SSoLDAC-22

Smart Energy Applications

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Associate Professor in Smart Buildings and Digital Engineering

The Bartlett Institute for Environmental Design and Engineering, University College London (UCL)

Academic excellence

30 Nobel laureates
11 academic faculties
43,800 students
14,300 employees
2nd in UK for research power (REF 2021)
440 undergraduate programmes
150+ nationalities represented
by student body
675 postgraduate programmes

Rankings:

8th in the world (QS 2022)
4th in Europe
4th in the UK

The Bartlett

UCL's global faculty of the built environment
Largest postgraduate faculty in the UK
Ranked 1st (2020) and 3rd (2021)
Over 350 academics in 13 Schools and Institutes:

- Architecture
- Construction & Project Management
- Development Planning Unit (DPU)
- Planning
- **Environment, Energy and Resources**

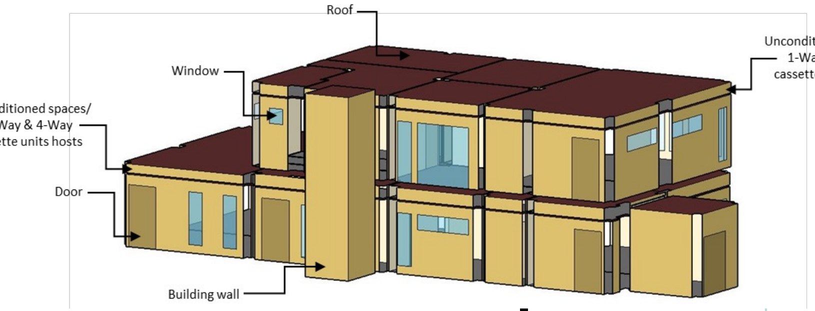
Dimitrios Rovas

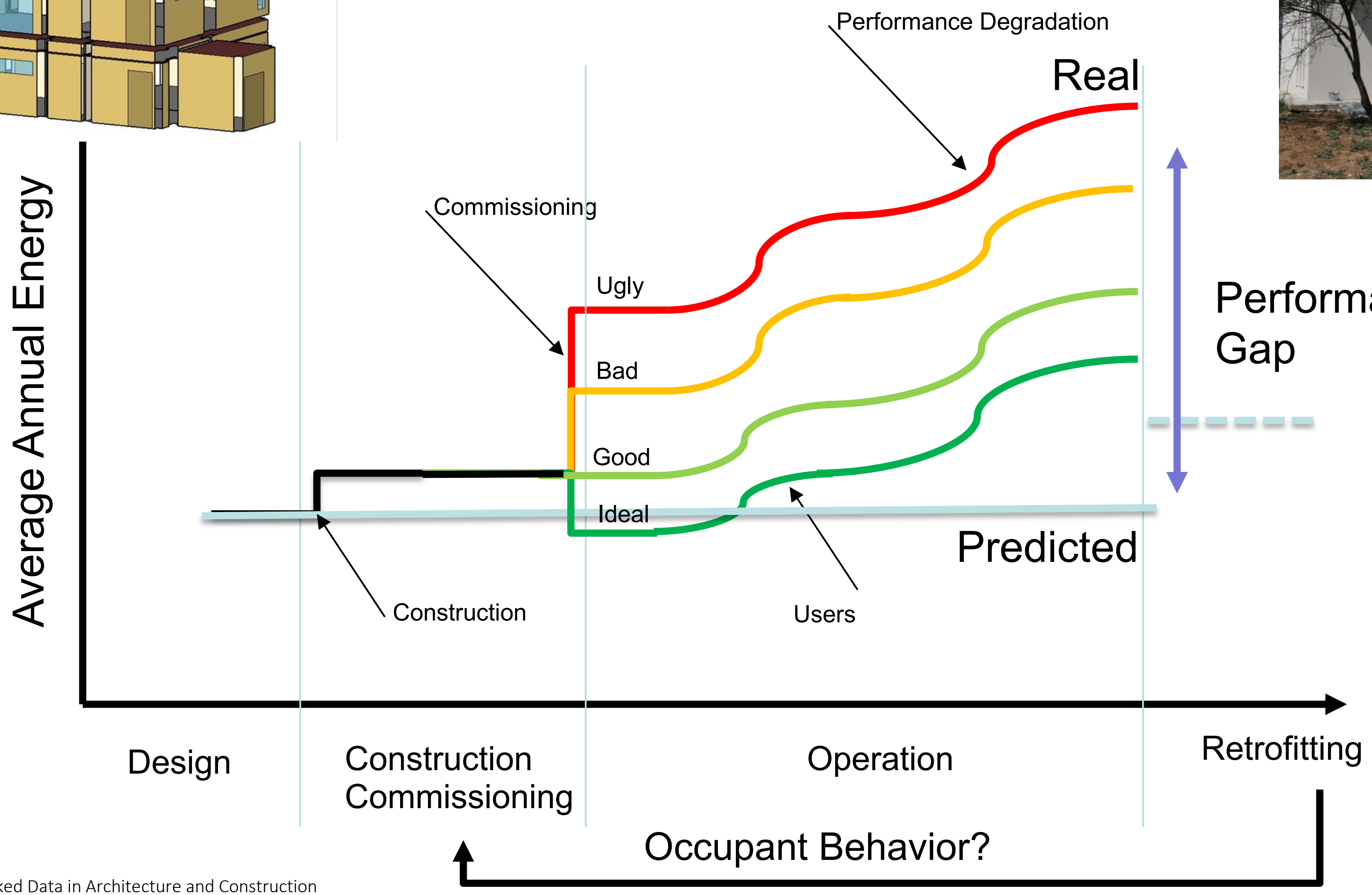
Associate Professor
The Bartlett School of Environment, Energy and Resources
University College London, UK

Background:
Mechanical Engineering/Applied Math

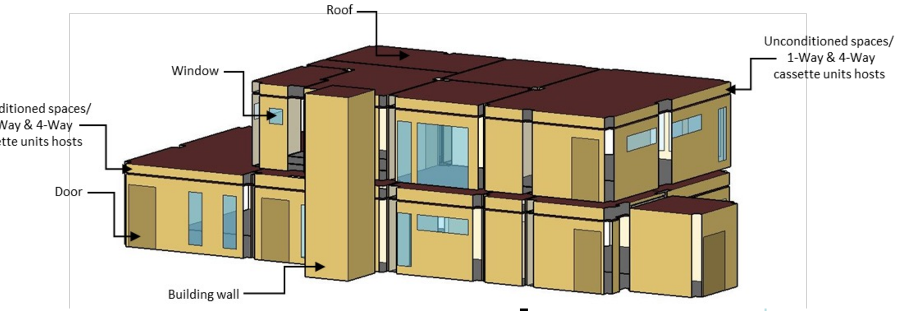
Leading activities in:
Group on Smart Buildings and Digital Engineering
Developed MSc SBDE
Co-leading IEA Annex 81 (Data-driven Smart Buildings)
Several HE/H2020/UK projects in the space

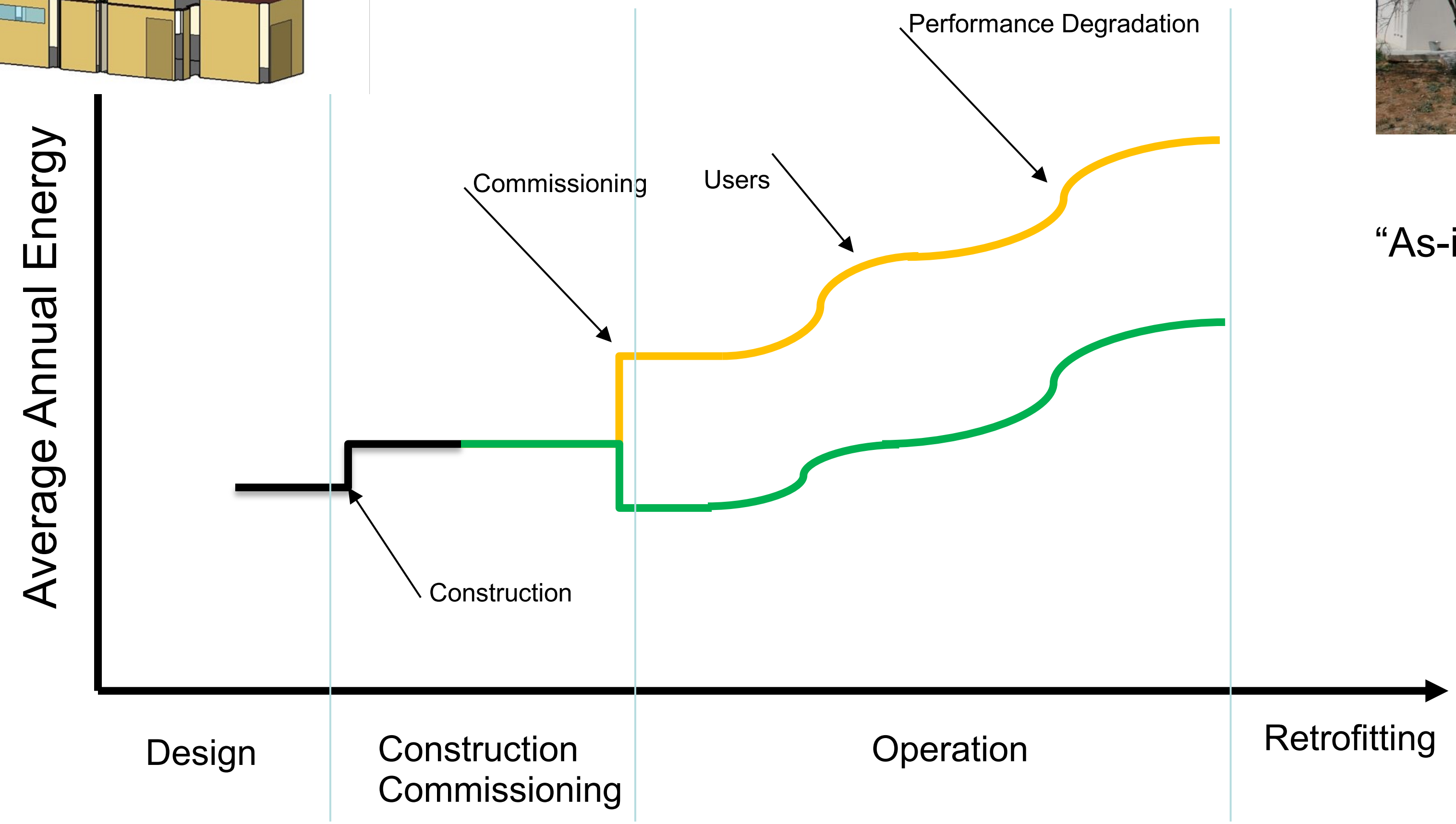
Context: Energy Monitoring and Modelling





Context: Existing buildings, Performance Gap





"As-is"

Building Energy Management Systems (BEMS)

-

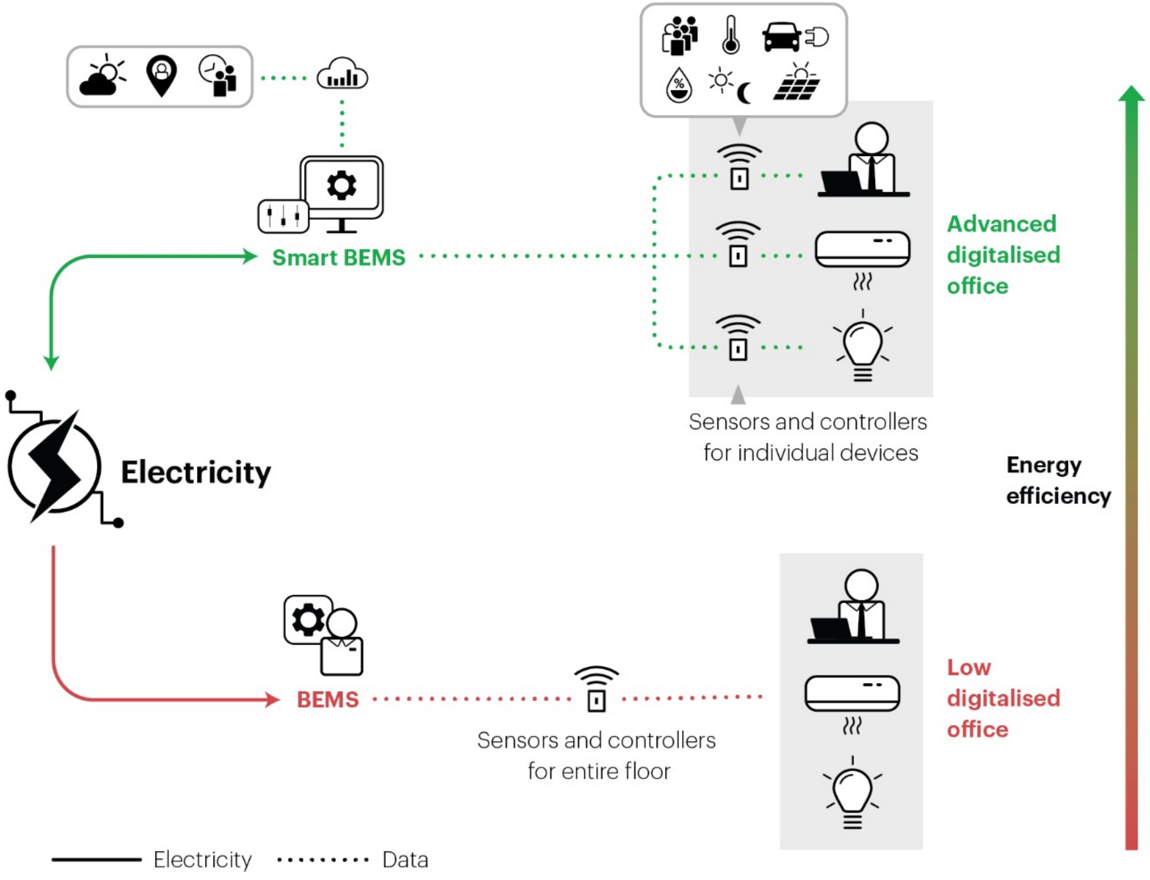
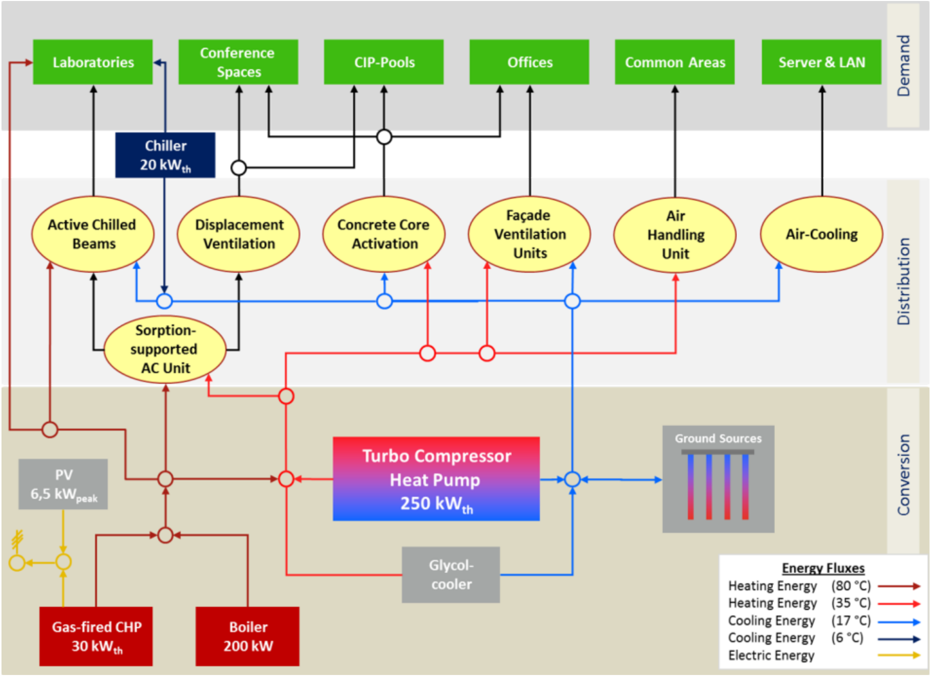


Image source: Energy Efficiency 2019, IEA



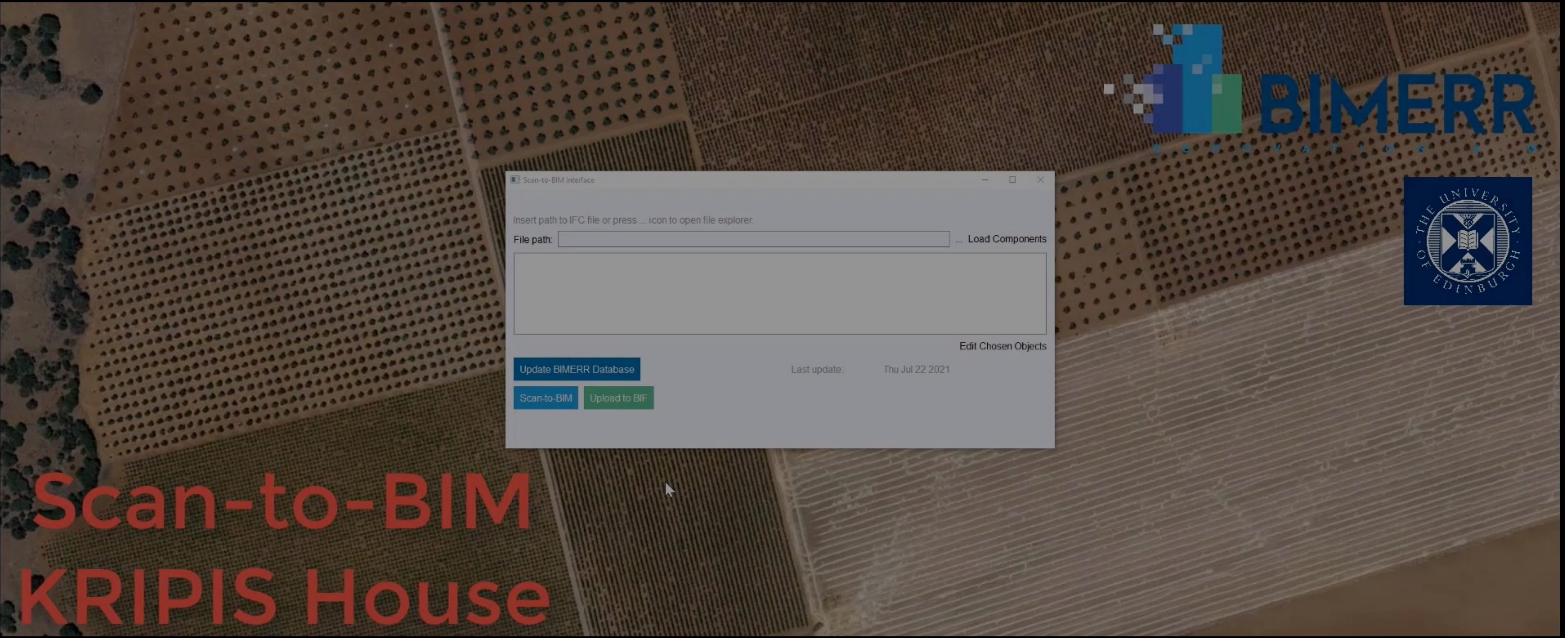
Source: PEBBLE, FP7

Built Environment Digital Twins Maturity Levels

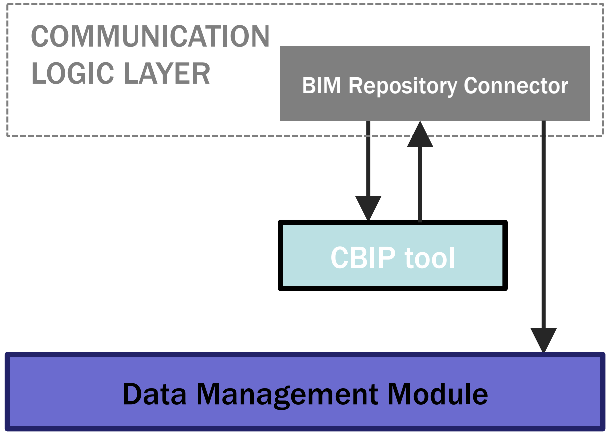
Element (logarithmic scale of complexity)	Defining principle	Outline usage
0	Reality capture	As-built survey
1	2D map/system or 3D model	Design/asset optimisation and co-ordination
2	Static data, metadata and BIM Stage 2	4D / 5D simulation
3	Real-time data	Operational efficiency
4	Two-way data integration and interaction	Remote and immersive operations
5	Autonomous operations and maintenance	Self-governance, over-sight and transparency

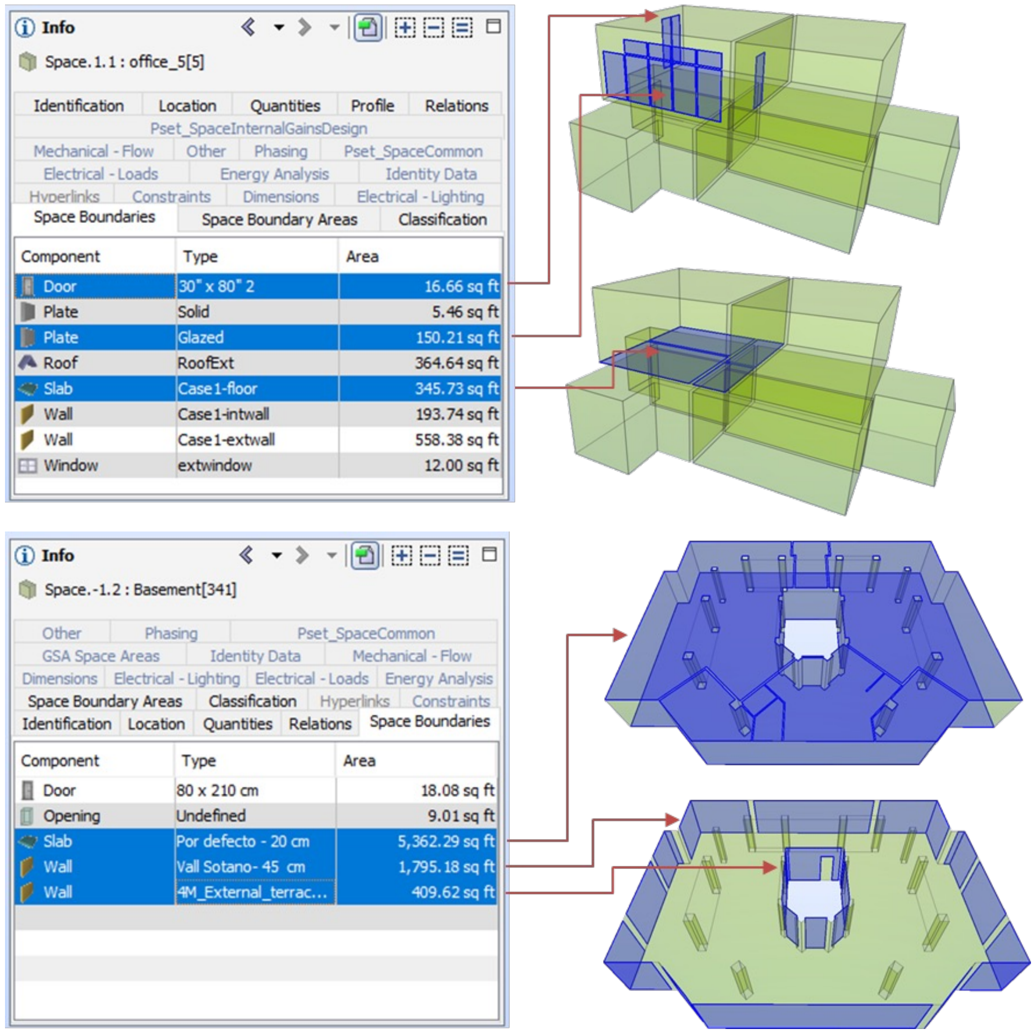
Digital twin – A realistic digital representation of assets, processes or systems, in the built or national environment. The complexity of that representation, and degree of connectedness, varies depending on maturity

Source: IET Digital Twins for the Built Environment

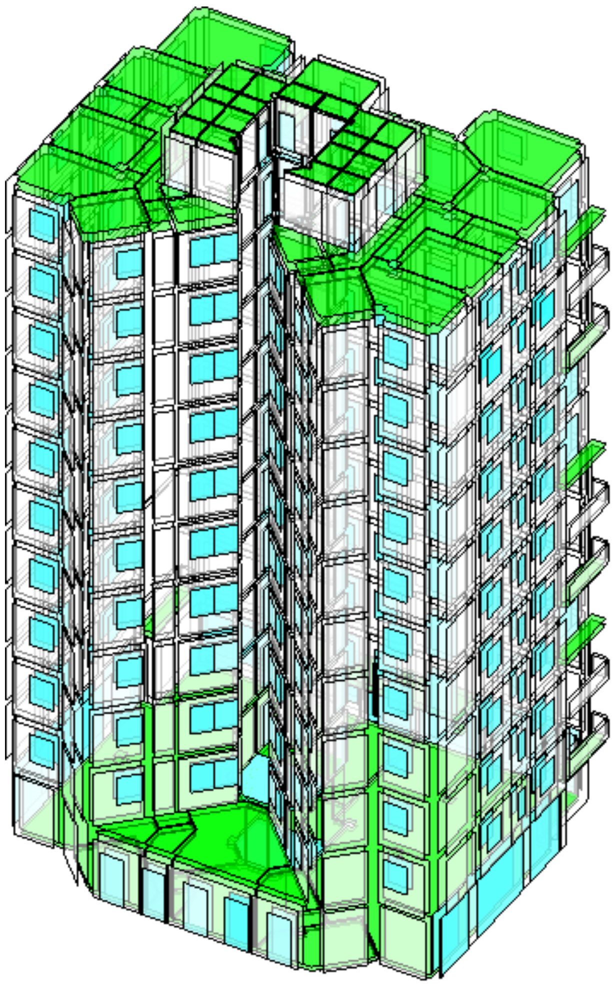

BIMERR
Scan-to-BIM Interface
Insert path to IFC file or press ... icon to open file explorer.
File path:
... Load Components
Edit Chosen Objects
Update BIMERR Database
Last update:
Thu Jul 22 2021
Scan-to-BIM
Upload to BIF
Scan-to-BIM
KRIPIS House

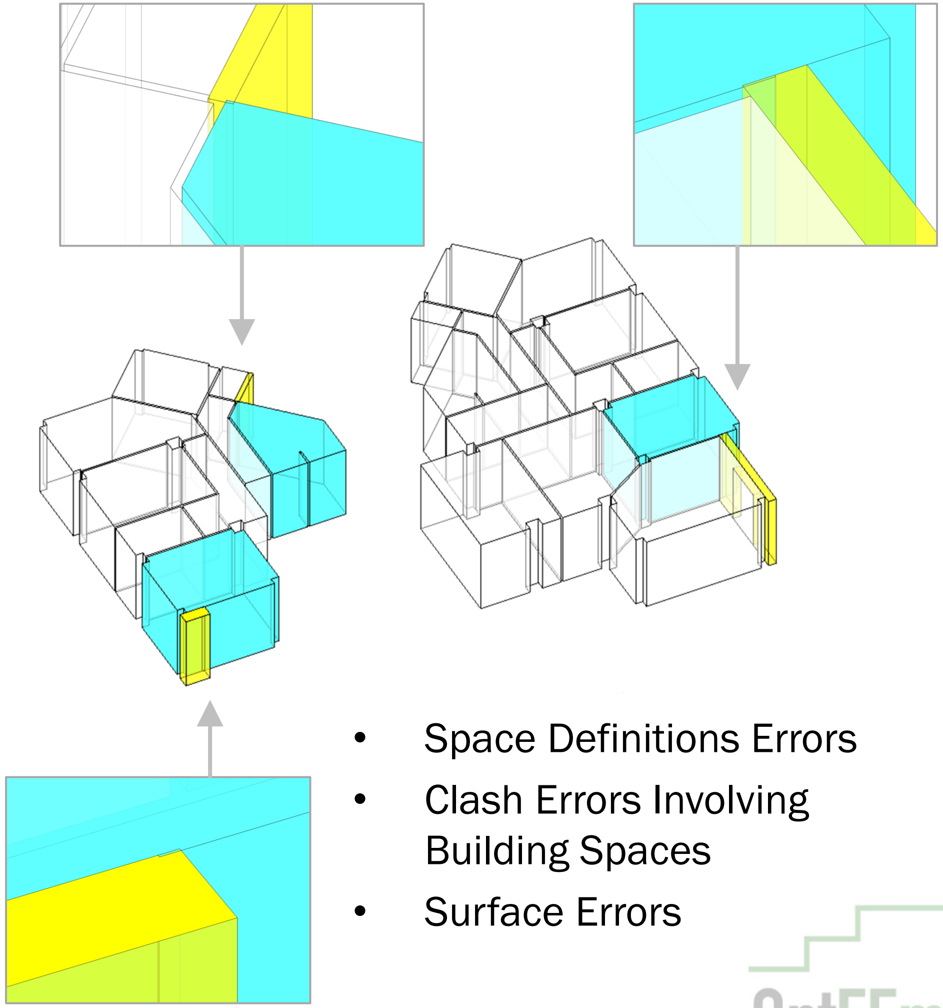
Semantic Enrichment: 2nd-level space boundaries





Semantic Enrichment: Error correction

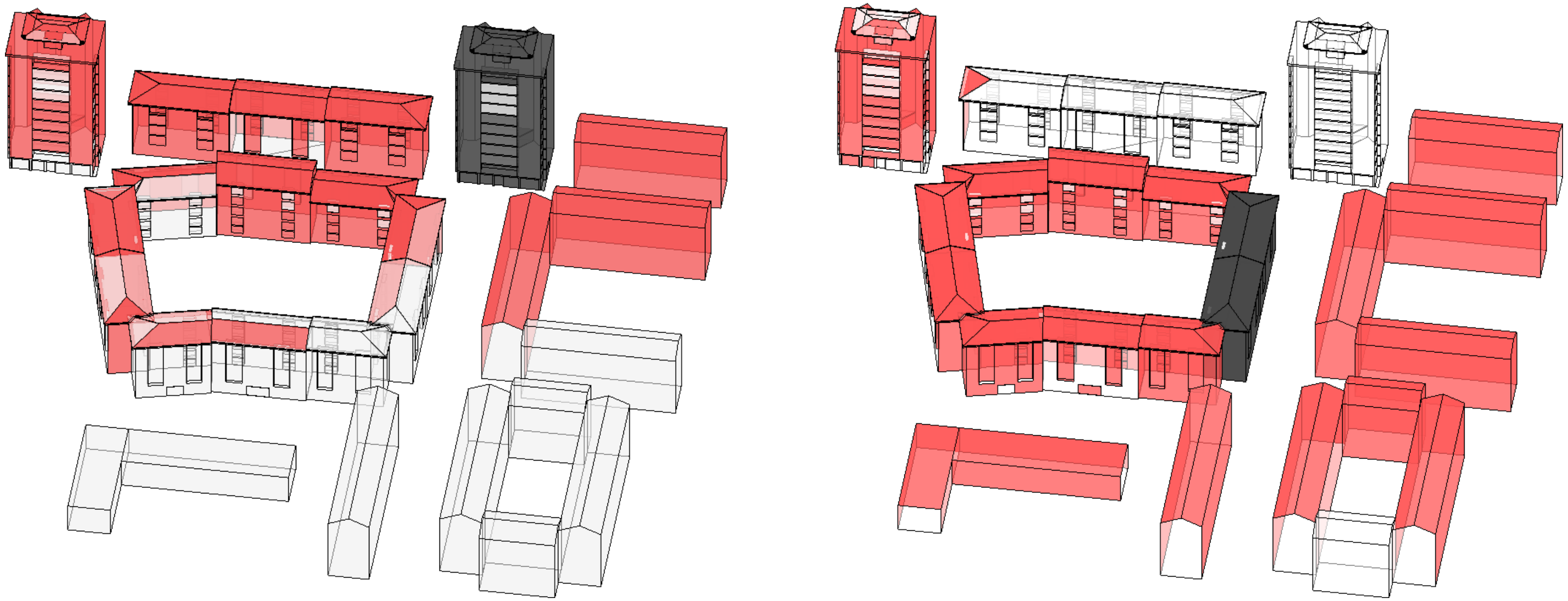




- Space Definitions Errors
- Clash Errors Involving Building Spaces
- Surface Errors

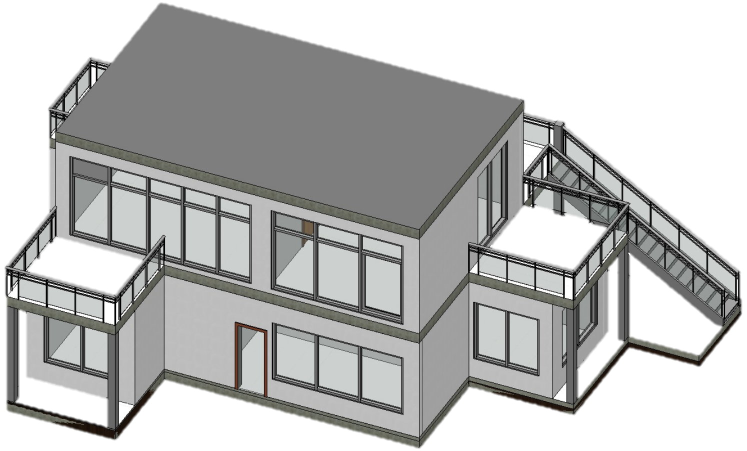
OPTIMISED ENERGY EFFICIENT DESIGN PLATFORM FOR REFURBISHMENT AT DISTRICT LEVEL

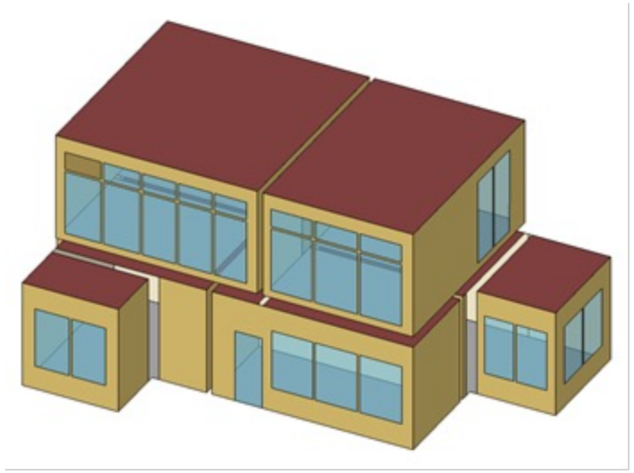
Semantic Enrichment: Data integration



CityGML

Energy model generation





BIM Model

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ISO-10303-21;
HEADER;

FILE_DESCRIPTION(('ViewDefinition [DesignTransferView_V1.0]'),'2;1');
FILE_NAME('Project Number','2017-09-14T15:02:31',(''),(''),'The EXPRESS Data Manager Version 5.02.0100.07 : 28 Aug 2013','2017063
FILE_SCHEMA(('IFC4'));
ENDSEC;

DATA;
#1= IFCORGANIZATION($,'Autodesk Revit 2018 (ENU)',$,$,$);
#5= IFCAPPLICATION(#1,'2018','Autodesk Revit 2018 (ENU)','Revit');
#6= IFCCARTESIANPOINT((0.,0.,0.));
#10= IFCCARTESIANPOINT((0.,0.));
#12= IFCDIRECTION((1.,0.,0.));
#14= IFCDIRECTION((-1.,0.,0.));
#16= IFCDIRECTION((0.,1.,0.));
#18= IFCDIRECTION((0.,-1.,0.));
#20= IFCDIRECTION((0.,0.,1.));
#22= IFCDIRECTION((0.,0.,-1.));
#24= IFCDIRECTION((1.,0.));
#26= IFCDIRECTION((-1.,0.));
#28= IFCDIRECTION((0.,1.));
#30= IFCDIRECTION((0.,-1.));
#32= IFCAXIS2PLACEMENT3D(#6,$,$);
#33= IFCLOCALPLACEMENT(#20279,#32);
#36= IFCPERSON($,'','katsigarakis@gmail.com',$,$,$,$,$);
#38= IFCORGANIZATION($,'','',$,$);
#39= IFCPERSONANDORGANIZATION(#36,#38,$);
#42= IFCOWNERHISTORY(#39,#5,$,.NOCHANGE.,$,$,$,1504212861);
#43= IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#44= IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#45= IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#46= IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#47= IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#48= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.0174532925199433),#46);
#49= IFCCONVERSIONBASEDUNIT(#47,.PLANEANGLEUNIT.,'DEGREE',#48);
#51= IFCSIUNIT(*,.MASSUNIT.,.KILO.,.GRAM.);
#52= IFCDERIVEDUNITELEMENT(#51,1);
#53= IFCDERIVEDUNITELEMENT(#43,-3);
#54= IFCDERIVEDUNIT((#52,#53),.MASSDENSITYUNIT.,$);
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BEPS Model

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Version,
    8.7;

SizingPeriod:WeatherFileConditionType,
    SUMMER-EXTREME,
    SummerExtreme,
    Monday,
    Yes,
    Yes;

SizingPeriod:WeatherFileConditionType,
    WINTER-EXTREME,
    WinterExtreme,
    Monday,
    Yes,
    Yes;

Output:Table:SummaryReports,
    AnnualBuildingUtilityPerformanceSummary;

OutputControl:Table:Style,
    XML,
    JtoKWH;

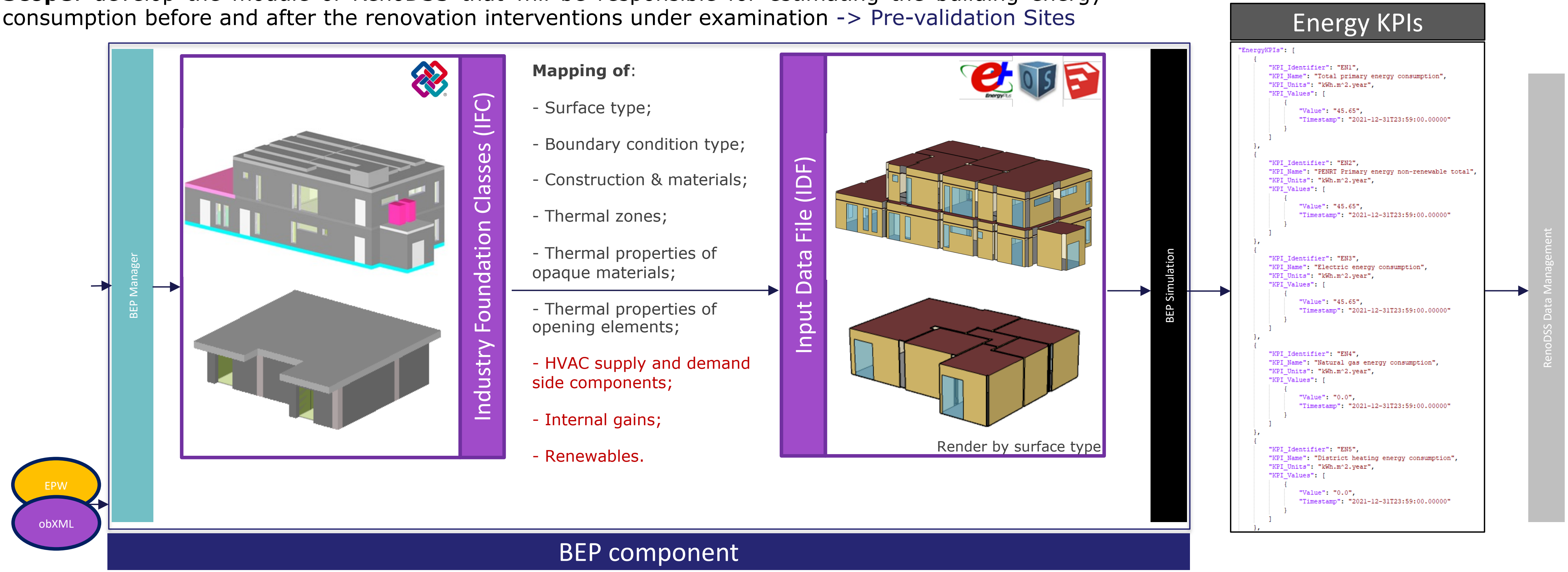
Sizing:Parameters,
    1.2,
    1.2,
    ;

SimulationControl,
    Yes,
    Yes,
    Yes,
    No,
    Yes,
    No,
    1;

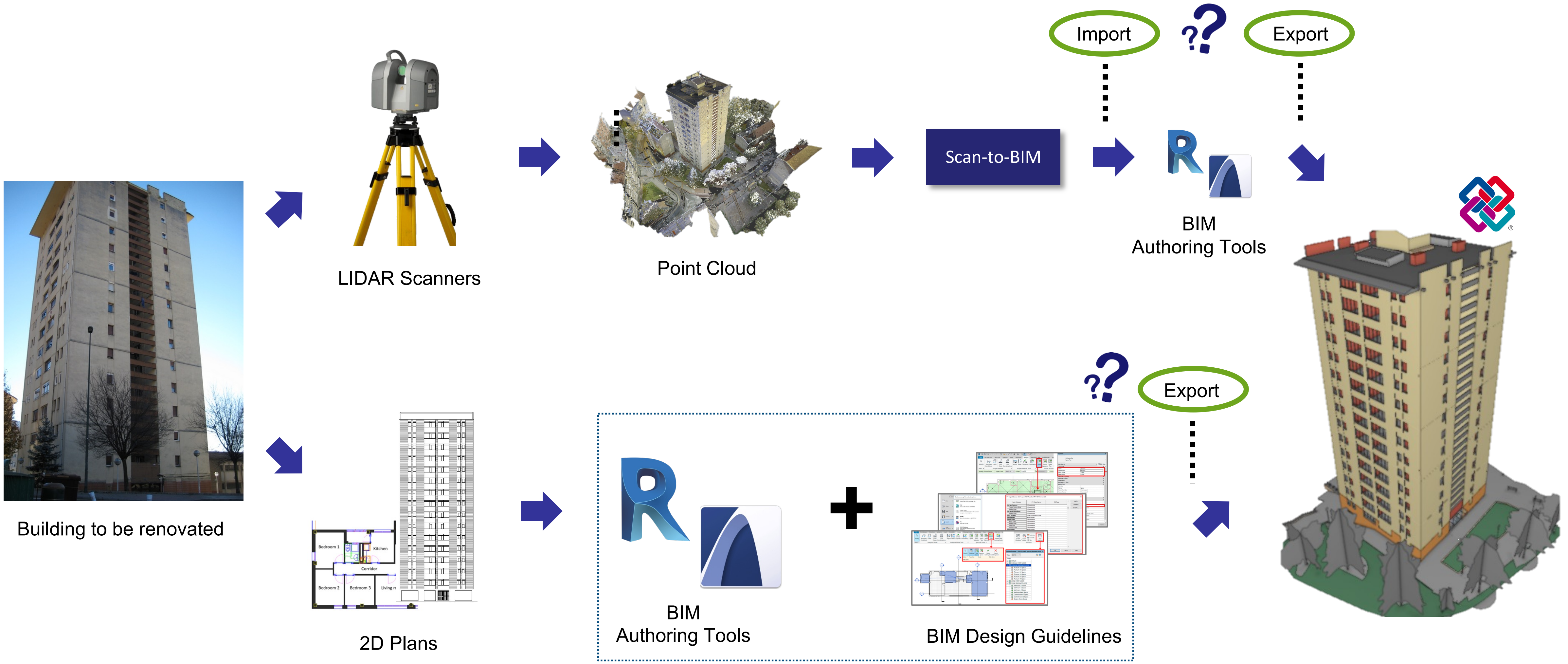
Timestep,
    6;
```

From information to energy models

Scope: develop the module of RenoDSS that will be responsible for estimating the building energy consumption before and after the renovation interventions under examination -> Pre-validation Sites

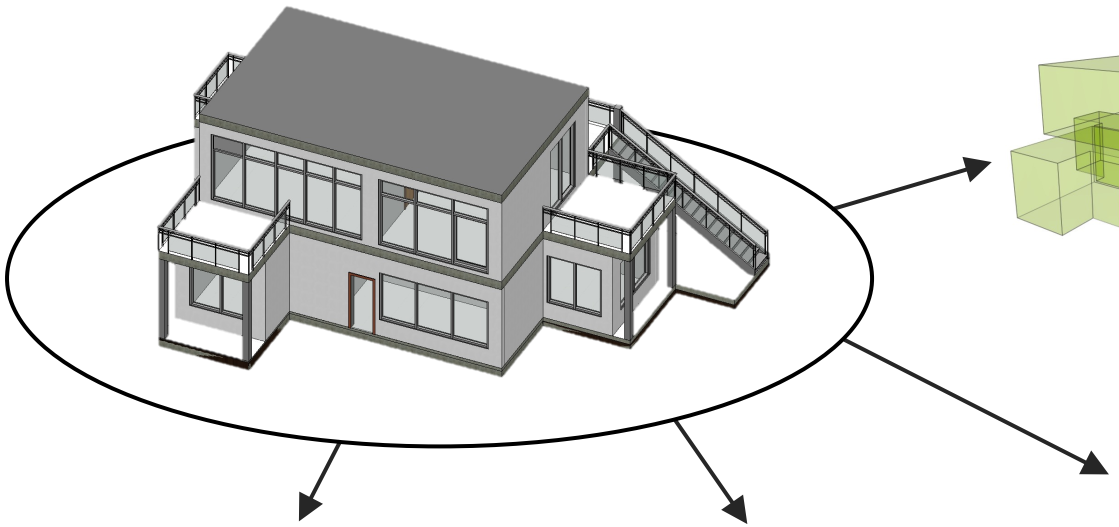


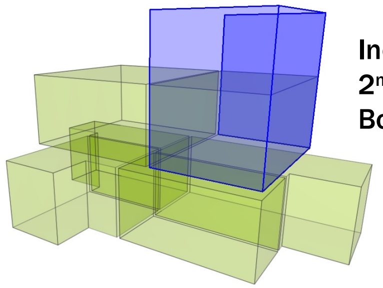
Challenges: Integration with professional BIM tools



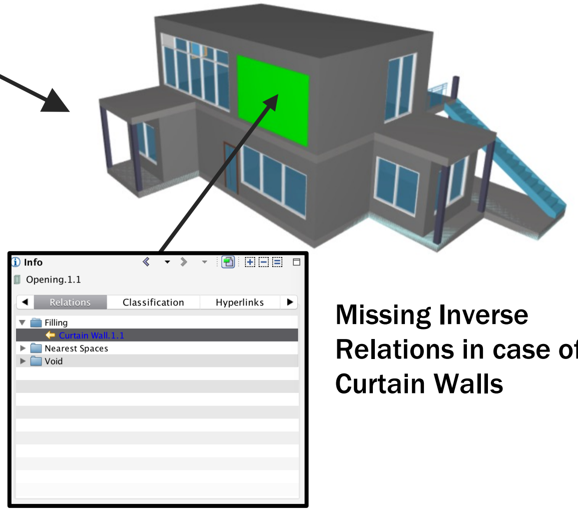
13

Data Quality: Challenges

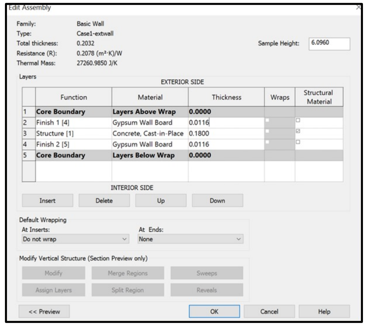




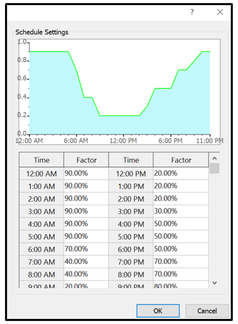
Incorrect or Missing 2nd Level Space Boundaries



Missing Inverse Relations in case of Curtain Walls

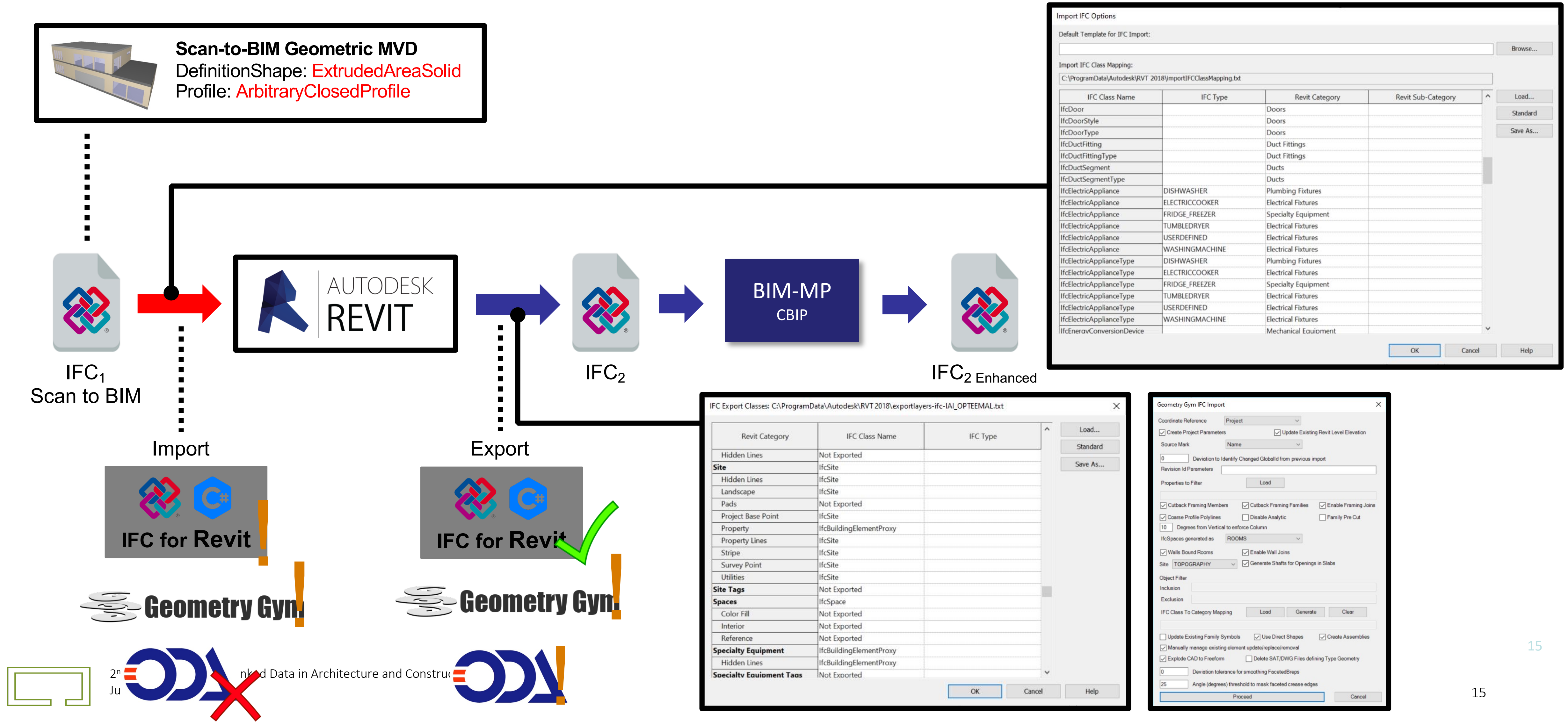


Missing Thermal Properties



Missing Light, Occupancy and Equipment Schedules

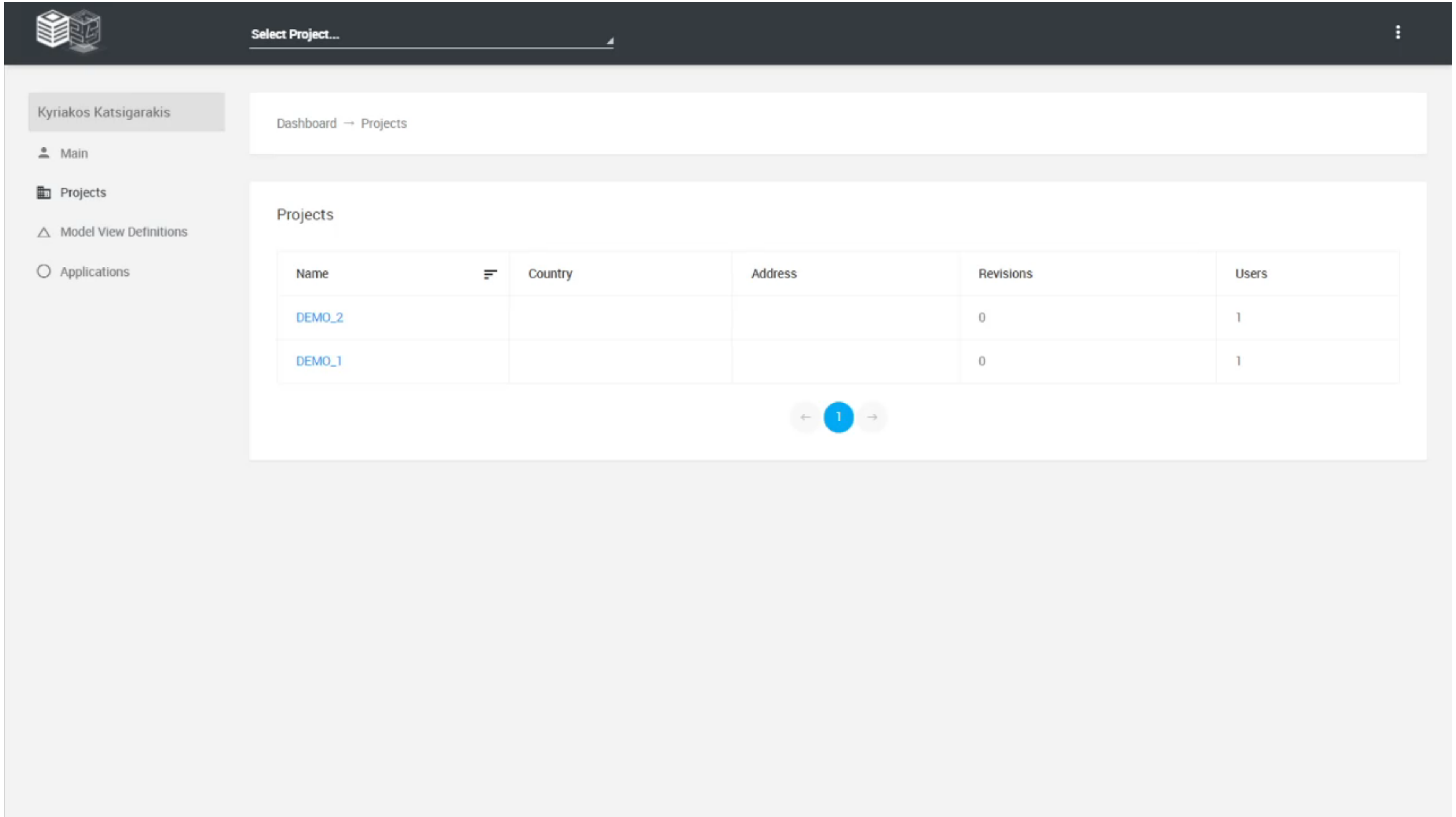
Challenges: Integration with Professional BIM authoring tools



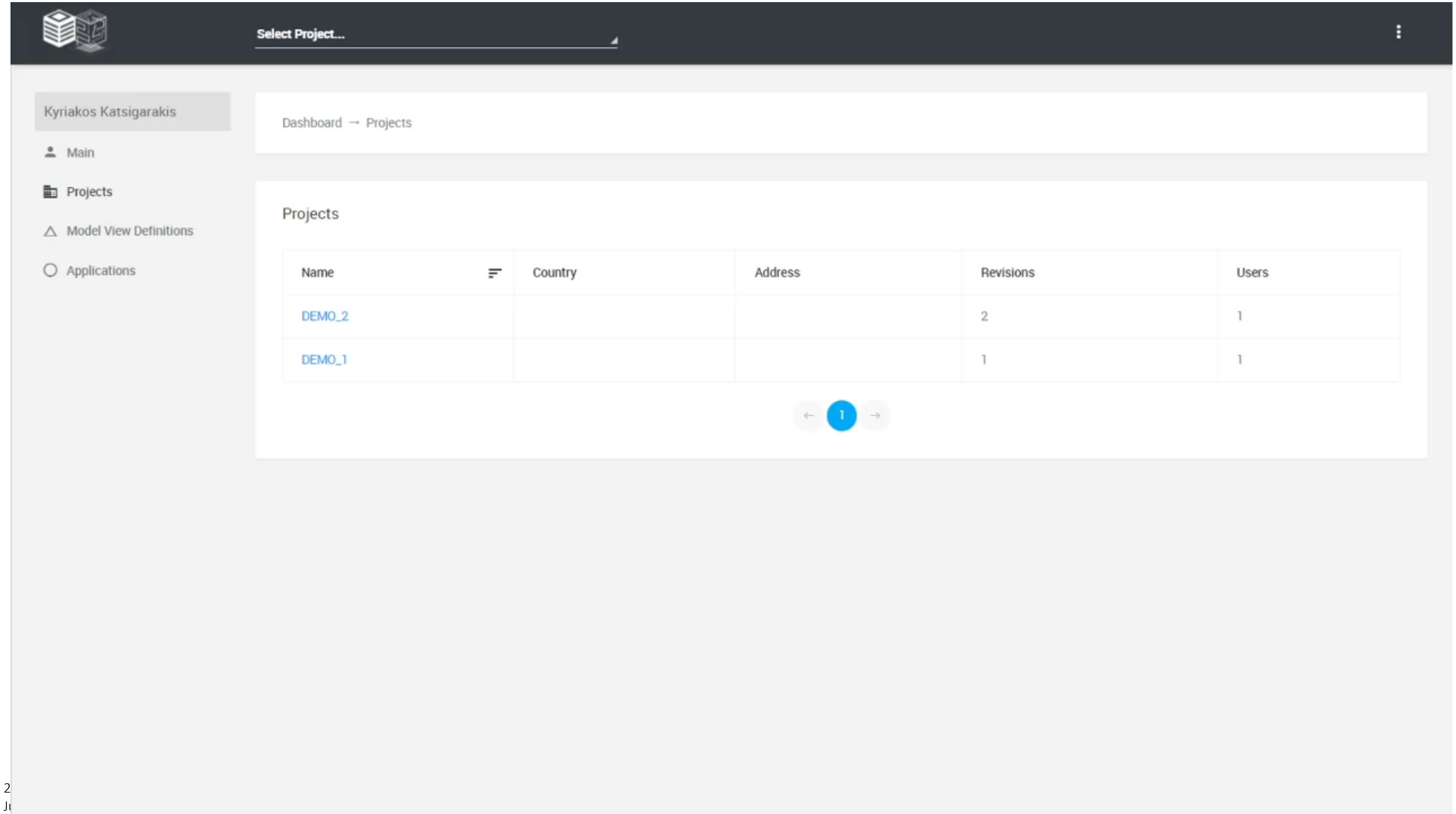
IFC Class Name	IFC Type	Revit Category	Revit Sub-Category
IfcDoor		Doors	
IfcDoorStyle		Doors	
IfcDoorType		Doors	
IfcDuctFitting		Duct Fittings	
IfcDuctFittingType		Duct Fittings	
IfcDuctSegment		Ducts	
IfcDuctSegmentType		Ducts	
IfcElectricAppliance	DISHWASHER	Plumbing Fixtures	
IfcElectricAppliance	ELECTRICCOOKER	Electrical Fixtures	
IfcElectricAppliance	FRIDGE_FREEZER	Specialty Equipment	
IfcElectricAppliance	TUMBLEDRYER	Electrical Fixtures	
IfcElectricAppliance	USERDEFINED	Electrical Fixtures	
IfcElectricAppliance	WASHINGMACHINE	Electrical Fixtures	
IfcElectricApplianceType	DISHWASHER	Plumbing Fixtures	
IfcElectricApplianceType	ELECTRICCOOKER	Electrical Fixtures	
IfcElectricApplianceType	FRIDGE_FREEZER	Specialty Equipment	
IfcElectricApplianceType	TUMBLEDRYER	Electrical Fixtures	
IfcElectricApplianceType	USERDEFINED	Electrical Fixtures	
IfcElectricApplianceType	WASHINGMACHINE	Electrical Fixtures	
IfcEnergyConversionDevice		Mechanical Equipment	

Revit Category	IFC Class Name	IFC Type
Hidden Lines	Not Exported	
Site	IfcSite	
Hidden Lines	IfcSite	
Landscape	IfcSite	
Pads	Not Exported	
Project Base Point	IfcSite	
Property	IfcBuildingElementProxy	
Property Lines	IfcSite	
Stripe	IfcSite	
Survey Point	IfcSite	
Utilities	IfcSite	
Site Tags	Not Exported	
Spaces	IfcSpace	
Color Fill	Not Exported	
Interior	Not Exported	
Reference	Not Exported	
Specialty Equipment	IfcBuildingElementProxy	
Hidden Lines	IfcBuildingElementProxy	
Specialty Equipment Tags	Not Exported	

Challenges: Working with different IFC versions



Beyond Geometry: 4D BIM



Built Environment Digital Twins Maturity Levels

Element (logarithmic scale of complexity)	Defining principle	Outline usage
0	Reality capture	As-built survey
1	2D map/system or 3D model	Design/asset optimisation and co-ordination
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4	Two-way data integration and interaction	Remote and immersive operations
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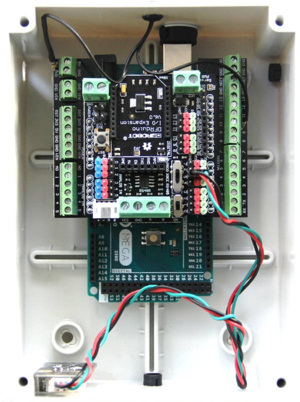
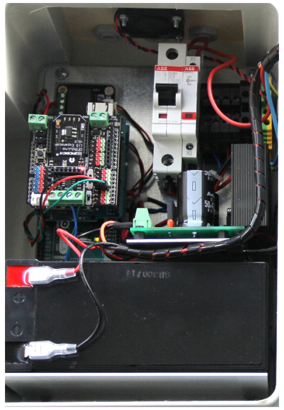
Digital twin – A realistic digital representation of assets, processes or systems, in the built or national environment. The complexity of that representation, and degree of connectedness, varies depending on maturity

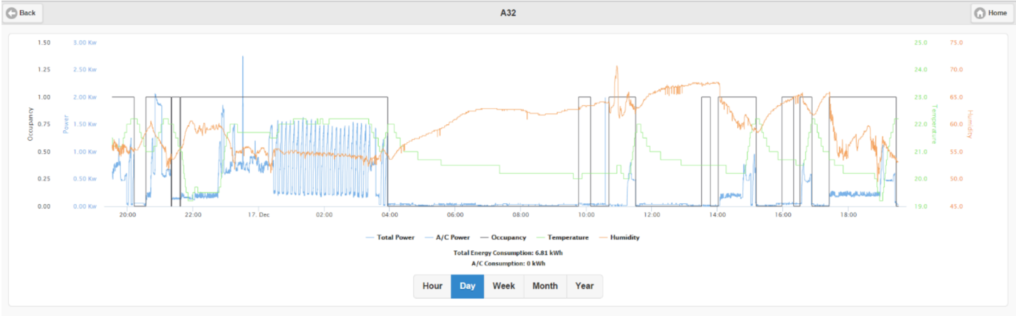
Source: IET Digital Twins for the Built Environment

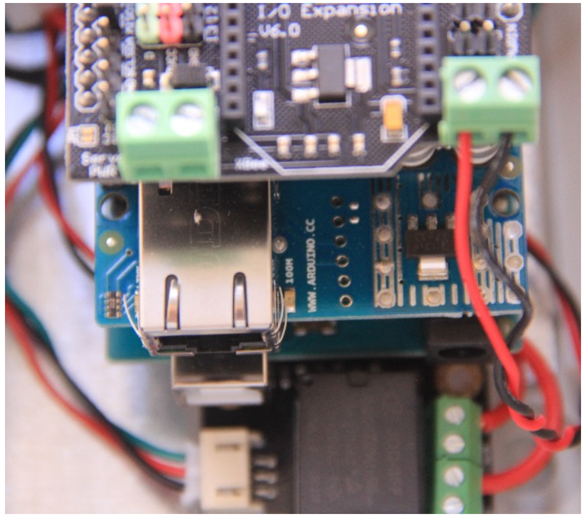
Getting data from the field:
IoT and Middleware platforms (Home Applications)





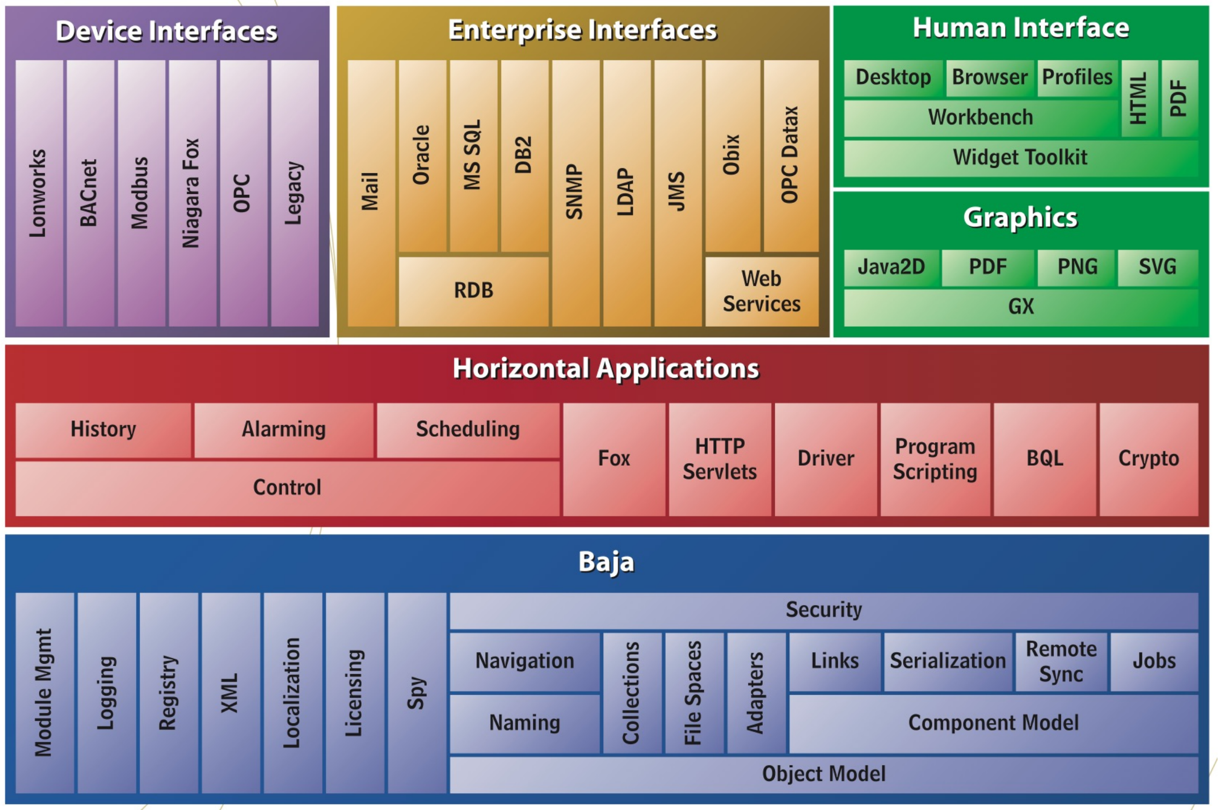
Room Controller
Building Gateway



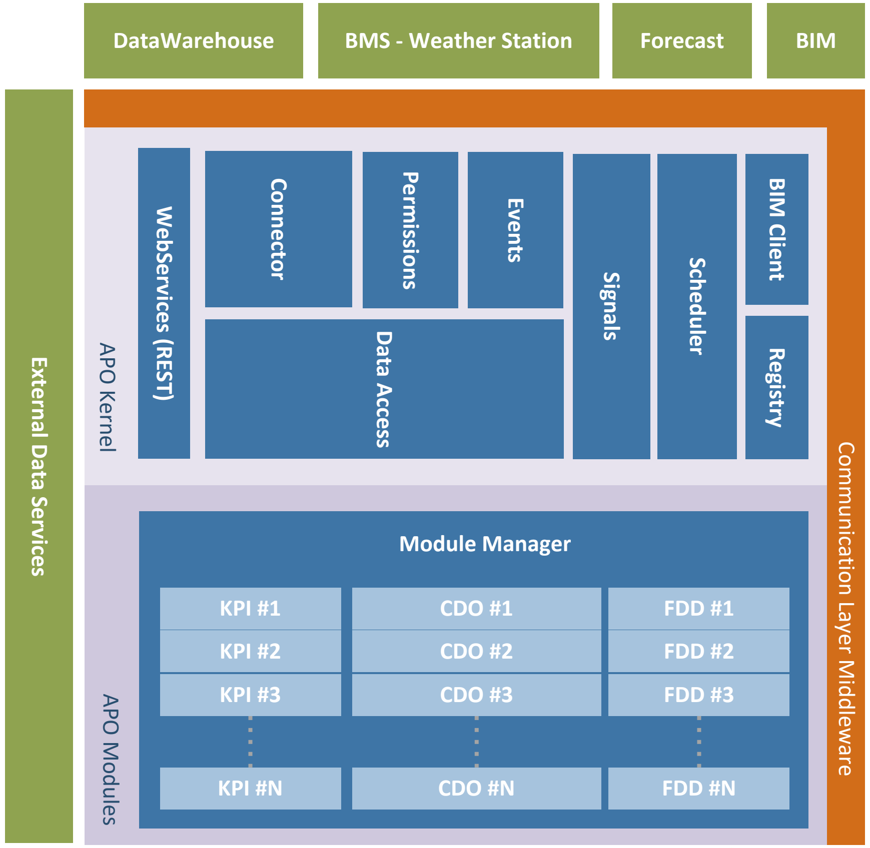


Open Hardware

Getting data from the field:
IoT and Middleware platforms (Field devices)



TRiDiUM
Connecting minds and machines



BaaS
Buildings as a Service

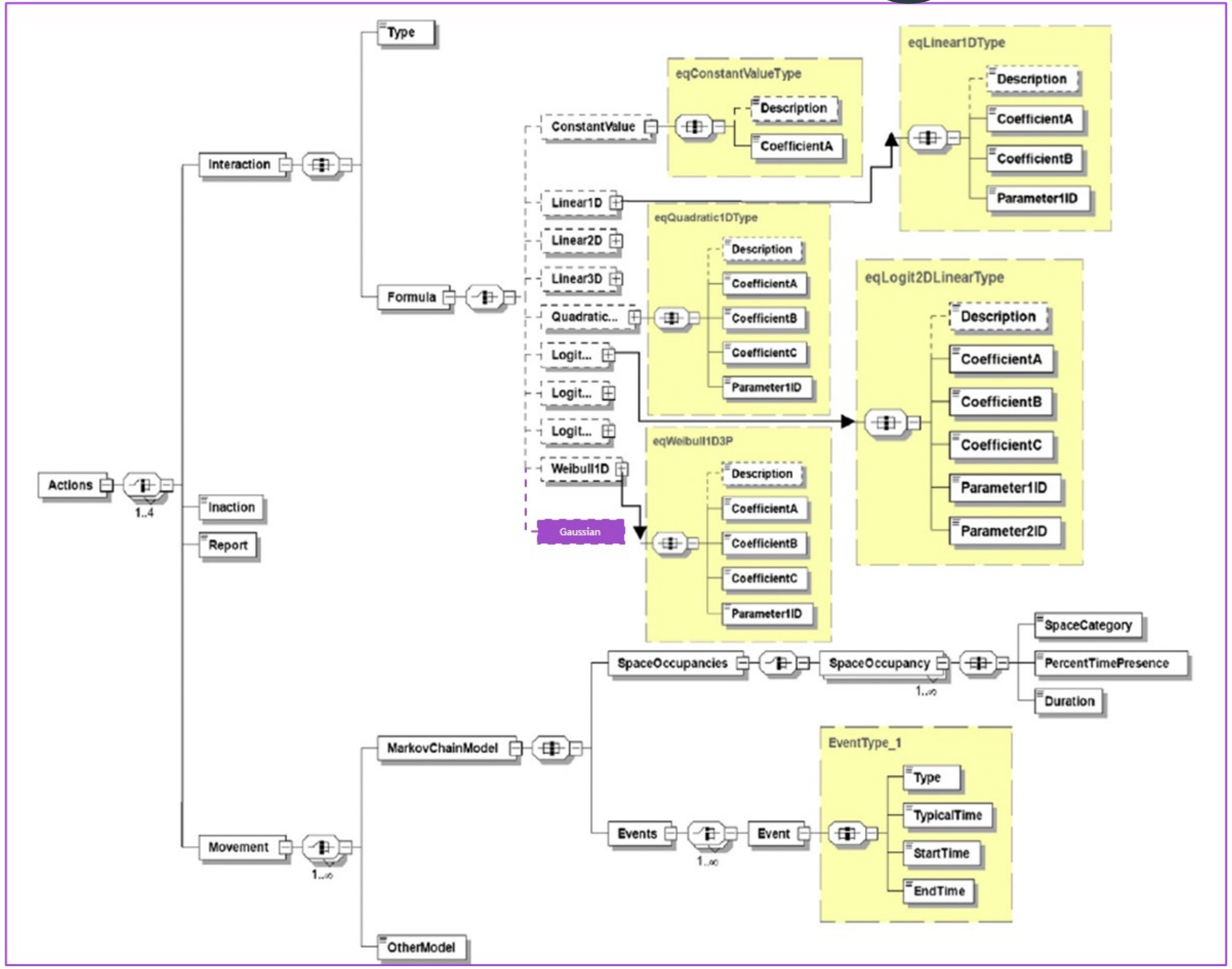
How operational data are used?

Building operation
- *Weather predictions*
- *Occupancy modelling (e.g. IEA Annex 66 work)*
- *Model calibration and uncertainty quantification*
- *Model training (in ML-based approaches)*
- *Demand response, B2G*

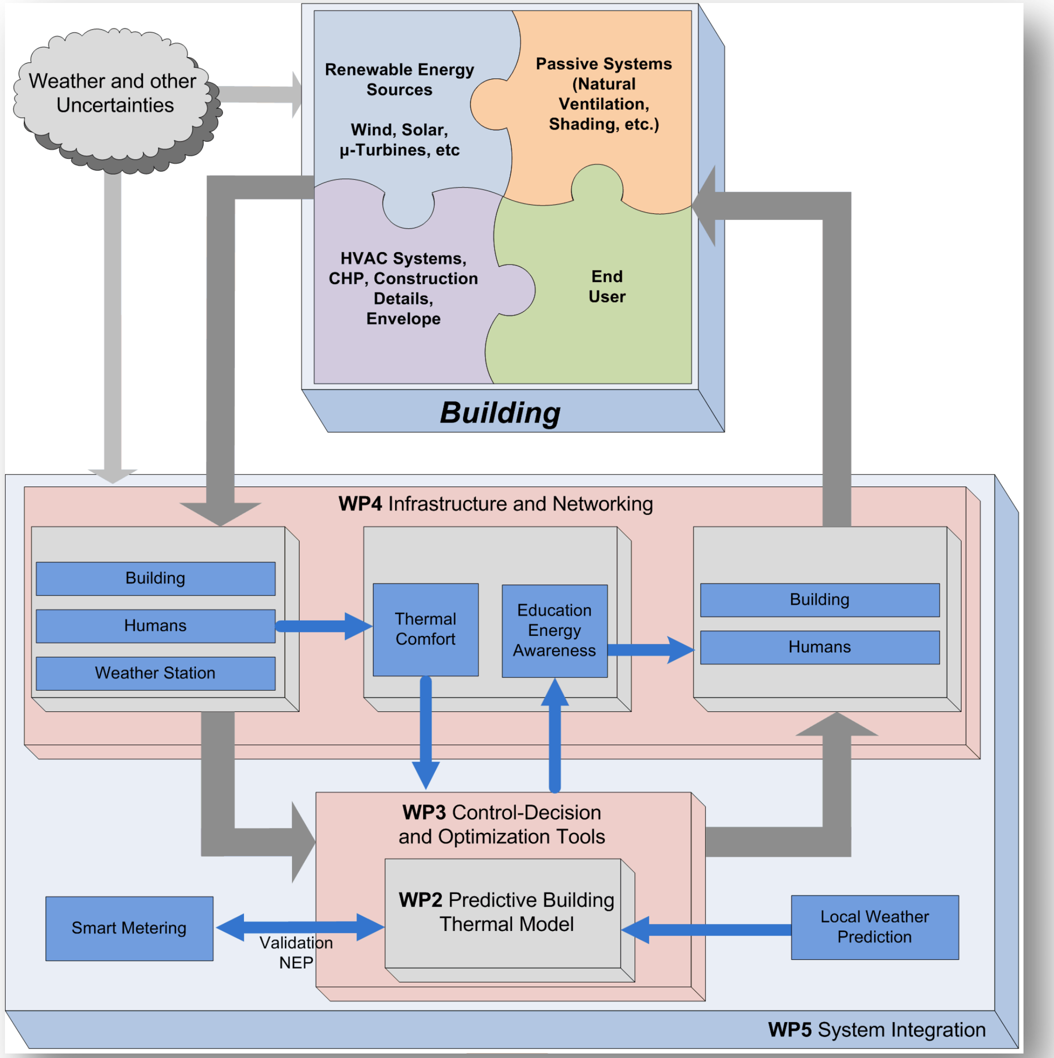
Fault Detection and Diagnostics
- *Predictive maintenance*
- *Benchmarking*

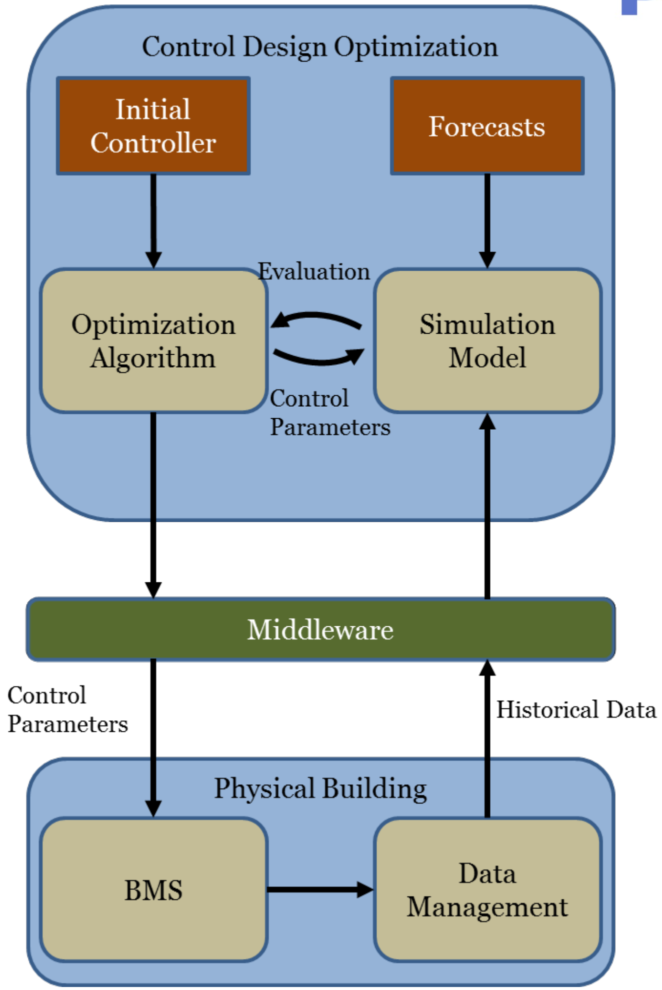
obXML Generator

obXML



Using a digital twin for operation (PEBBLE, DT Maturity Level: 4-5)



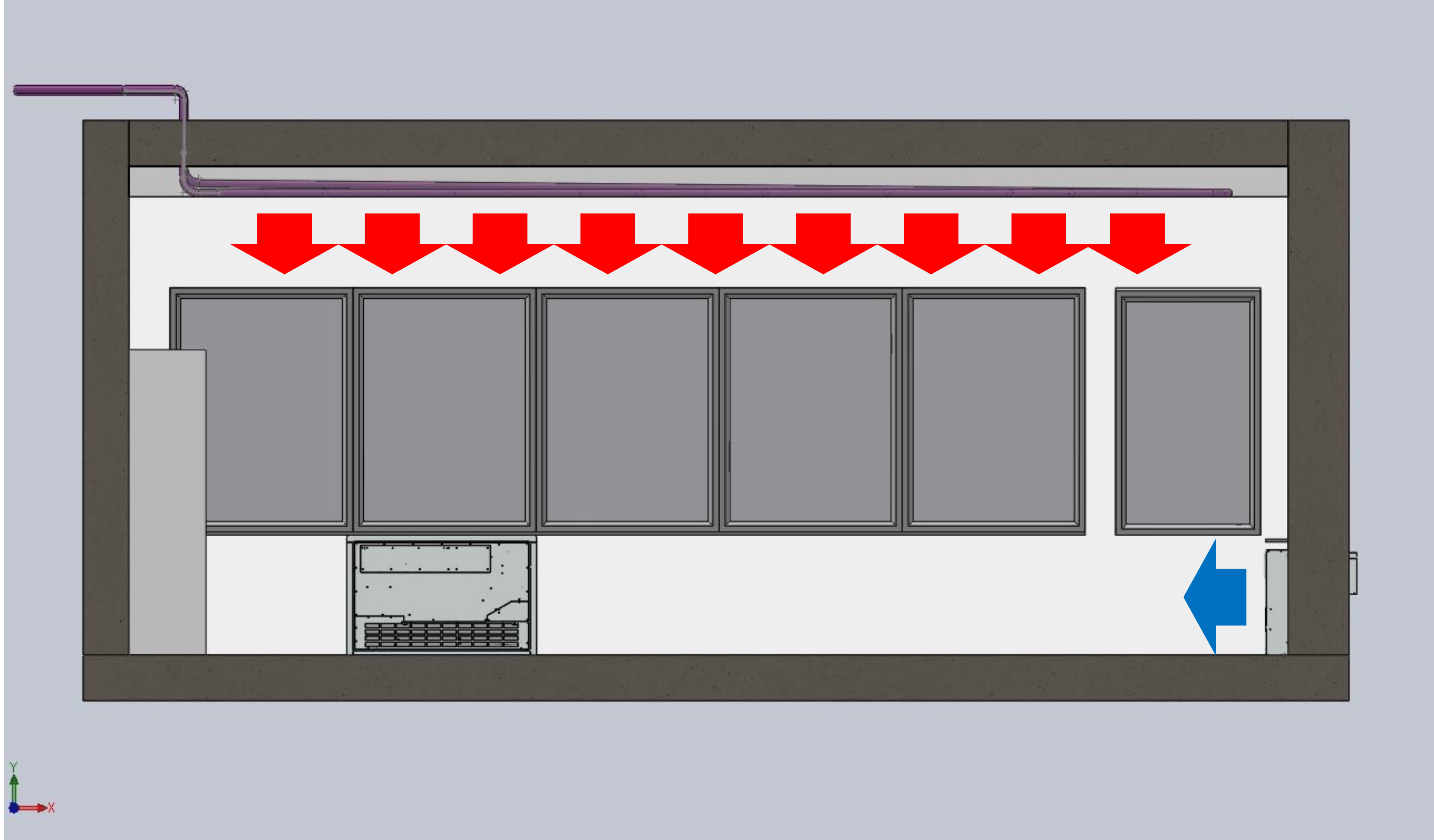


1. ZUB (Fraunhofer)

2. RWTH (Aachen)

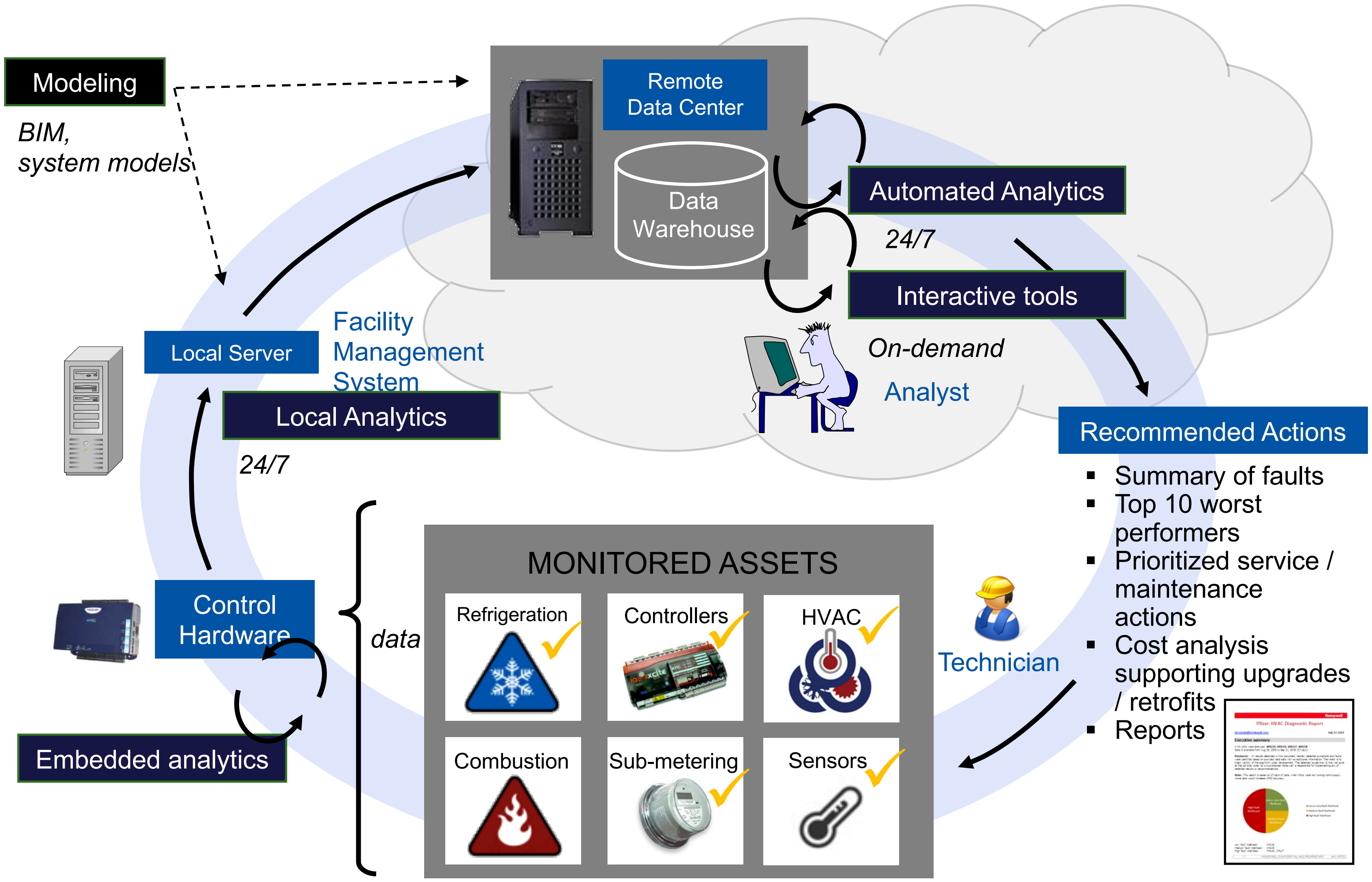
3. TUC

Emergent behaviours



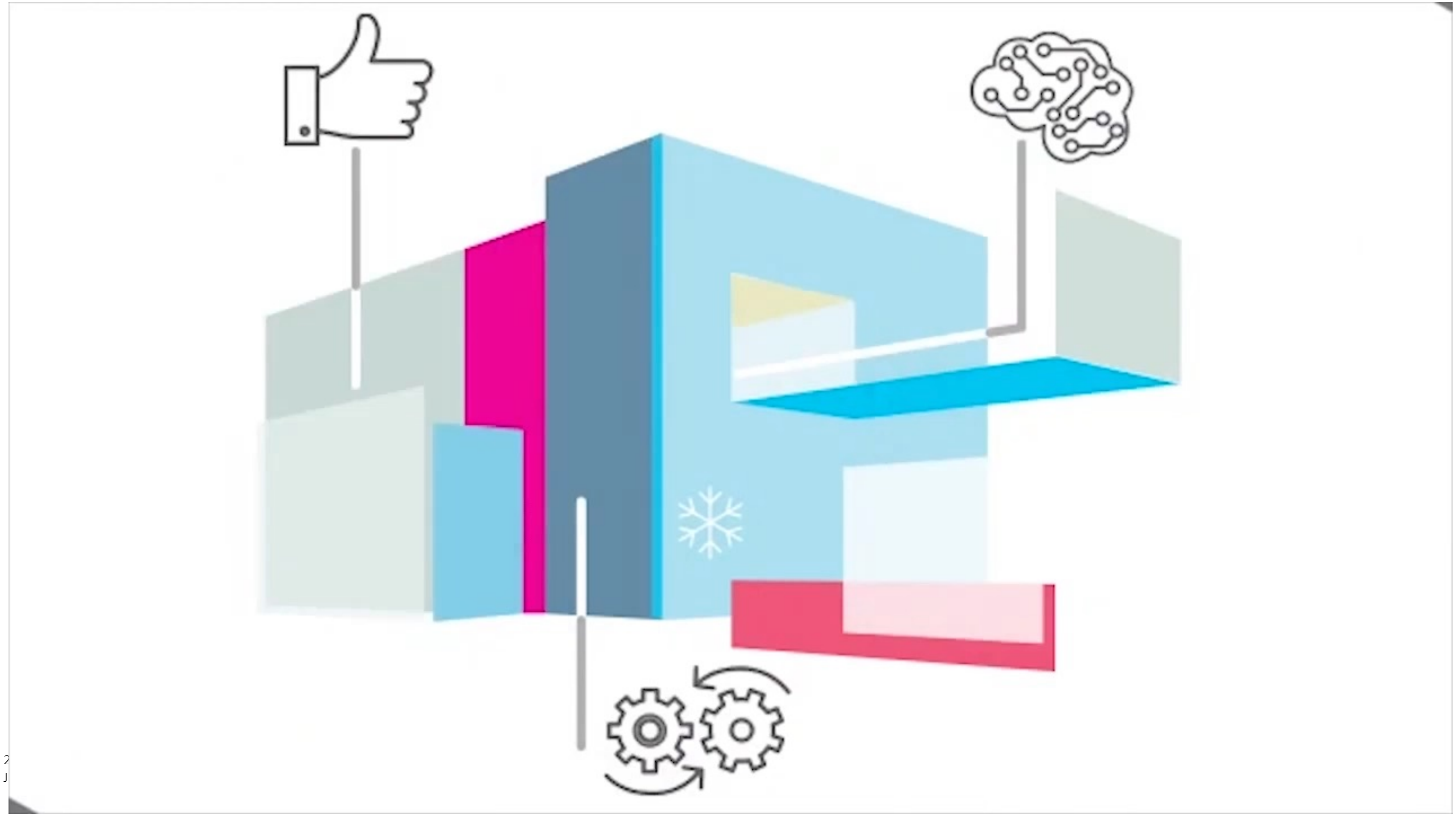
Simultaneous Heating and Cooling

Building as a Service (BaaS)

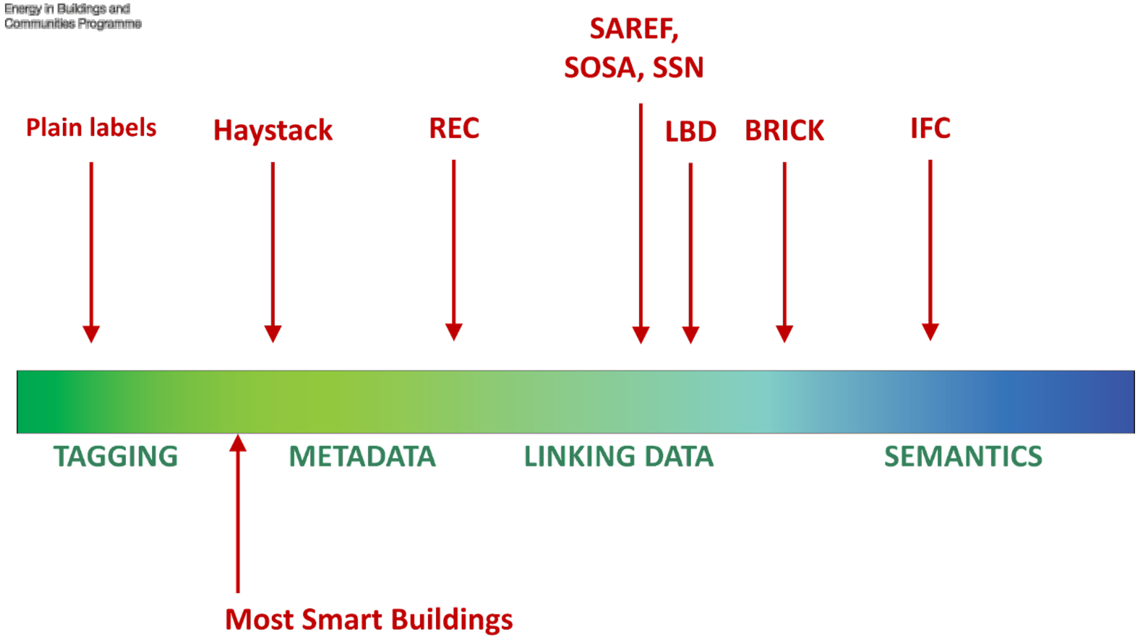


Source: Honeywell/BaaS

Digital twins and the role of knowledge graphs



Meta-data representation (Role of knowledge graphs)



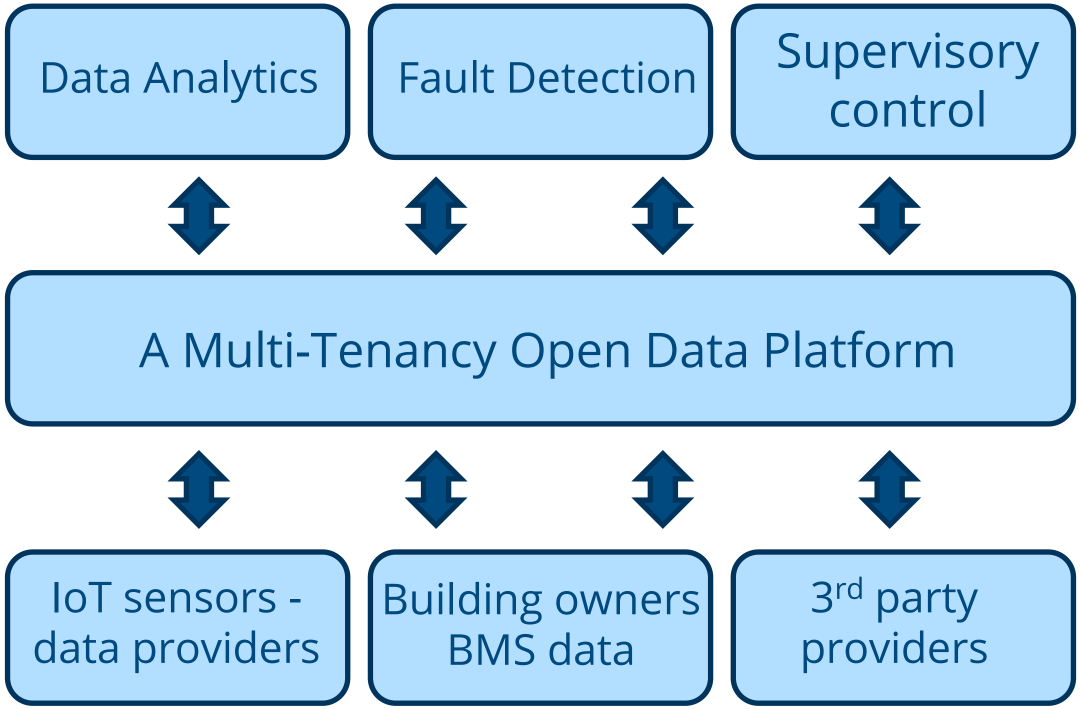
A spectrum of building data representation from more flexible and ad-hoc (leftmost) to more formal and semantically defined (rightmost); plus the estimated location on that scale for several existing metadata schemas.

Source: Annex 81, A3 Survey of Data-driven buildings metadata

Annex 81: Enabling innovation and value creation

Energy in Buildings and Communities Programme

Data sharing 'platform' to match 'data' supply and demand facilitating an open digital services ecosystem



Data Consumers
("Applications" owned by service providers)

Data Marketplace
(Shared non-competing infrastructure for delivering services)

Data Providers
(Data owned and access controlled by data provider)

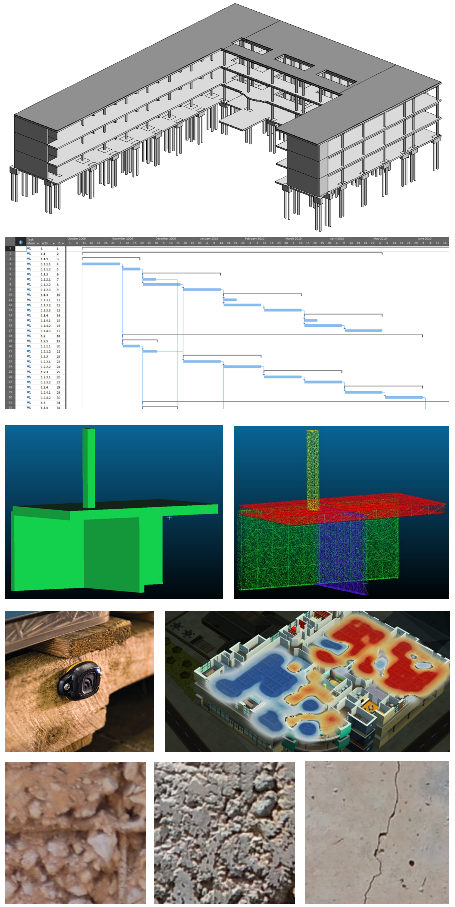
Concept of value and values

Digital twin platform (COGITO)

COGITO

External Input Data Sources

GOGITO Applications & Data Pre-processing Tools



BIM Model

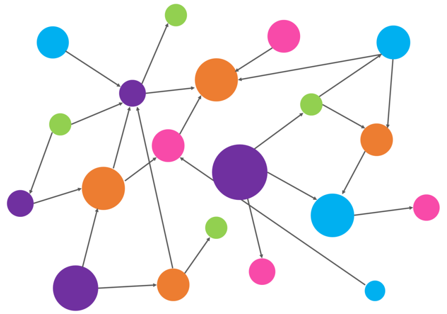
Construction Schedule

Point Clouds & Geometry Quality Control Results

Location Tracking Data

Imagery & Visual Defects

DTP Input Data



Semantically Linked Data (Triplestore)

Relational DB

Key-Value DB

Timeseries DB

BIM Data Post-processing Services

Extraction, Transformation & Loading Services

Data Management Services

Digital Twin Platform

Geometric Data of Building Elements

Construction Tasks

Location Tracking Data

Imagery and Point Clouds

Visual and Geometry Quality Checking

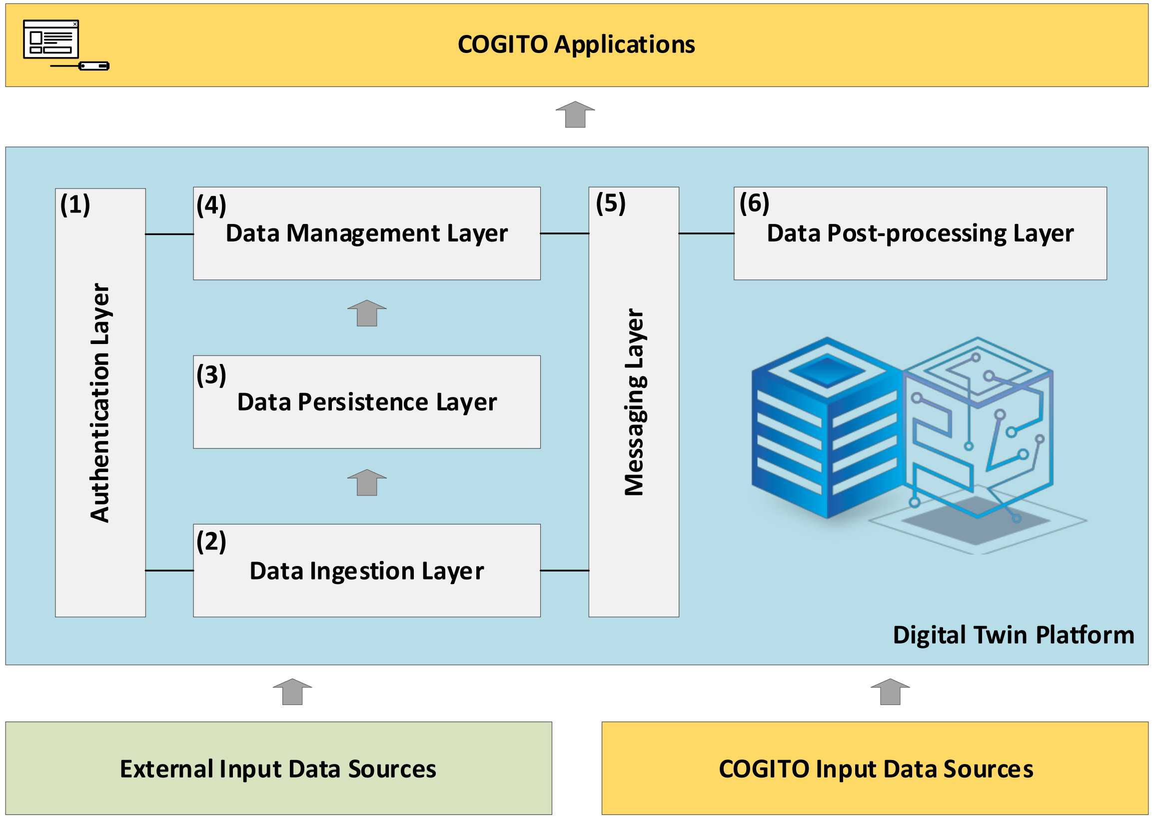
Construction Schedule

DTP Output Data

GOGITO Applications

(Health & Safety, Quality Control, Process Modelin Visualization)

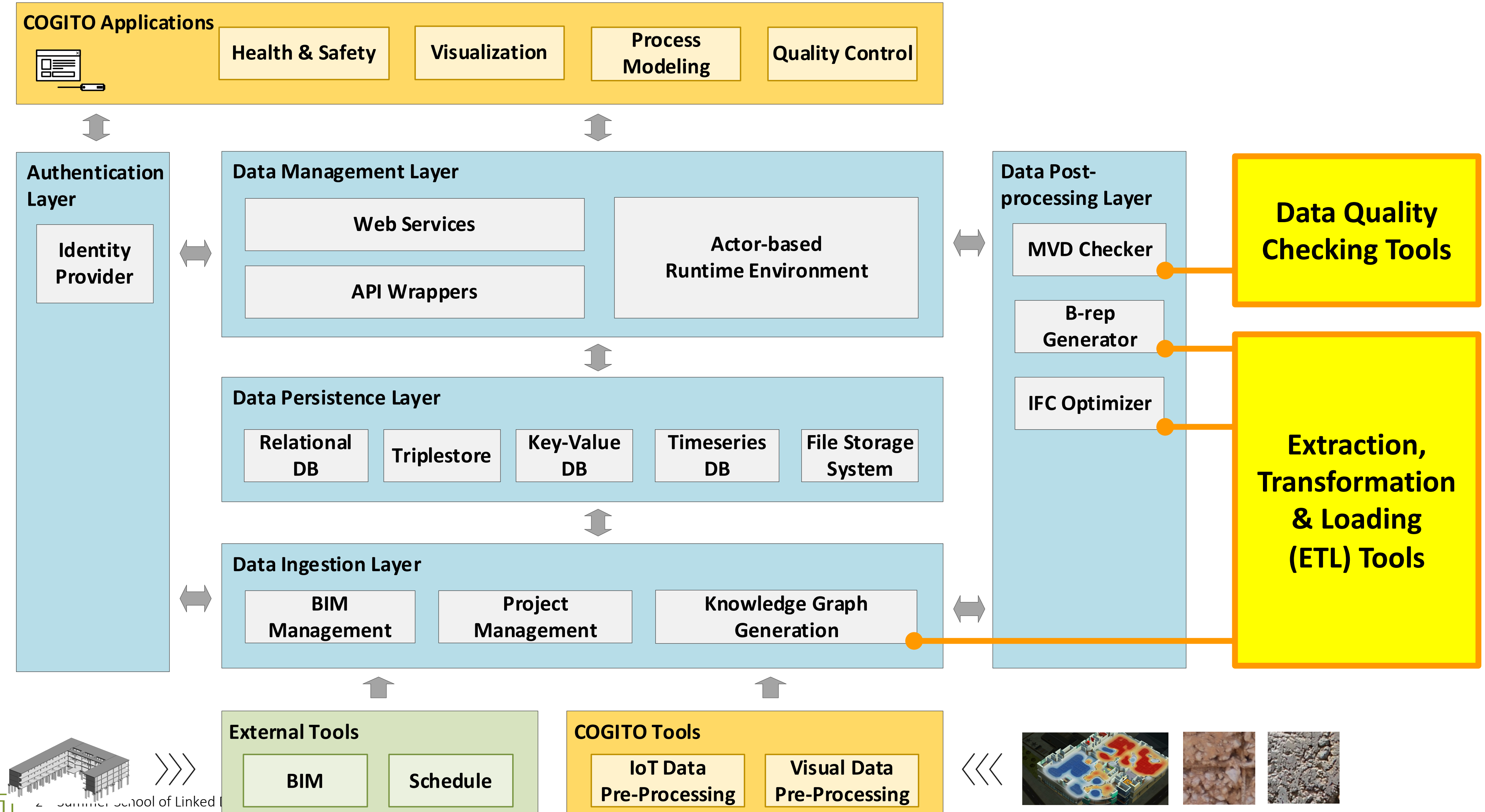
Digital Twin Platform (DTP): Functional components



DTP's six-layered architecture

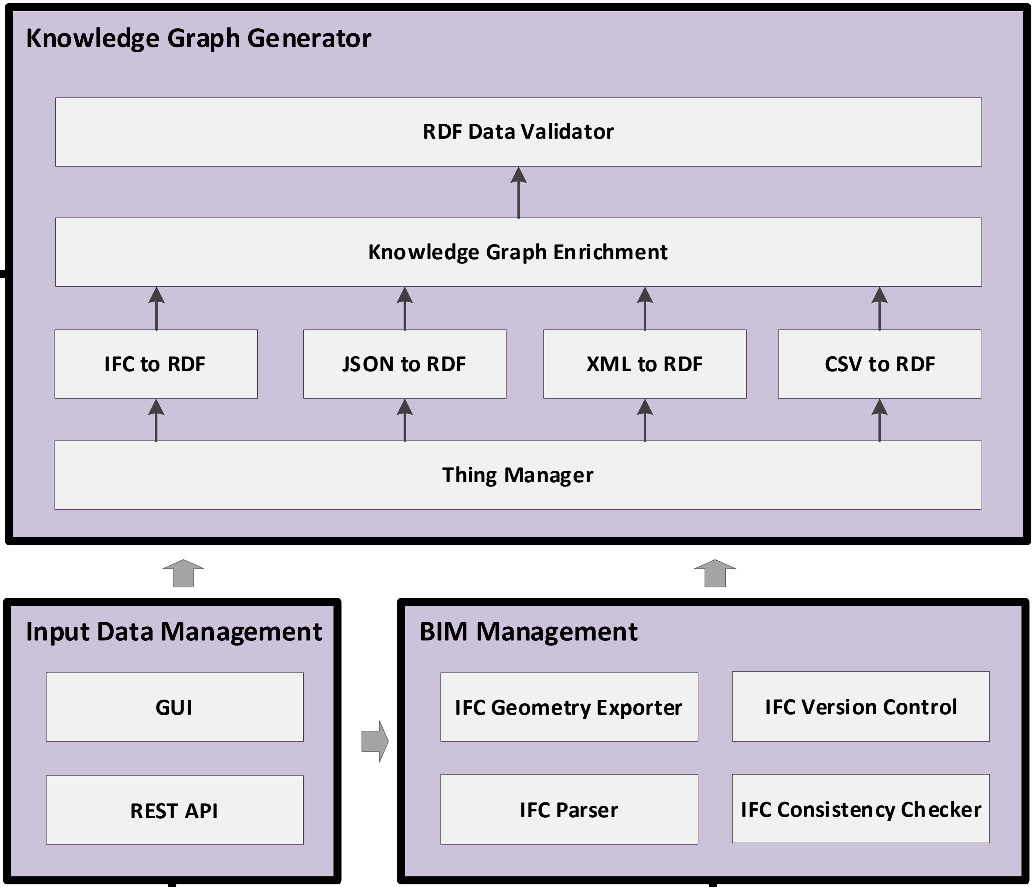
1. **Authentication Layer** ensures that access to resources and services is restricted to specific users with the appropriate permissions.
2. **Data Ingestion Layer** loads the as-designed and as-built data and real-time IoT data to the DTP and orchestrates the execution of the included ETL services to generate the knowledge graph and populate corresponding databases.
3. **Data Persistence Layer** for data storage in different formats.
4. **Data Management Layer** for data query management and connection of Data Persistence layer components to other COGITO tools.
5. **Messaging Layer** for message and notification handling among COGITO applications.
6. **Data Post-processing Layer** for performing ETL and data quality checking operations on BIM data.

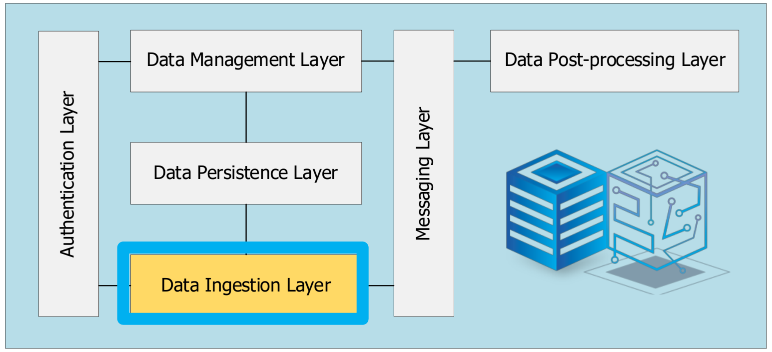
DTP High-level architecture



DTP: Data Ingestion Layer

The **Knowledge Graph Generator** is responsible for generating, validating and storing RDF data coming from heterogeneous data sources in several data formats such as IFC, JSON, XML and CSV.





The **Data Ingestion Layer** includes software components responsible for project creation, BIM data handling, ontology population and generating Thing Descriptions.

The **Input Data Management** component provides a standalone web-based application responsible for creating a new project, assigning users, and loading data from the other COGITO applications.

The **BIM Management** component is responsible for parsing IFC data and loading the corresponding objects into the key-value database of the Persistence Layer. It is responsible for serializing/deserialising, querying, updating, and merging the IFC data

- **IFC4, IFC4x3**
- **IFC Geometry Exporter**
- **IFC Versioning**
- **IFC Consistency Checker**
- **IFC Library** (Read, Process, Write)

DTP: Data Persistence Layer

MySQL

Relational Database

The **Relational DB** is used for storing project and user data

redis

Key-Value Database

The **Key-value DB** is used for versioning and storing IFC objects

influxdb

Timeseries Database

The **Time-series DB** is used for storing IoT location tracking data

GraphDB

Triplestore

The **Triplestore** is used for storing COGITO's knowledge graphs in RDF format

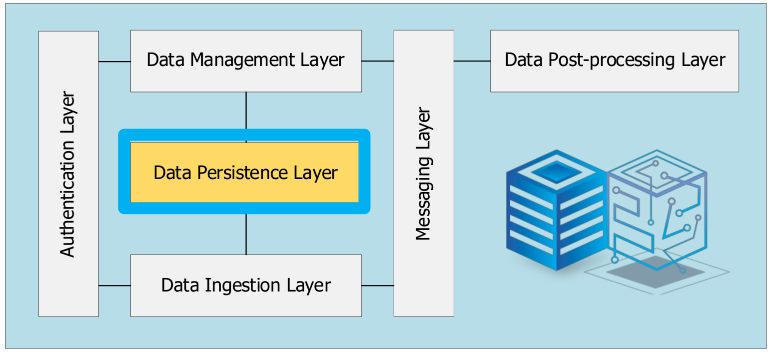
File System

The **File System** is used for storing files generated by other COGITO applications

WoT Hive

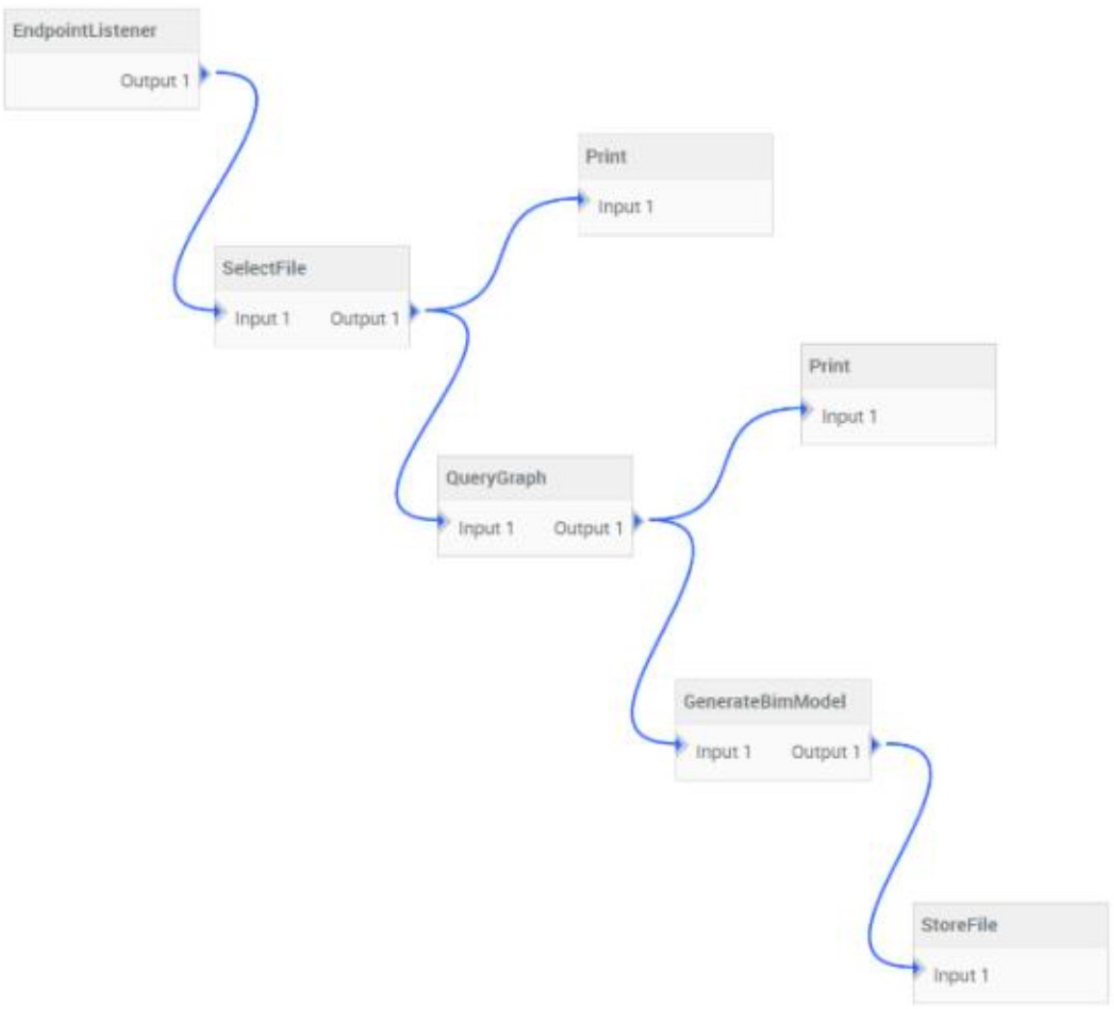
Thing Directory

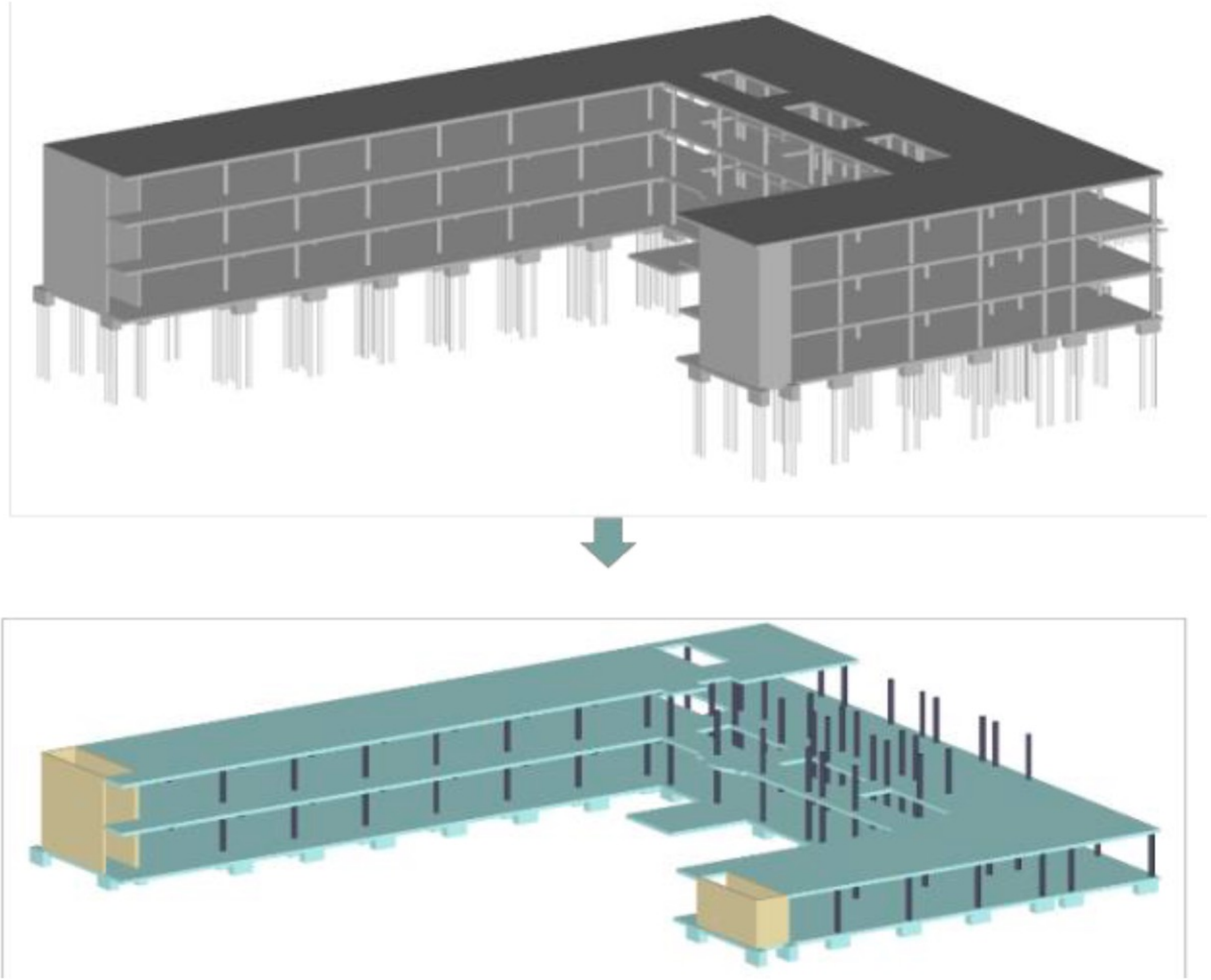
The **TD** supports discovery, creation, retrieval, update and deletion of TD's



The **Data Persistence Layer** contains different types of databases for storing structured data of various data formats.

DTP: Data Management Layer

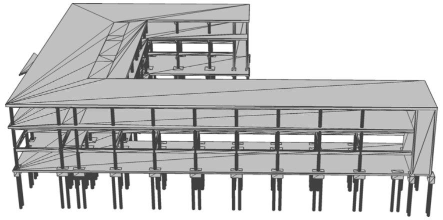




DTP: Data Post-Processing

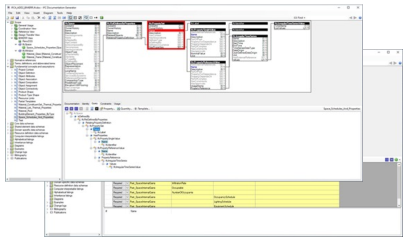
B-rep Generation

Produces graphics-friendly triangulated boundary representations of BIM elements for rendering purposes from their IFC parametric and non-parametric descriptions.



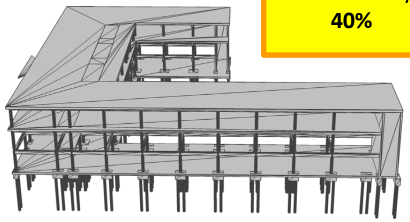
Model View Definition Checker

Implements data quality checks on input BIM (IFC) files based on Model View Definition rules defined in an mvdXML file produced by the IfcDoc tool.

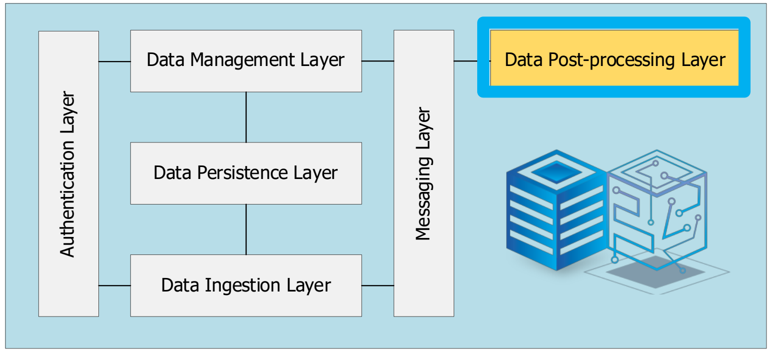


IFC Optimizer

Performs lossless compression of an IFC file to speed up loading and data transformation processes. This component generates a new IFC with reduced file size.



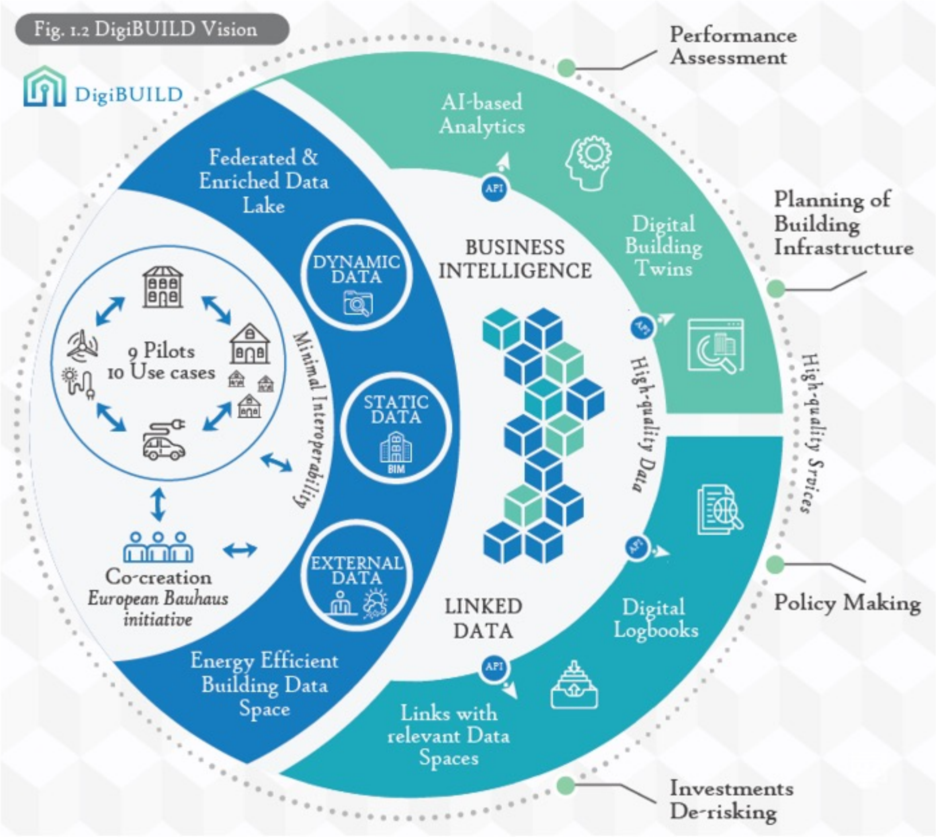
IFC file size reduction by **40%**

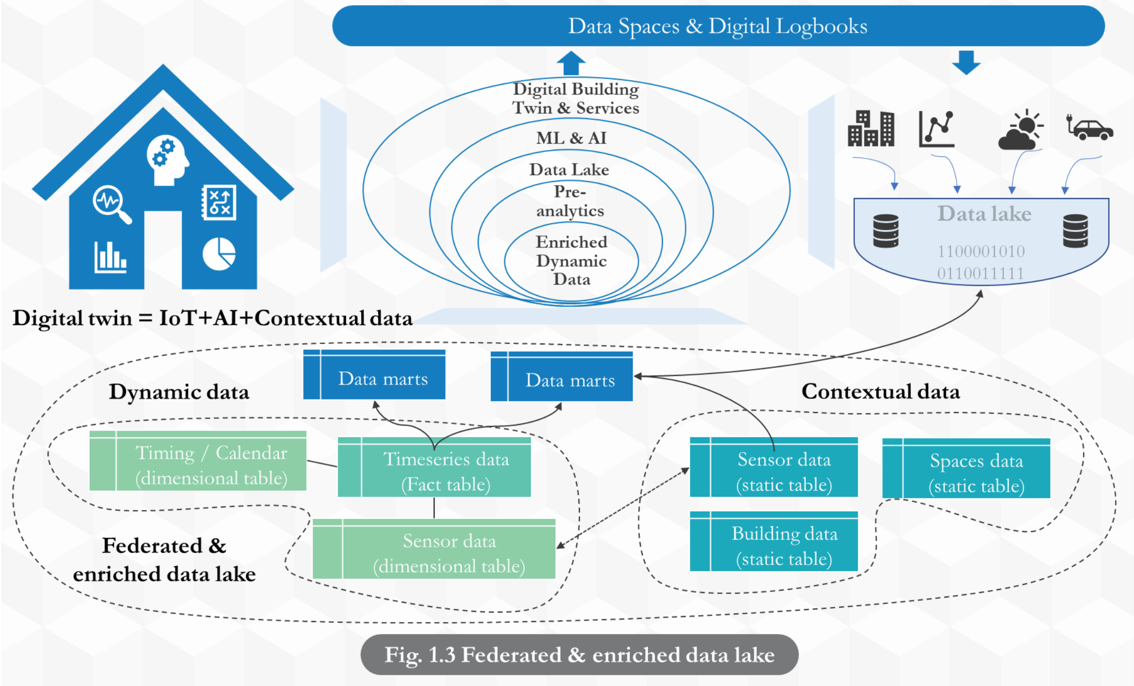


The **Data Post-processing Layer** comprises components for handling time-consuming processes. These components are modular, and additional can be included in an extensible manner.

Looking forward: DigiBuild

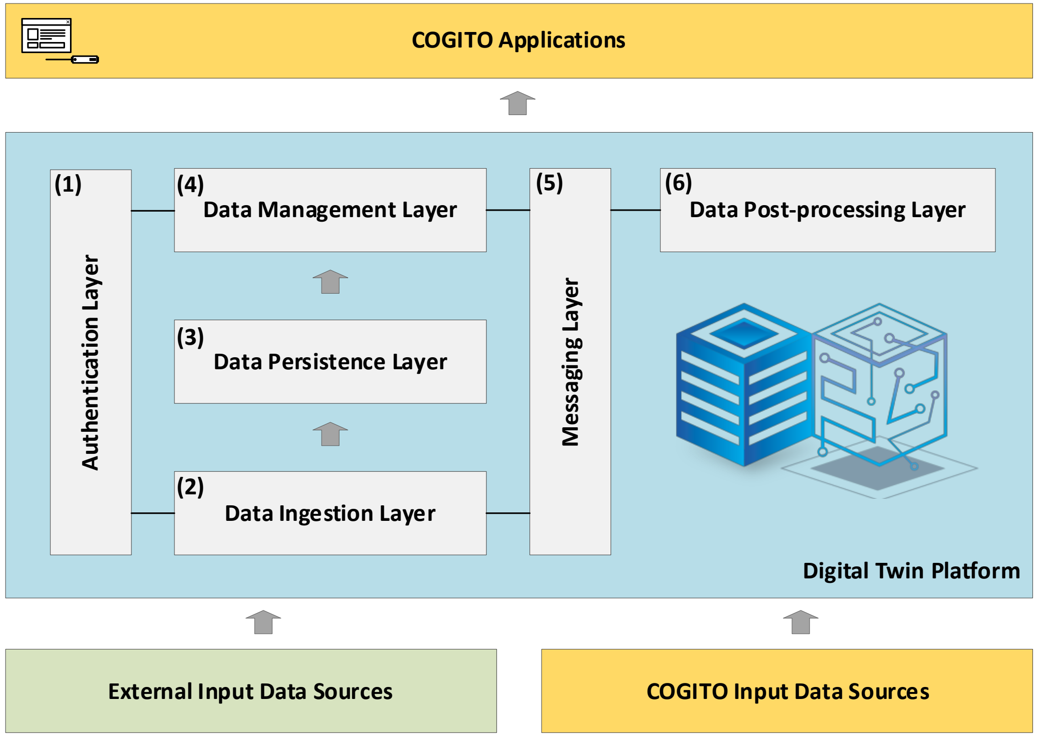
DigiBUILD





Built Environment Digital Twins Maturity Levels

Element (logarithmic scale of complexity)	Defining principle	Outline usage
0	Reality capture	As-built survey
1	2D map/system or 3D model	Design/asset optimisation and co-ordination
2	atic data, metadata and BIM Stage 2	4D / 5D simulation
3	Real-time data	Operational efficiency
4	Two-way data integration and interaction	Remote and immersive operations
5	Autonomous operations and maintenance	Self-governance, over-sight and transparency

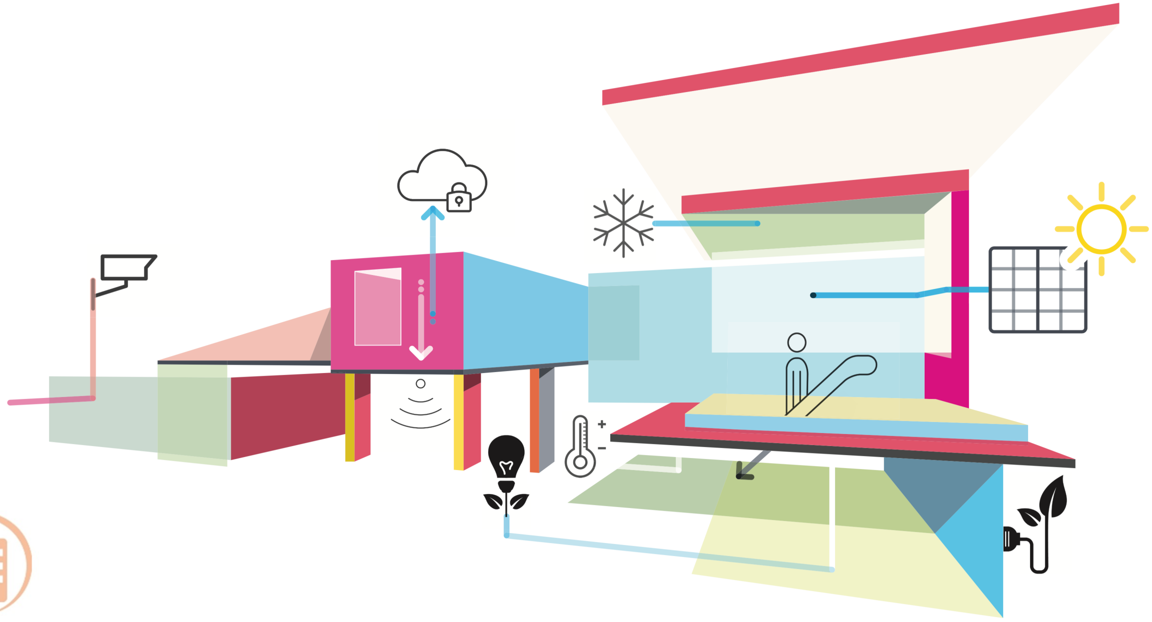


Source: IET Digital Twins for the Built Environment

Conclusions

- Digital Building Twins: A useful conceptualization, reflective of ideas that have been evolving for some time
- Need for meta-data, and must make a conscious selection of ways to represent data
- Advanced applications should consider the value generated, move beyond EE
- Different DT maturity levels:
  - Static BIM (Low maturity)
  - Including operational data (Insights)
  - Autonomous operation and continuous optimization
- Operational Efficiency is a continuous process – to reduce the energy performance “gap.”
- Tools (Platforms & Algorithms) providing (ICT) services and generic frameworks necessary to deliver of the concept.
- BIM remains relevant (and quite necessary) for (most?) applications.

For more information



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Support and participating members of:

BaaS Buildings as a Service
PEBBLE
EBC Energy in Buildings and Communities Programme
MOEEBIUS
OptEEmAL OPTIMISED ENERGY EFFICIENT DESIGN PLATFORM FOR REFURBISHMENT AT DISTRICT LEVEL
COGITO
BIMERR RENOVATION 4.0
CBIM CBIM - European Training Network Cloud-based Building Information Modelling

Acknowledgement: UCL Group (K. Katsigarakis, G. Lilis),
BIMERR and COGITO project collaborators (UEDIN, UPM, HYP)