning

Inferred facts



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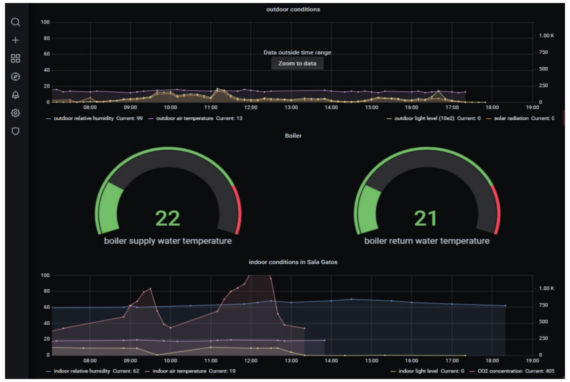
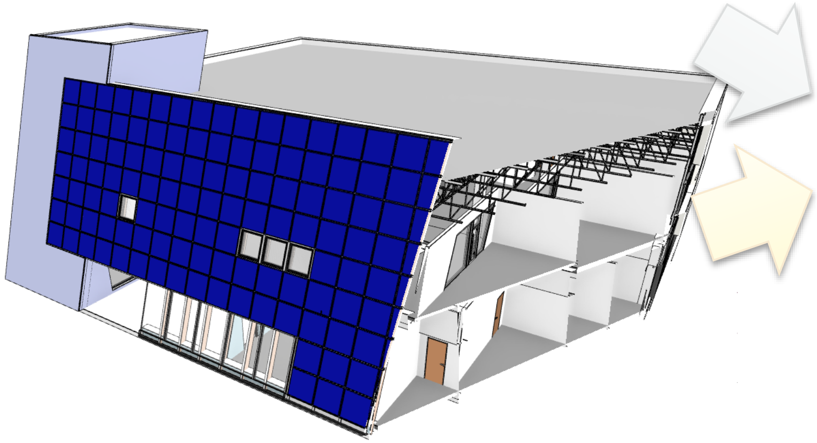
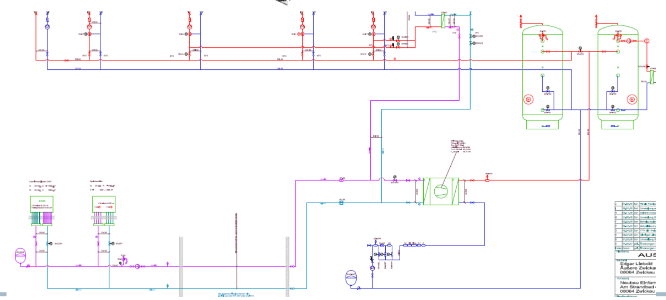
Implementation







Monitoring System Back-End Storage

Import

Fact Base

cached data

monitoring metadata

building metadata

Building elements topology:

- site
- building
- zone
- storey
- room
- component
- system

relations to building topological elements

Rule Set
r1: A(?x) -> C(?x)
r2: C(?x) -> A(?x)
…

Knowledge Base

Processing Module

- *recommendation x_0*
- *recommendation x_1*
- *recommendation x_n*
- …

export

Front-End App

<u>**3 levels of processing (asynchronous):**</u>

- ***<u>1st level</u>: system characterization (metadata processing)***
  - Ontological rules used for system characterization
- ***<u>2nd level</u>: state interpretation (data processing)***
  - Functions for interpretation of operational conditions
- ***<u>3rd level</u>: procedural rules (post-processing):***
  - Generate warnings / recommendations on basis of system characterization and state interpretation

- Selection of energy-optimized control strategies, energy conservation measures
- Operational state of HVAC system and components: energy wastes, malfunctions, failures…
- Configuration of BACS system

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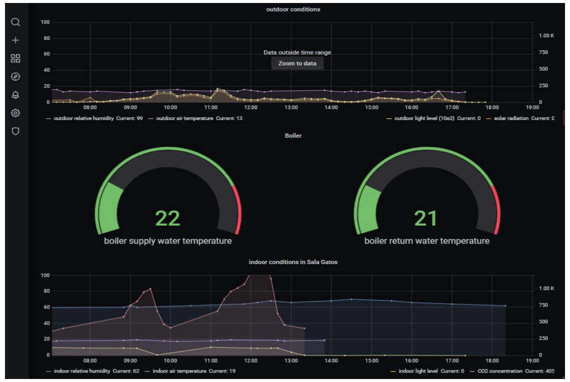
Implementation



Monitoring System Back-End Storage

SQL

Import

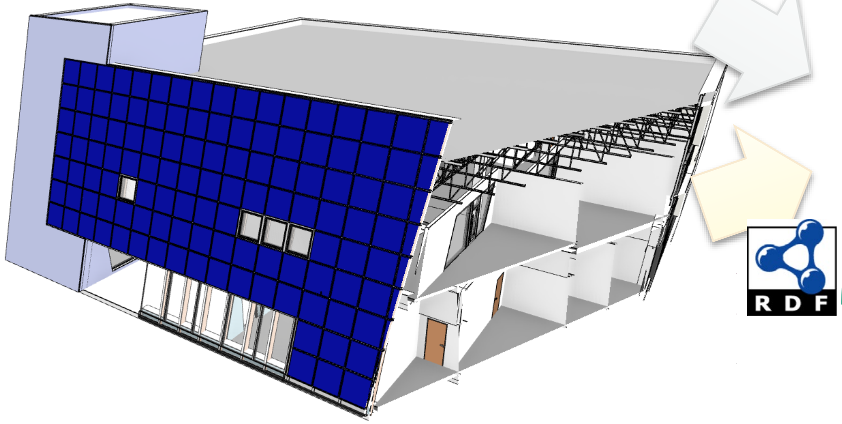
Fact Base

cached data

monitoring metadata

building metadata

RDF



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Processing Module

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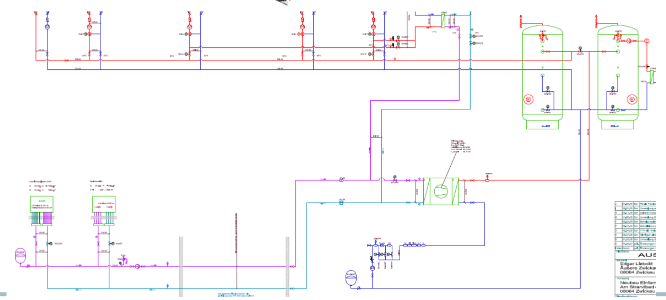
export

Front-End App

REST API

{JSON}



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W3C OWL

- Selection of energy-optimized control strategies, energy conservation measures
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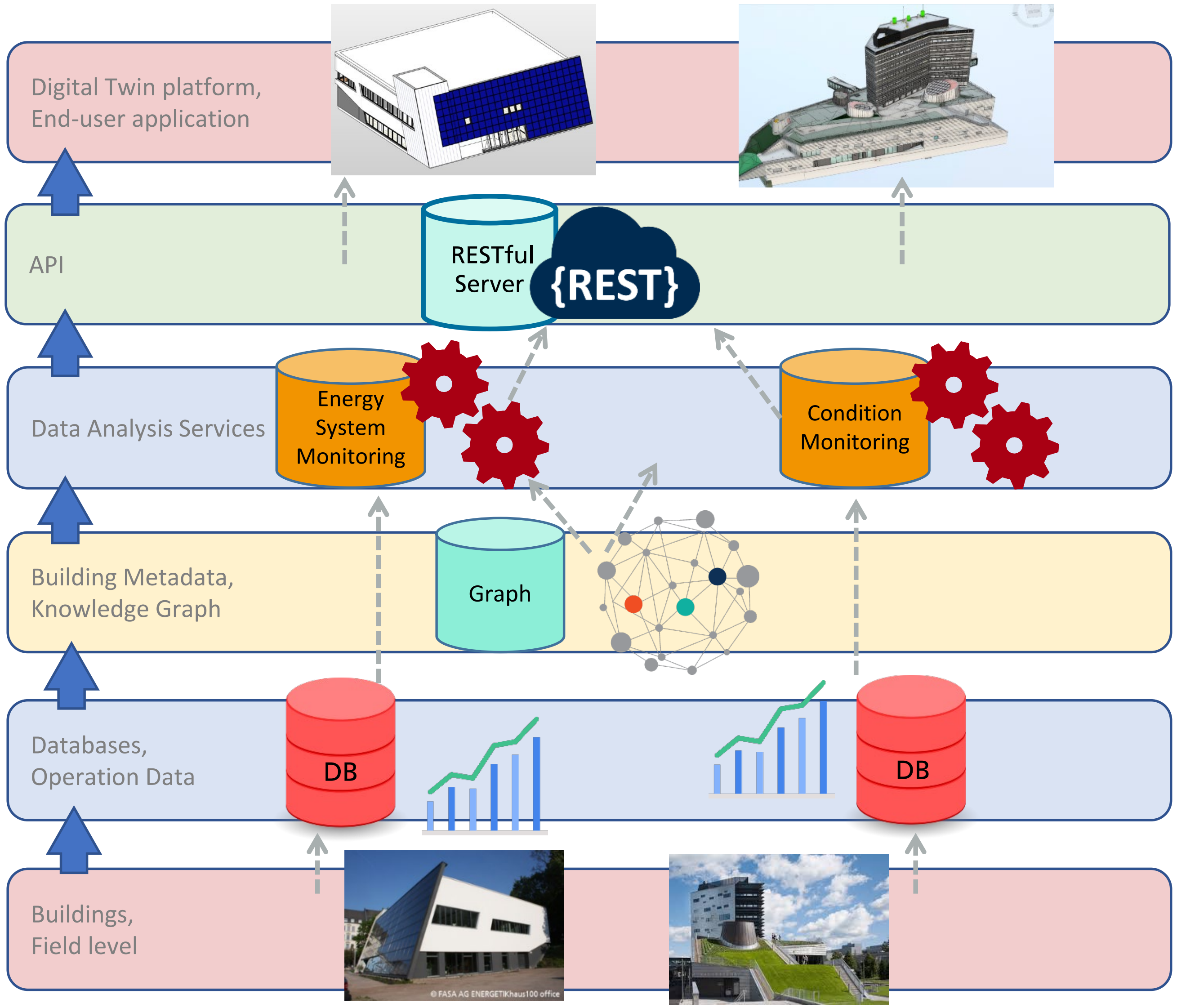
- Configuration of BACS system

Implementation: Layered Software Architecture



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Acknowledgment: eTEACHER project (H2020 IA)

FINISHED

- Prototype recommendation system deployed in a SaaS model
- Database-driven workflow
- Standard Web Interface (OPC-UA, REST) for communication between Expert System and Building Monitoring Data Storage (12 buildings).
- REST API for transfer of results over the web to end-user App (Front-End):


Locations Different buildings and their structural elements

- POST `/locations` add a location
- GET `/locations` get locations
- GET `/locations/{locationId}` get a location
- PUT `/locations/{locationId}` update a location
- DELETE `/locations/{locationId}` delete a location

Metrics Available metrics from digital twin (real or computed data)

Recommendations Advices provided by the Artifical Intelligence for specific locations

- POST `/recommendations` add a recommendation
- GET `/recommendations` get recommendations
- POST `/recommendations/template` add a recommendation template
- GET `/recommendations/template` Get recommendation templates
- GET `/recommendations/{recommendationId}` get a recommendation
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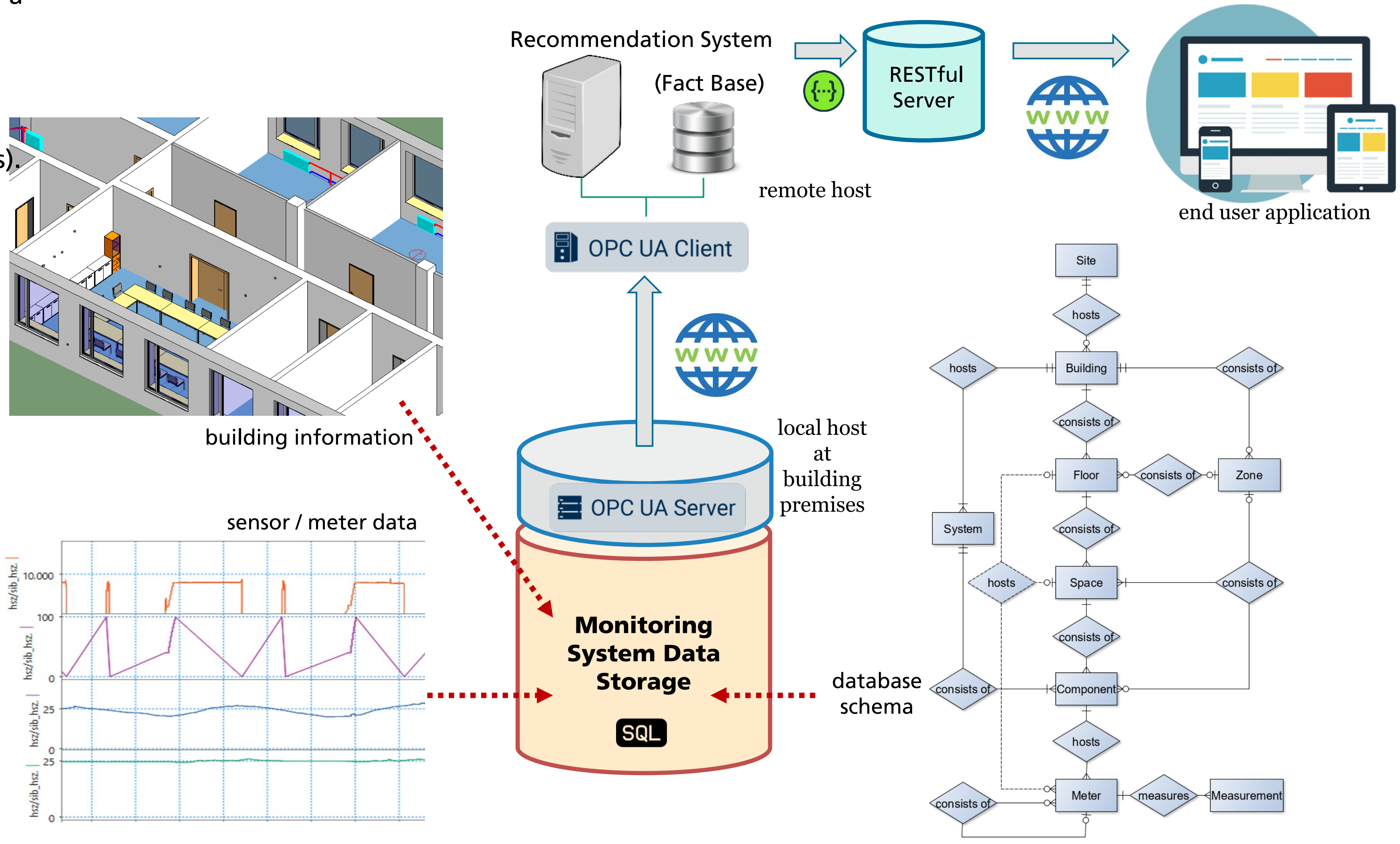
Notifications Messages that are relevant to specific locations



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FINISHED

Acknowledgment: eTEACHER project (H2020 IA)

REST API:

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Notifications Messages that are relevant to specific locations

REST API

OAR - Floor 2

Project Begin: | Project End:

SORT FILTER ARCHIVE

It seems there is no activity here anymore. Turn off cooling if you no longer need that room.
(save energy when facility not occupied)
22.05.2020, 16:49:20
22.05.2020, 16:49:20
OPEN

This space is unused since a while but some devices are still consuming energy in there. Please turn off these appliances.
(save electrical energy turning appliances down when room unoccupied)
22.05.2020, 16:45:27
22.05.2020, 16:45:27
OPEN

The room seems unoccupied but some light was left on. Please turn off light if you don't use that room anymore.
(save lighting energy turning off lights when space unoccupied)
22.05.2020, 16:40:45
22.05.2020, 16:40:45
OPEN

Do you really need the lights on, make use of natural light.
(save lighting energy)
22.05.2020, 14:00:40
22.05.2020, 14:00:40
OPEN

Take advantage of daylight. Open the blinds and turn lights down . You may save energy.
(save lighting energy)
22.05.2020, 14:00:40
22.05.2020, 14:00:40
OPEN

(Save energy when facility not occupied)
It seems there is no activity here anymore. Turn off cooling if you no longer need that room.

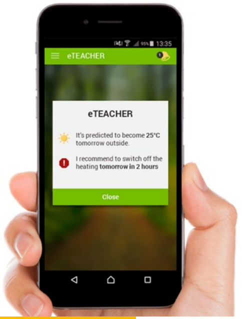
22.05.2020, 16:49:20

Saving Potential:

By following this recommendation you would save cooling energy in terms of kWh/(m2.a).

You could save up to 14 % of this resource if you turn off cooling if you no longer need that room.

Your total saving potential will be 14 %



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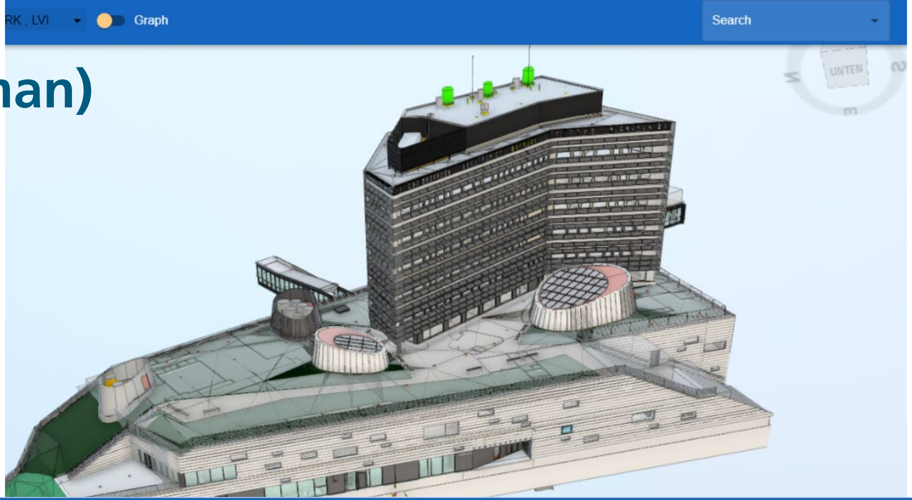
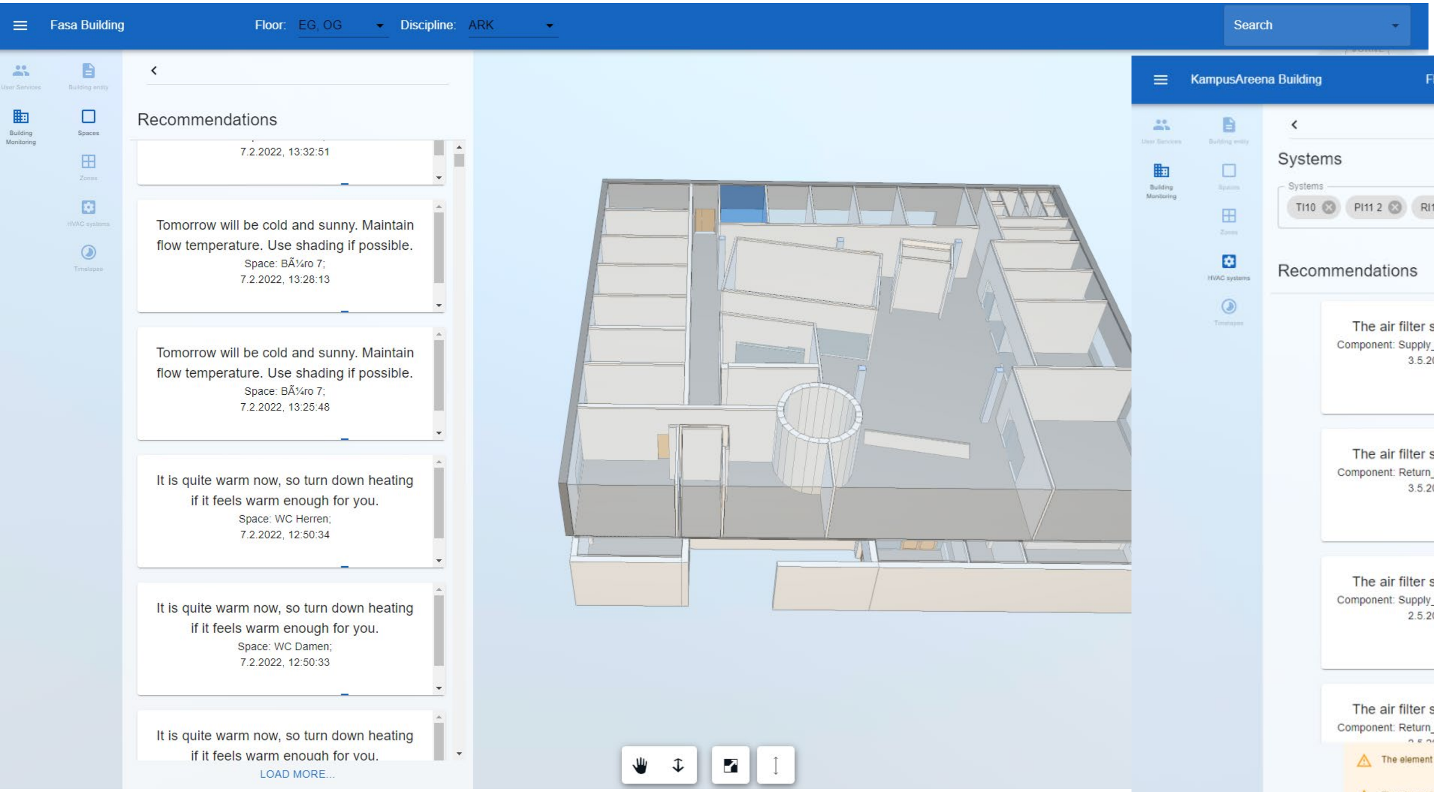
FINISHED

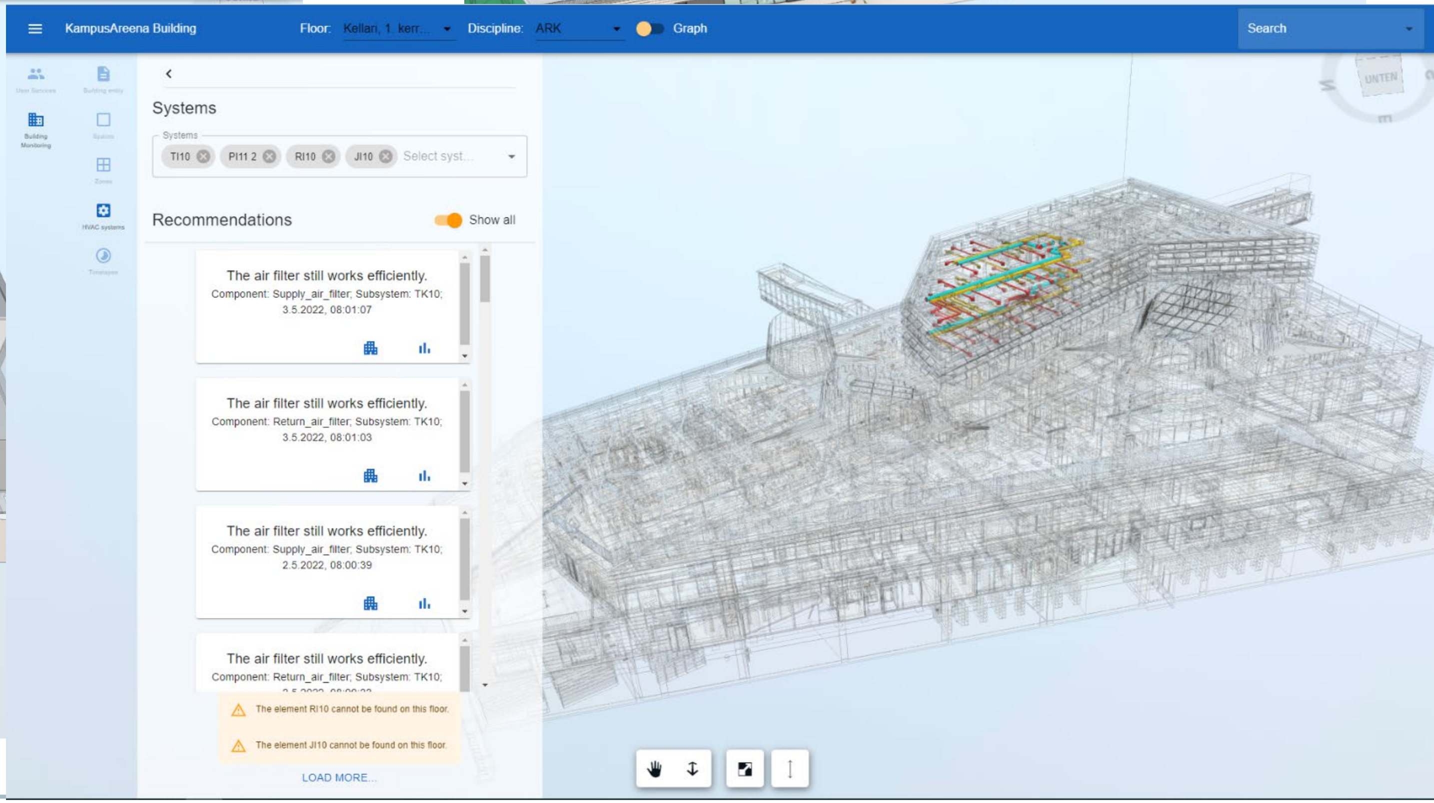
Acknowledgment: BIMLIFE project (EU Set-Plan Finnish / German)

- Target application -> Reuse of BIM into a Digital Twin for Energy Assistance and predictive maintenance
- Software platform: „Granlund Manager“

  -> https://www.granlundgroup.com/news/data-driven-building-is-future-proof/







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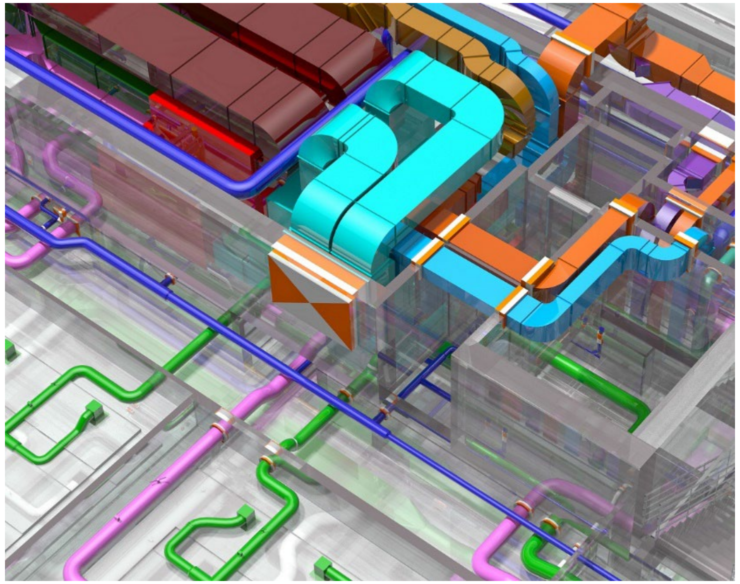
Ongoing project: SKAMO (BMWi, N5GEH Project)

- Target application -> Integration of IoT and legacy BACS systems into the workflow

Munich airport

- Automated FDD in HVAC systems
- When provisioning new sensors -> their data points and related metadata automatically integrated into the semantic digital twin
- And into relevant FDD and energy monitoring functions
- Use of „FIWARE“ IoT Stack as background
- 3 Pilot buildings on airport site



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Publications

ASCE

Ontology-Based Expert System for Automated Monitoring of Building Energy Systems

Smart Infrastructure and Construction

ice Publishing

A recommendation system for energy saving and user engagement in existing buildings

Journal / Conference Proceedings

Journal articles:

Pruvost, H., Wilde, A., & Enge-Rosenblatt, O. (2023). **Ontology-Based Expert System for Automated Monitoring of Building Energy Systems.** Journal of Computing in Civil Engineering, 37(1), https://doi.org/10.1061/(ASCE)CP.1943-5487.0001065

Pruvost, H., Calleja-Rodríguez, G., Enge-Rosenblatt, O., Jiménez-Redondo, N., & Peralta-Escalante, J. J. (2022). **A recommendation system for energy saving and user engagement in existing buildings.** Proceedings of the Institution of Civil Engineers-Smart Infrastructure and Construction, 176(1), https://doi.org/10.1680/jsmic.21.00023

Pruvost, H., & Scherer, R. J. (2017). Analysis of risk in building life cycle coupling BIM-based energy simulation and semantic modeling. Procedia engineering, 196, 1106-1113, Elsevier, https://doi.org/10.1016/j.proeng.2017.08.068

Papers:

Pruvost, H., Forns-Samso, F., Gnepper, O., & Enge-Rosenblatt, O. (2023, October). **Integrating Energy System Monitoring and Maintenance Services into a BIM-Based Digital Twin.** In IECON 2023-49th Annual Conference of the IEEE Industrial Electronics Society (pp. 1-6). IEEE, https://doi.org/10.1109/IECON51785.2023.10311659

Pruvost, H., & Wilde, A. (2023, May). **Ontologies for Formalizing the Process of Configuring and Deploying Building Management Systems**. In European Semantic Web Conference (pp. 205-209). Cham: Springer Nature Switzerland, https://doi.org/10.1007/978-3-031-43458-7_39

Pruvost, H., & Enge-Rosenblatt, O. (2022). **Using ontologies for knowledge-based monitoring of building energy systems**. In Computing in Civil Engineering 2021 (pp. 762-770), https://doi.org/10.1061/9780784483893.094

Pruvost, H., Enge-Rosenblatt, O., & Haufe, J. (2018, October). **Information integration and semantic interpretation for building energy system operation and maintenance**. In IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society (pp. 813-818). IEEE, https://doi.org/10.1109/IECON.2018.8591740

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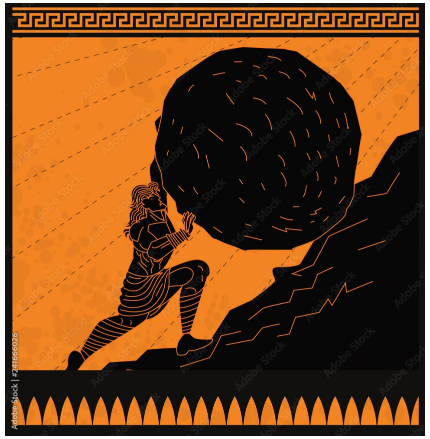
Conclusion

- **Method:**
  - Take benefit of building design information in commissioning and operation (available digital model as preliminary condition)
  - Model-based approach for bringing flexibility
    - new building -> new model, but same tool chain and same knowledge
  - Formalize expert knowledge, using risk Paradigm
- **Potential industrial application:**
  - Support for BMS designer by saving design time and setup time
  - Deploy Monitoring System for facility manager & building users
  - Normalized Data Structure for Digital Twins
  - Faster deployment and spreading of BMS, FDD and Energy digital services for energy saving and carbon emissions reduction at larger scale
- **Barriers:**
  - Metadata availability
  - Graph generation should be automatic, not the case yet
  - Solutions: BIM, ML, Standardization…
- **Forthcoming:**
  - Ongoing projects: SKAMO (BMWi, N5GEH Project) and iECO (BMWi, GAIA-X)
  - Automated provisioning of sensors into the semantic digital twin
  - Reuse of „FIWARE“ Stack as IoT framework
  - BIM2FM workflow
  - PhD



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THANK YOU FOR YOUR ATTENTION

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