SUSTAINABLE PLACES 2024

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY

DATA-DRIVEN SMART BUILDINGS WORKSHOP

25 September 2024, 14:00 – 17:30

European Convention Center, Luxembourg & Online (Hybrid)

Extended session with 2 intertwined topics:
Data Models and Interoperability & Services for Advanced Energy Efficiency

BuildON dedalus DigiBUILD MODERATE

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SUSTAINABLE PLACES 2024

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY LIST

R2M RESEARCH TO MARKET SOLUTION

DATA-DRIVEN SMART BUILDINGS WORKSHOP

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Panel Discussion

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R2M RESEARCH TO MARKET SOLUTION

Semantic models for scalable and portable smart building applications

25 September 2024

Flavia de Andrade Pereira, UCL
Prof Dimitrios Rovas, UCL

UCL

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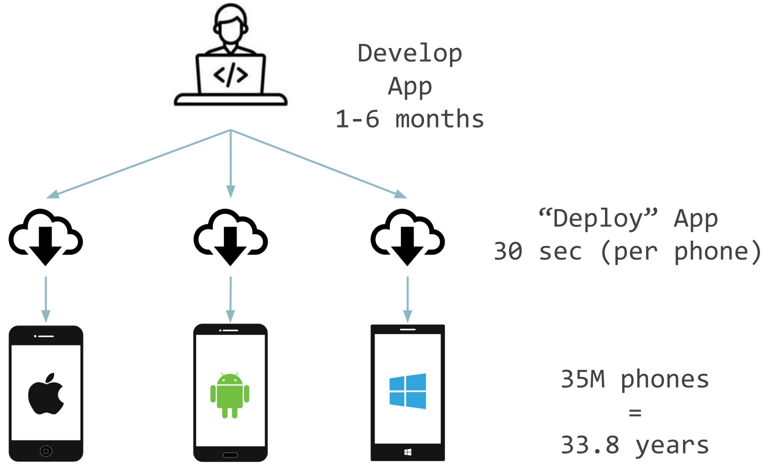
Agenda

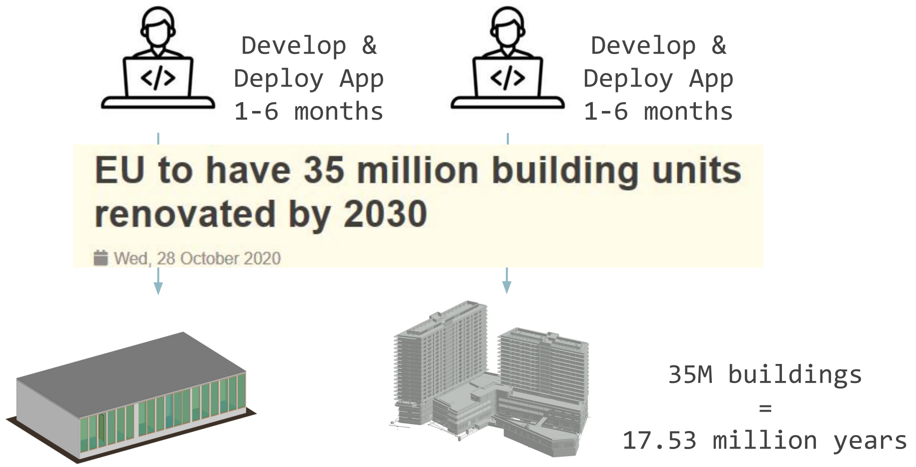
- Overview on portability of applications and semantic models
- **DigiBUILD** tools to extend existing ontologies and create semantic models
- **BuildON** architecture leveraging semantic models for portable applications
- Demonstration

Portability of applications: plug-and-play, the ideal goal

Mobile industry



Building industry



Current practice is not scalable!

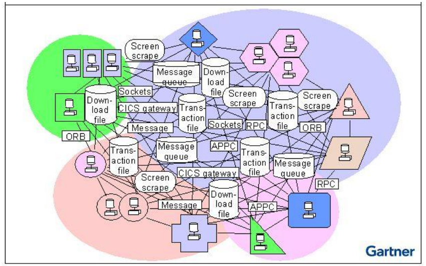
Portability of applications

Why is developing portable applications so hard?

- Heterogeneity
  - Data sources with various formats, vendors, protocols
  - Custom design of systems

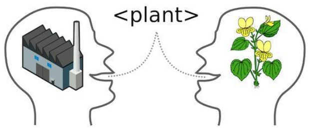
“ Every building is a prototype. No two are alike. -Helmut Jahn

Lack of syntatic (technical) interoperability



- Data silos and spaghetti arrangement (ad-hoc, point-to-point integration)
- Partially addressed by standard communication protocols (e.g., BACnet, Modbus..)

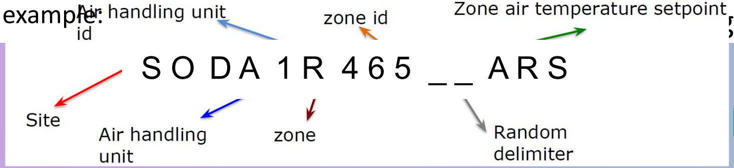
Lack of semantic interoperability



[Krantaz, 2010]

- The “meaning of the data” (metadata) is not easily interpretable
- Metadata are described by informal, customised, ambiguous point names (labels, graphics, docs..)

example: ... concepts



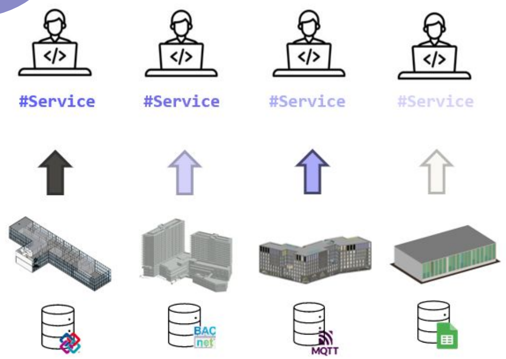
[Pritoni - LBNL, 2022]

Portability of applications

What can we do? Where can we improve?

Traditional workflow

Assess existing systems and user requirements in a specific building → Discover the data points in a specific building → Develop a building-specific application → Configure the application using a building-specific point mapping → Run app



Standalones Services...

"..can cost ***several hundreds of dollars per point*** *(Granderson and Lin 2016).*"

Could be highly **simplified** using **standardised** metadata **(semantic models)**

© *Pritoni - LBNL, 2022*

Portability of applications

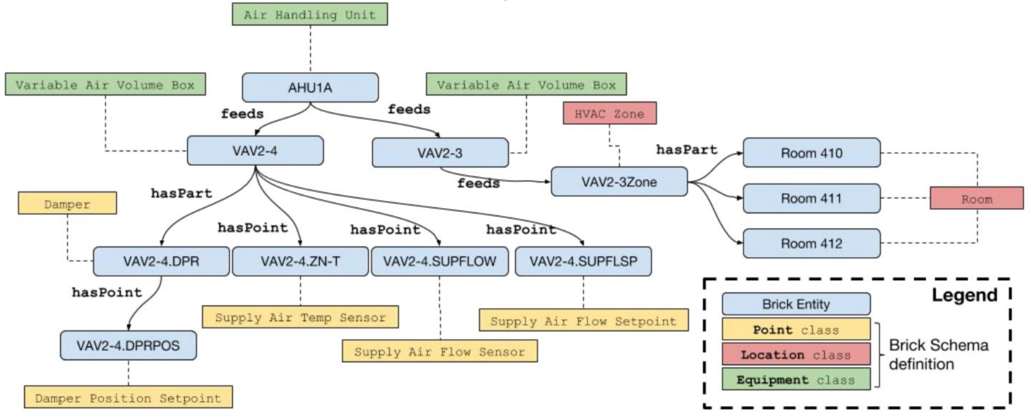
How to improve semantic interoperability?

- **Semantic models** are data models that structure, represent, and add context and meaning to data.

- Built on ontologies:
  - define concepts based on standard class structure and relationships
  - formal, well-defined, precise language
  - shared understanding among different systems and users

Building example

Building modelled with Brick

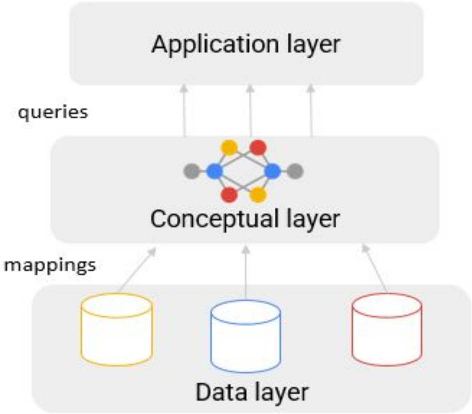


Fierro & Koh, 2019

Portability of applications

Ontology-based data access (OBDA)

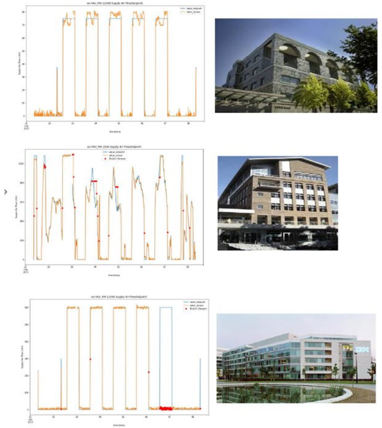
- Standard, consistent and easily discoverable data points
- Unified data access and self-configuration
- Reduce costs, rely less on human expertise and increase scalability

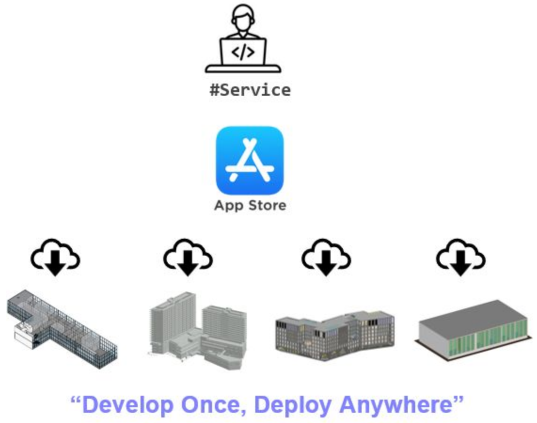


Query

```
SELECT ?tstat ?zone ?tstat_uri ?state_uuid ?temp_uuid ?weather_uuid FROM ciee WHERE {
    ?zone rdf:type brick:HVAC_Zone .
    ?rtu bf:feeds+ ?zone .

    ?tstat rdf:type/rdfs:subClassOf* brick:Thermostat .
    ?tstat bf:controls+ ?rtu .
    ?tstat bf:uri ?tstat_uri.

    ?tstat bf:hasPoint ?state .
    ?state rdf:type brick:Thermostat_HVAC_Operation_Status .
    ?state bf:uuid ?state_uuid .

    ?tstat bf:hasPoint ?temp .
    ?temp rdf:type/rdfs:subClassOf* brick:Temperature_Sensor .
    ?temp bf:uuid ?temp_uuid .

    ?tstat bf:hasSite ?site .
    ?weather_sensor bf:hasSite ?site .
    ?weather_sensor rdf:type/rdfs:subClassOf* brick:Temperature_Sensor .
    ?weather_sensor bf:uuid ?weather_uuid
};
```

executes





DigiBUILD

DigiBUILD tools to extend existing ontologies and create semantic models

Prof Dimitrios Rovas, UCL

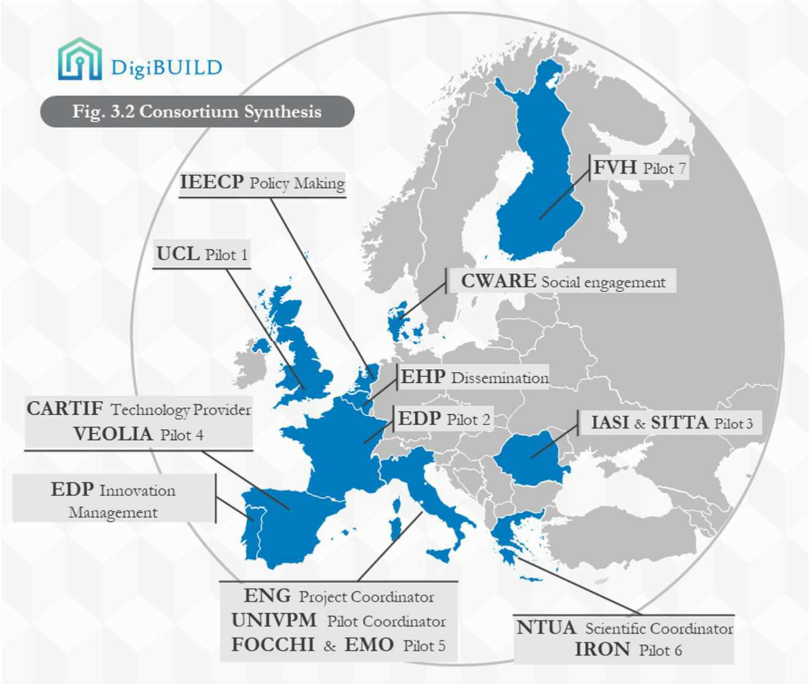
UCL

Funded by
the European Union

About DigiBUILD

High-Quality Data-Driven Services for a **Digital Built Environment** towards a **Climate-Neutral** Building Stock

- Call: “Advanced data-driven monitoring of building stock energy performance”
- Partnership: **17** organisations from **11** Countries (Coordinator: ENG,IT)
- 10 Pilots (mix residential and non-residential)
  - Cluster 1: Building Performance
  - Cluster 2: Buildings vs Infrastructure Smart Management
  - Cluster 3: Policy & Finance



DigiBUILD

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Challenge

Building Data *Data Model* *Querying* *Services*

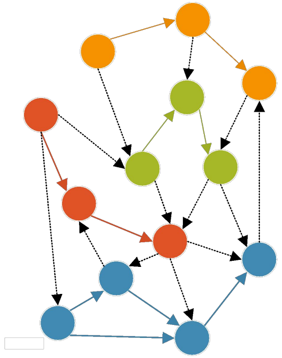
Design

Operation

BAC net

MQTT

RealEstateCore



Brick

WEB OF THINGS

```
SELECT ?lpsp ?blsp WHERE {
    ?room(?zone) rdf:type/rdfs:subClassof* brick:Room(Zone) .
    ?lighting rdf:type/rdfs:subClassOf* brick:Lighting_System .

    ?room(?zone) brick:isLocationOf ?lighting .

    ?lamp rdf:type/rdfs:subClassOf* brick:Luminance .
    ?light brick:hasPart ?lamp .
    ?lamp brick:hasPoint ?lpsp .
    ?lpsp rdf:type/rdfs:subClassOf* brick:Setpoint .

    ?blst rdf:type/rdfs:subClassOf* brick:Ballast .
    ?light brick:hasPart ?blst .
    ?blst brick:hasPoint ?blsp .
    ?blsp rdf:type/rdfs:subClassOf* brick:Setpoint .
    }
```

Monitoring

Assessment

Prediction

Optimisation

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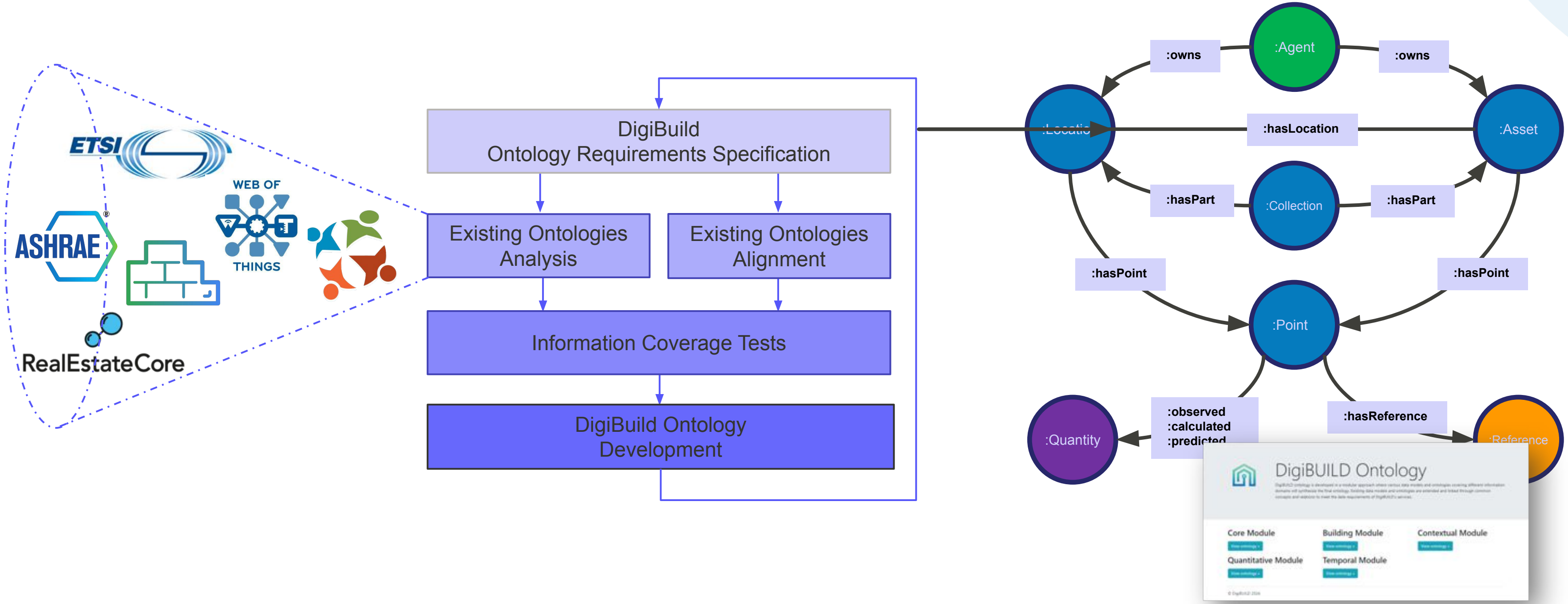
Ontology Development



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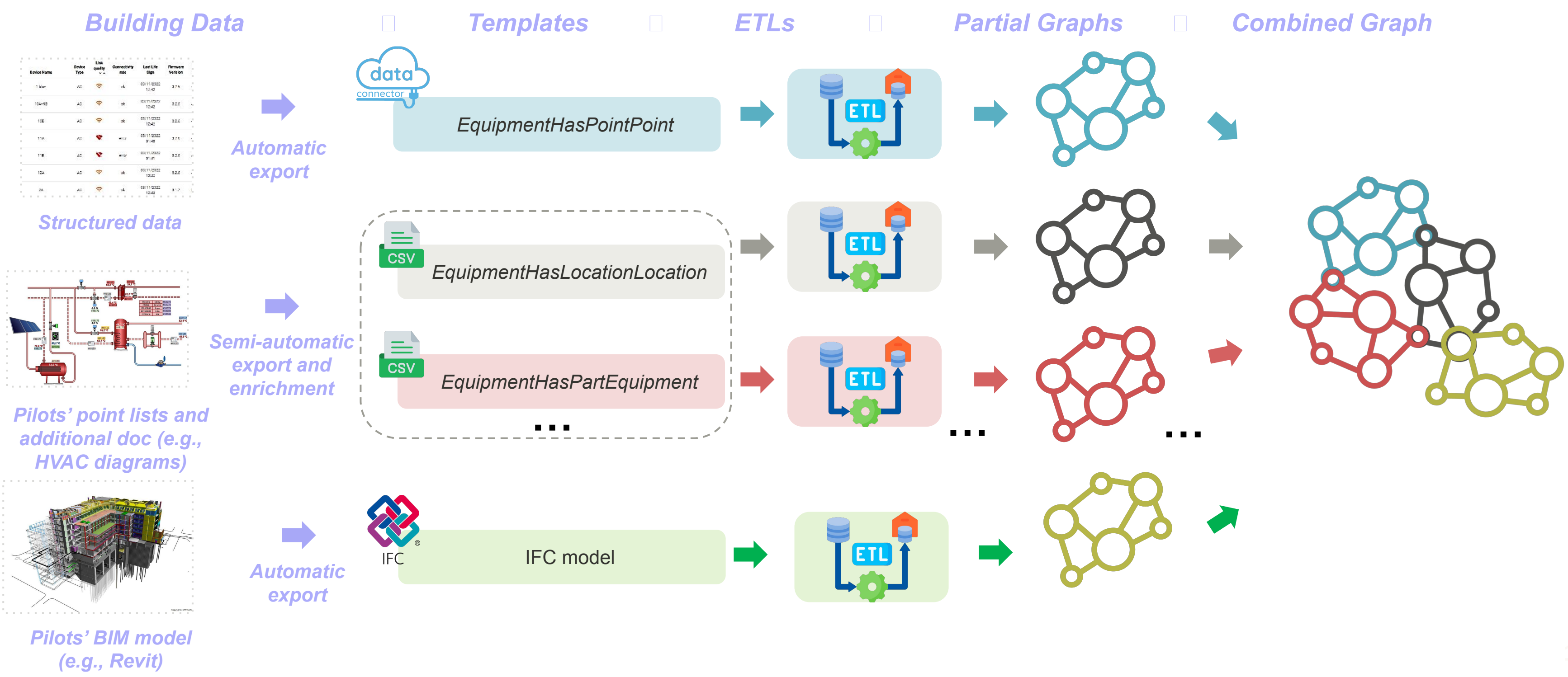
Knowledge Graph Network

DigiBUILD



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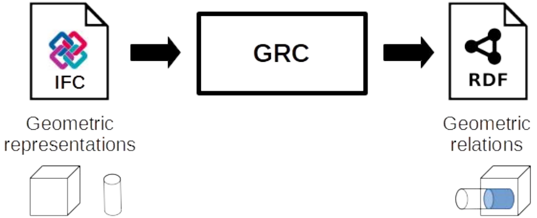
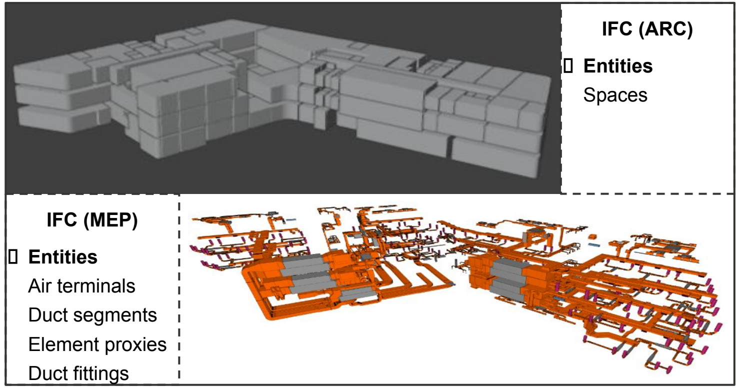
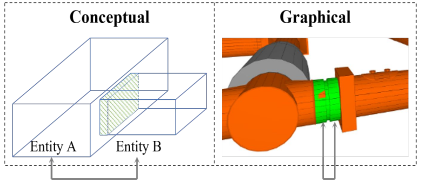
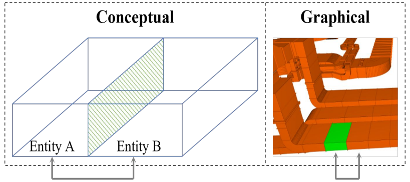
Semantic Enrichment: Geometric Relationship Checker (GRC)



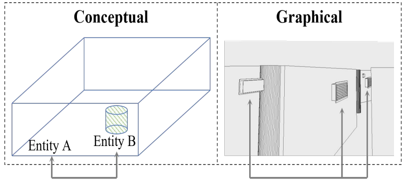




Geometric relation: **Clash** → Semantic relation: **Connectivity**

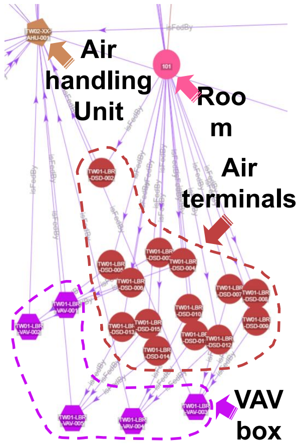


Geometric relation: **Adjacency** → Semantic relation: **Connectivity**



Geometric relation: **Containment** → Semantic relation: **Containment**

Geometric Relationship Checker (GRC)



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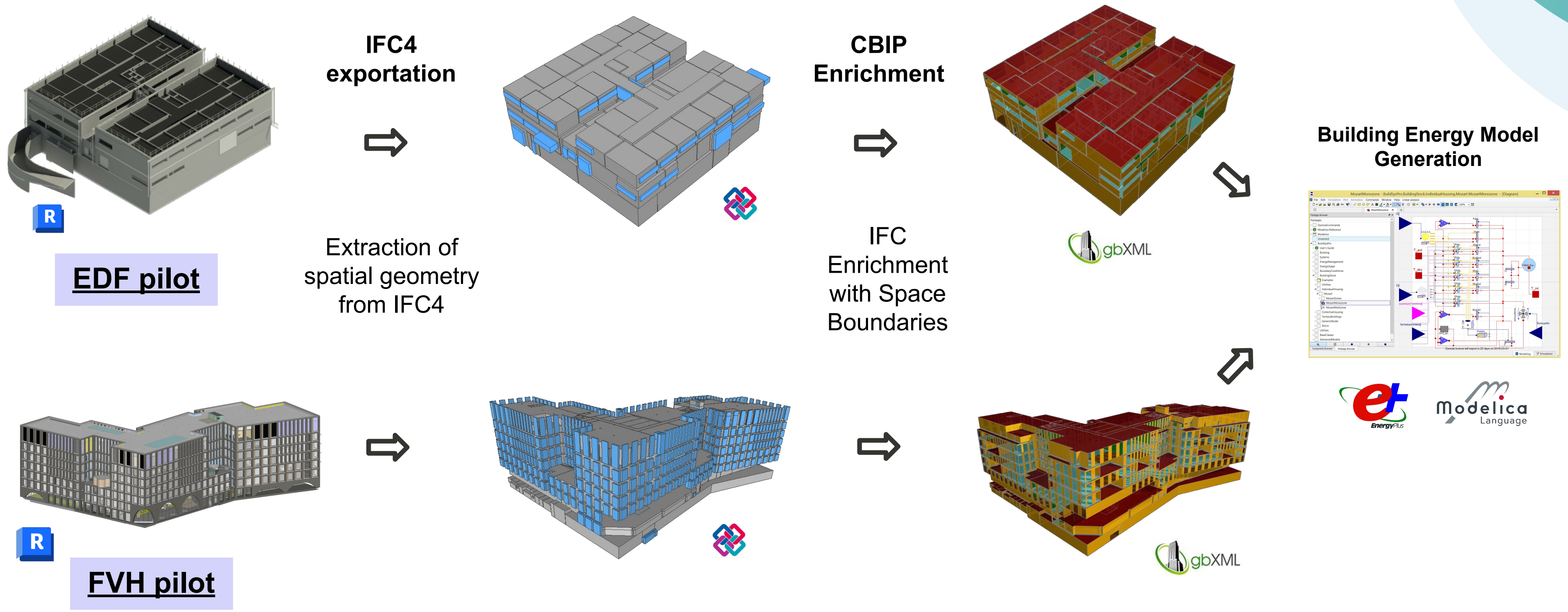
Semantic Enrichment: Energy Model Generation for Digital Twins

DigiBUILD



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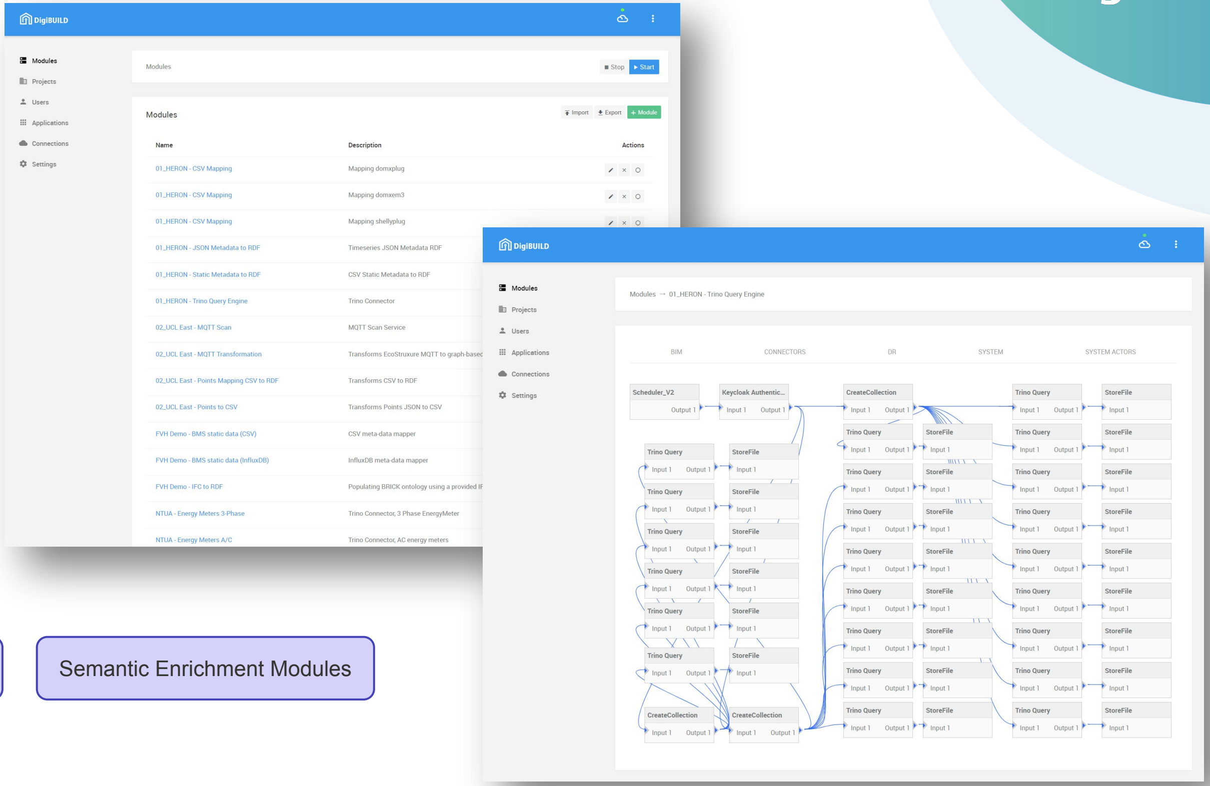
DigiBUILD Data Integration Middleware

Actor-base microservices framework

- CSV to RDF
- IFC to RDF
- JSON to RDF
- XML to RDF



RDF ETL Modules

Model Checking Modules

Semantic Enrichment Modules

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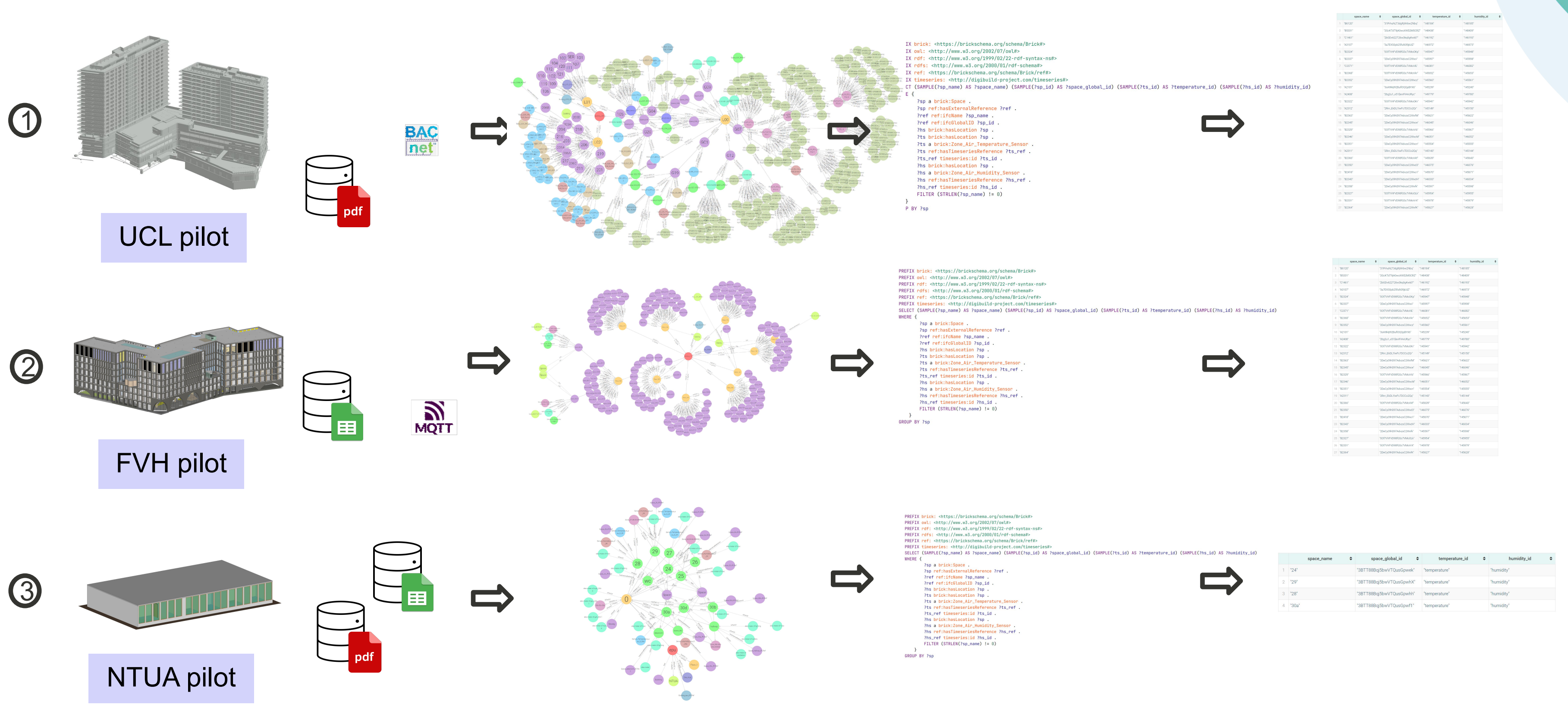
RDF ETL Modules: Knowledge Graph Generation



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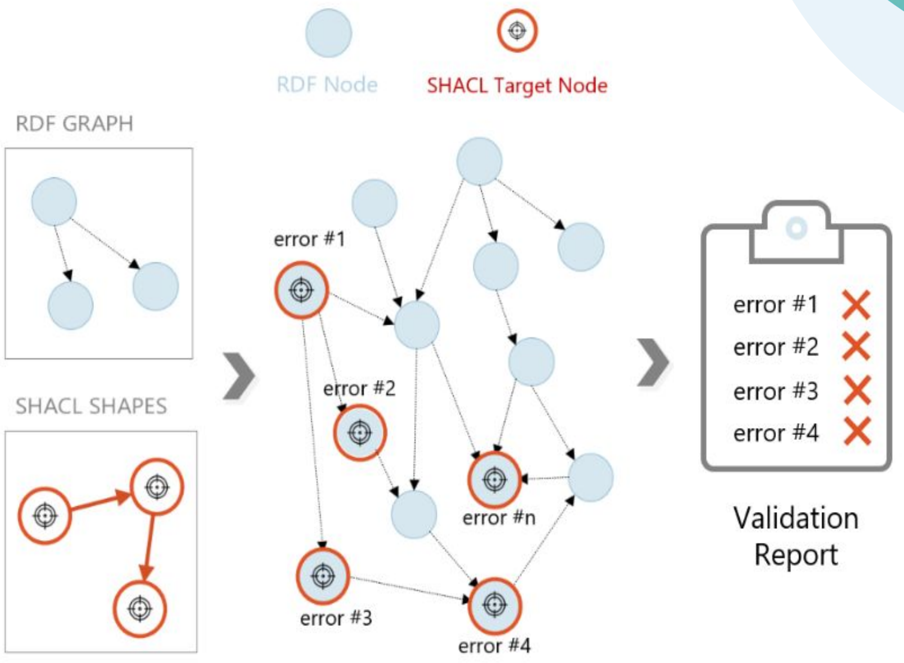
Semantic Validation & Completeness Checking

- Validate the **semantic completeness** of the RDF knowledge graphs
- **SHACL** (SHApes Constraint Language) takes the RDF graph and the SHACL Shapes
- **Validation Engine** (i.e., Pyshacl) returns a validation report including errors.



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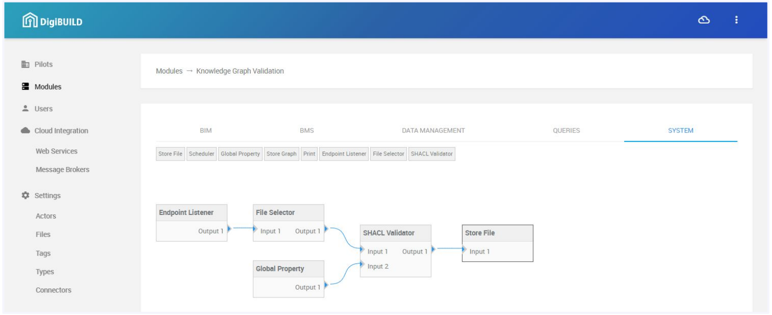
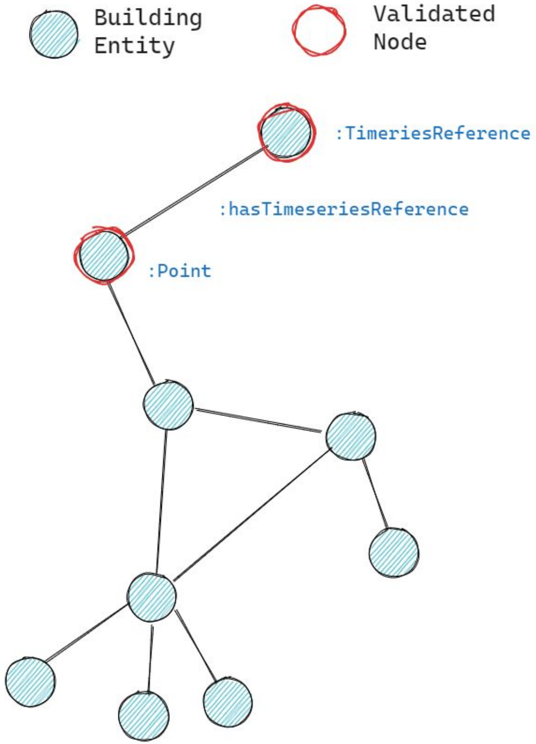
Semantic Validation & Completeness Checking

- For example, every `:Point` must have exactly one `:TimeseriesReference`
- Essential for the **integration** static and dynamic data
- **Automated** semantic validation for **thousands** of points
- Ensure **semantic completeness** for each knowledge graph





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BuildON architecture leveraging semantic models for portable applications

Flavia de Andrade, UCL

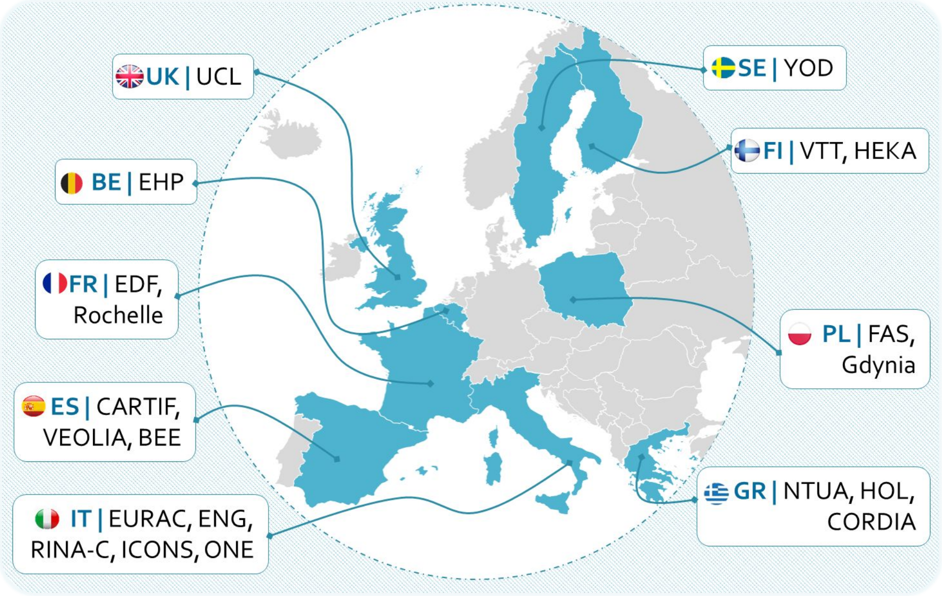
UCL

BuildON

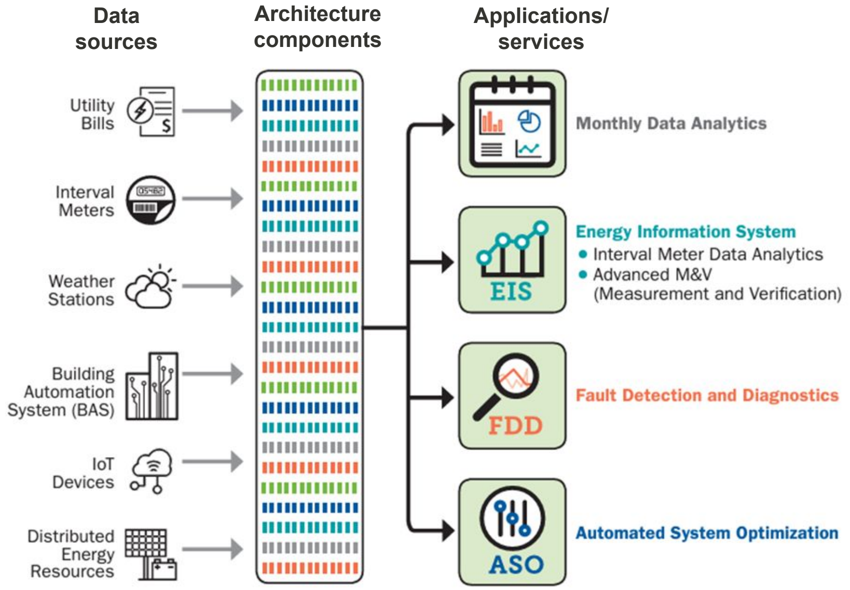
BuildON overview

***Affordable** and **digital** solutions to Build the next generatiON of smart EU buildings, focusing on **replicable** building applications.*

- Call: “Smarter buildings for better energy performance”
- Partnership: **20** organisations from **9** Countries (Coordinator: CARTIF,ES)
- 5 Pilots (mix residential and non-residential)
- 11 Monitor, Assess, Predict and Optimise (MAPO) services/applications

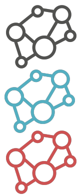


Software architecture



Crowe et al., 2020

Foundation to create components that support **portability of applications..**

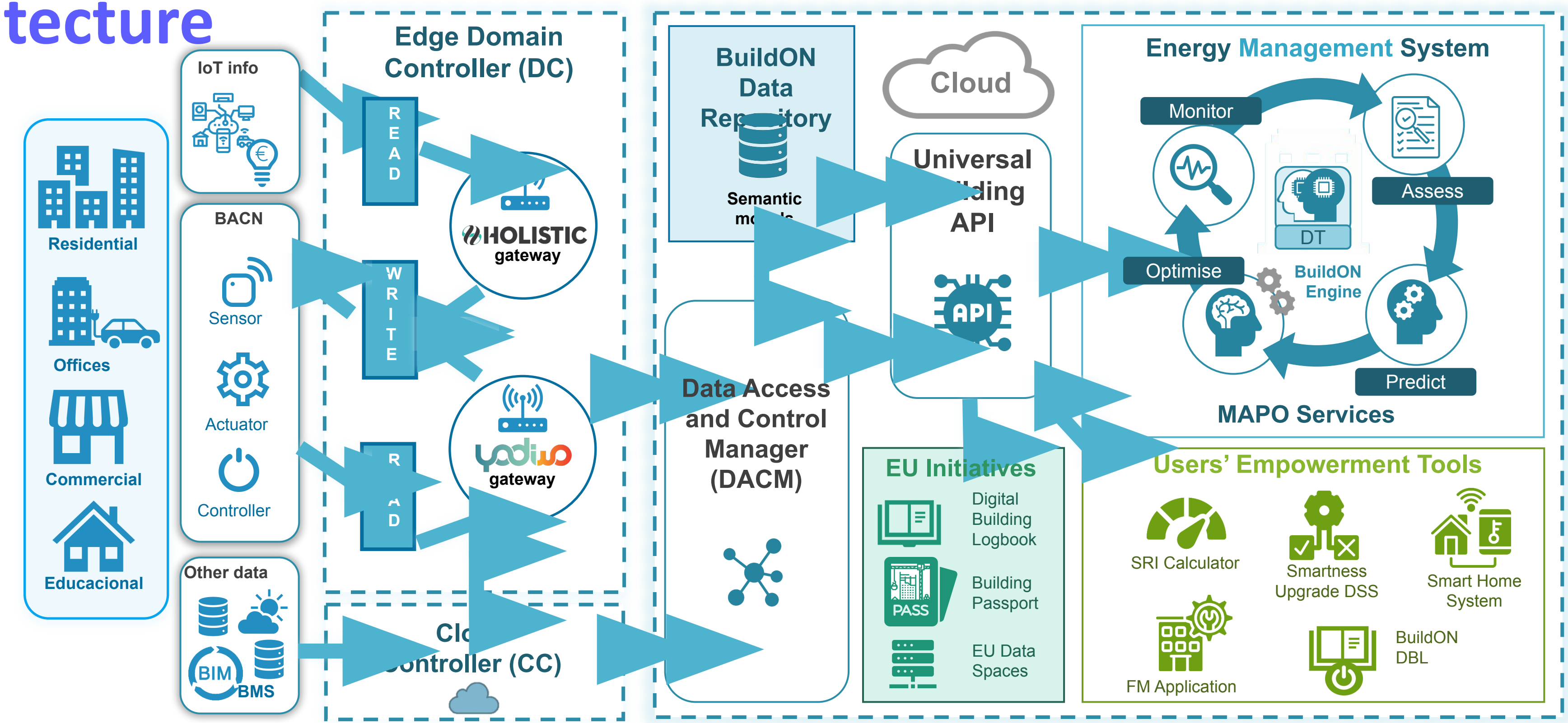


- Unified data access and contextualisation
- Enhanced interoperability (technical and semantic)
- Easy integration of new data sources
- Real-time response and data storage
- Security and privacy
- Reliability and fault tolerance
- Continuous logging for audit trails and root cause analysis

BuildON architecture

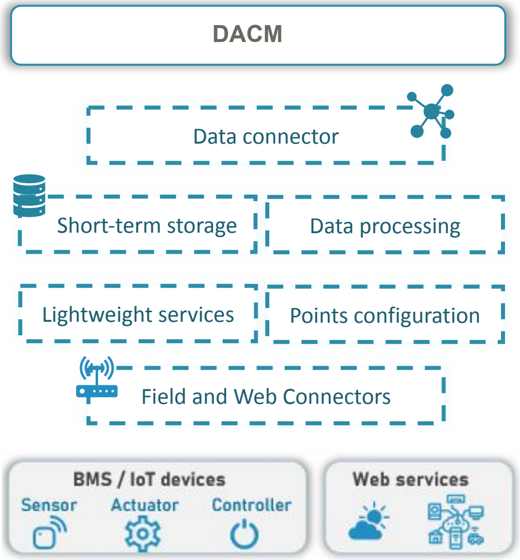
Core components

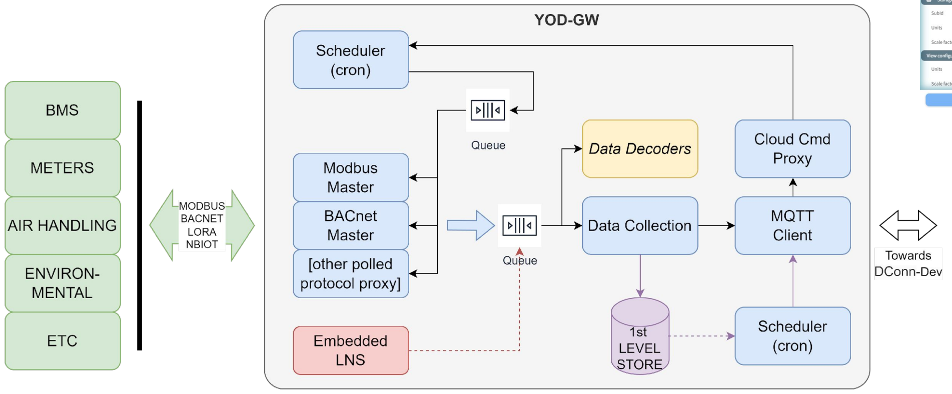
1. Edge domain controller (DC)
2. Cloud controller (CC)
3. Data access and control manager (DACM)
4. Data repository
5. Universal API

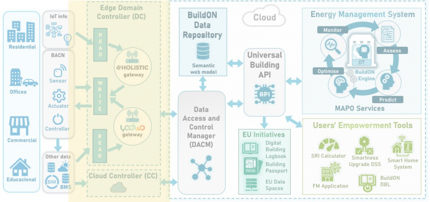


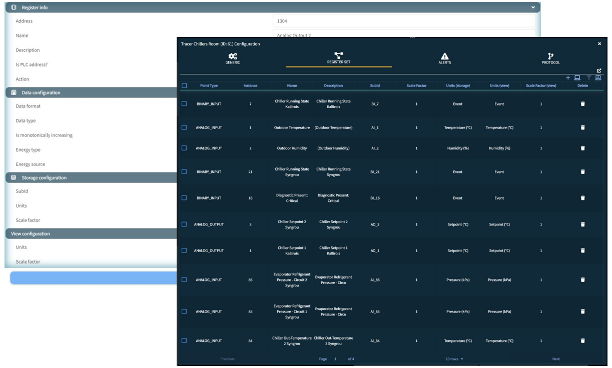
BuildON architecture

Domain Controller (DC) and Cloud Controller (CC)



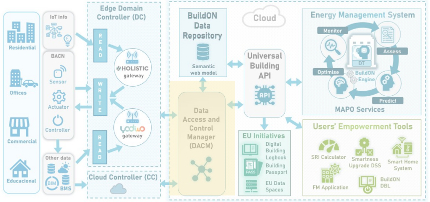




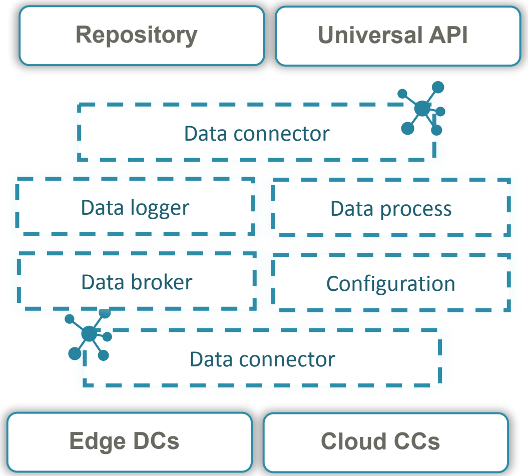


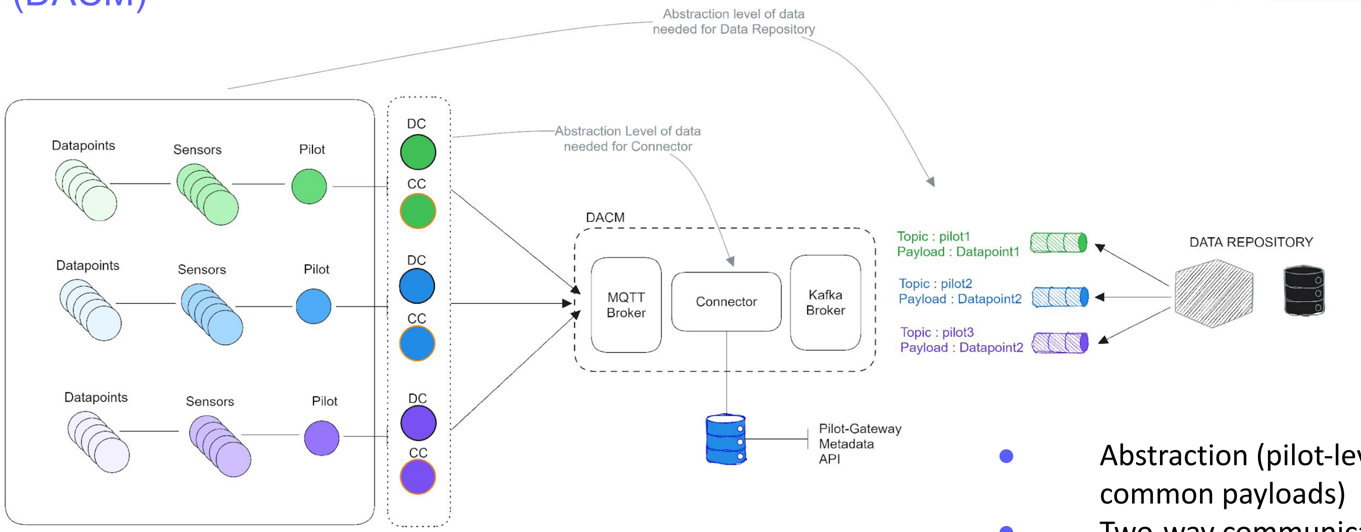
- Extensible interfaces, device-agnostic operations and multiple protocols
- Dynamic configuration and automated discovery (metadata)
- Data resilience (local storage during connectivity loss)

BuildON architecture



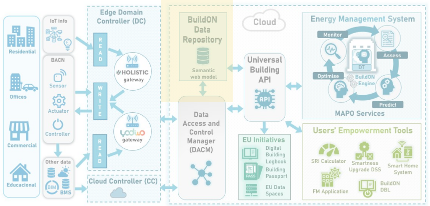
Data Access and Control Manager (DACM)



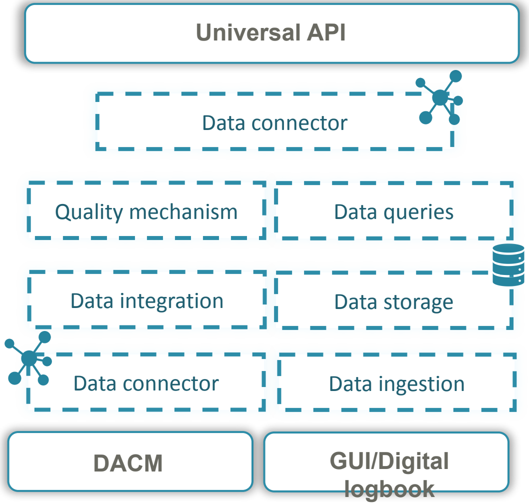


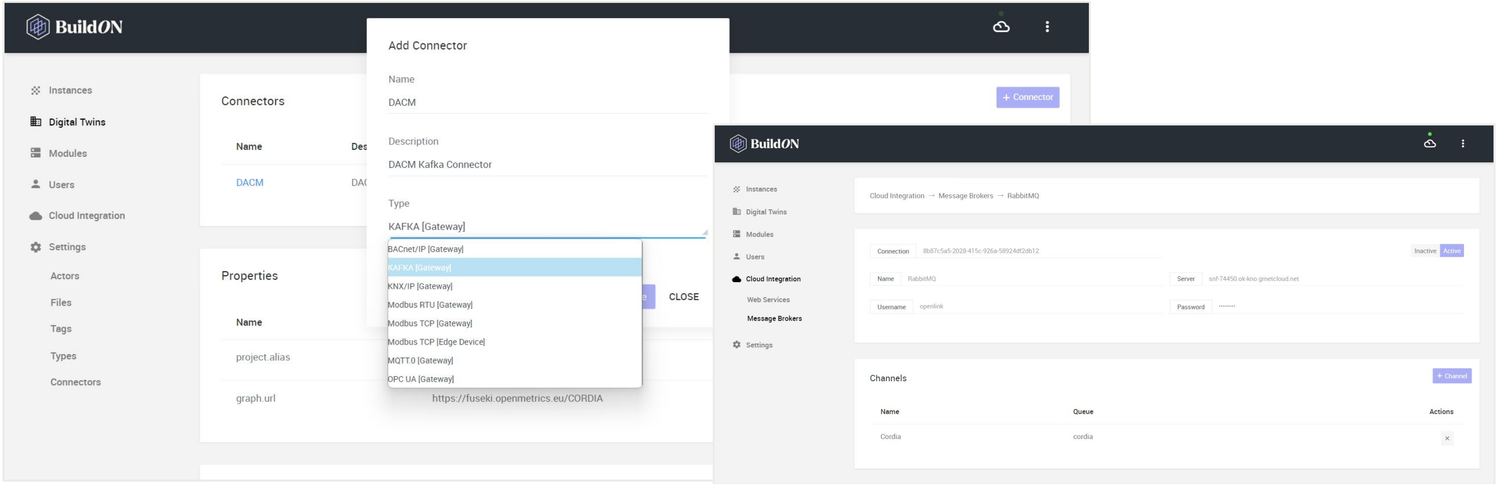
- Abstraction (pilot-level topics, common payloads)
- Two-way communication with DCs/CCs
- Quality checks (alerts, writing protection)

BuildON architecture



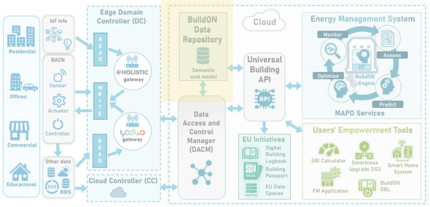
BuildON data repository



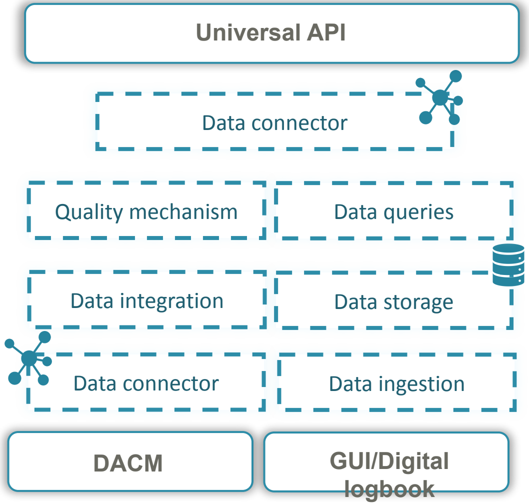


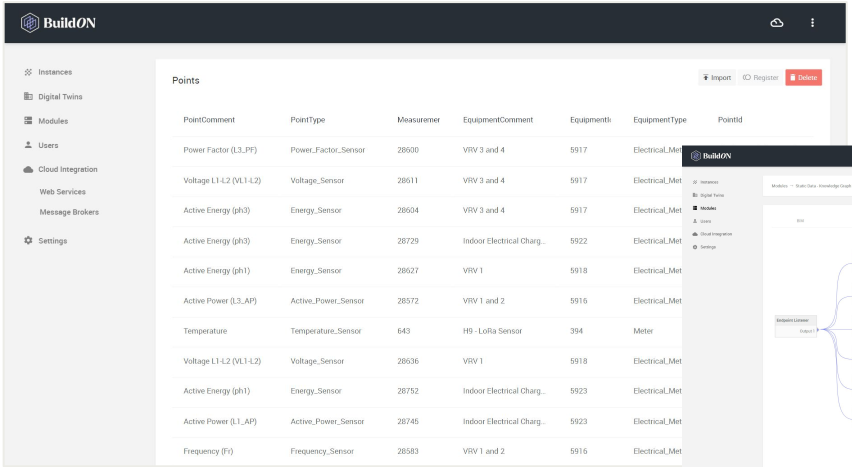
- Multiple data connectors

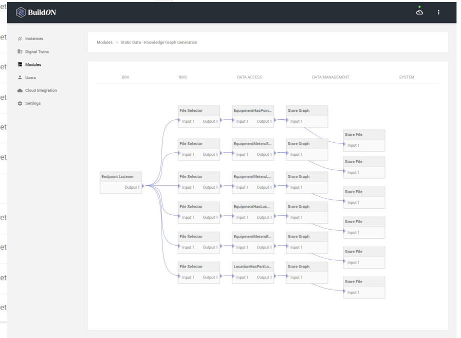
BuildON architecture



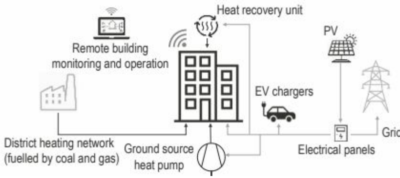
BuildON data repository

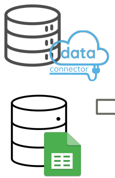


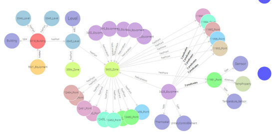




Pilot #n



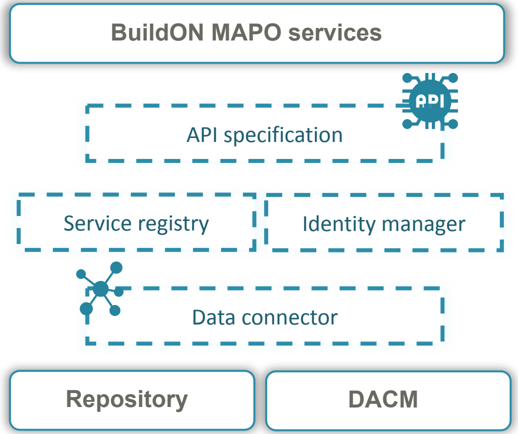


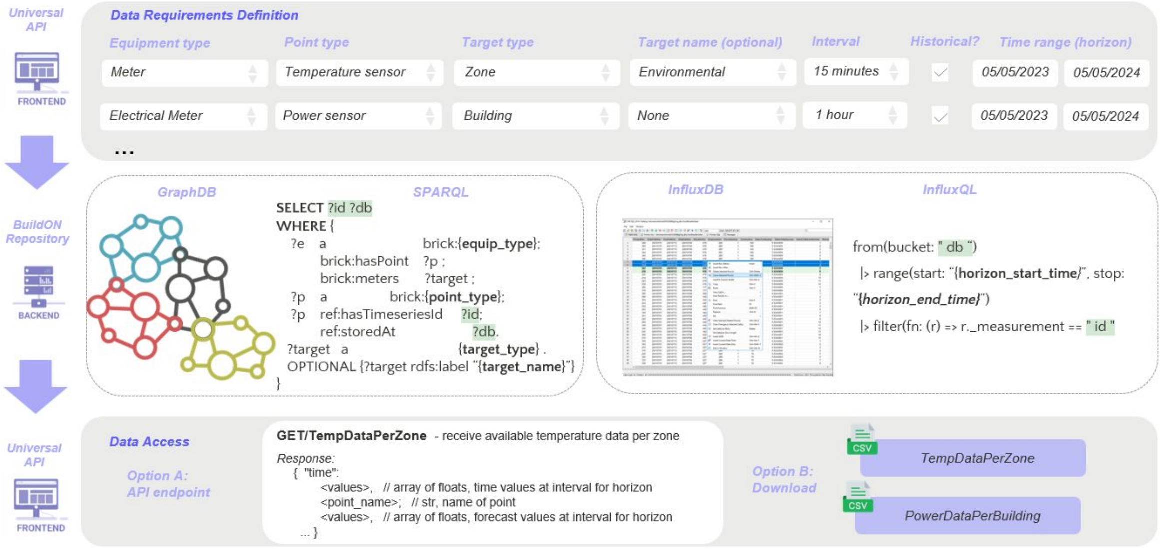


- Multiple data connectors
- Metadata registry for dynamic generation of graphs
- Support queries from Universal API

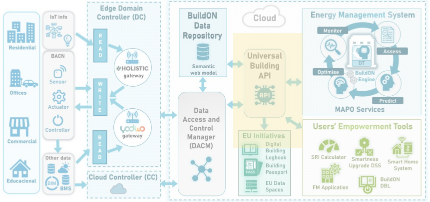
BuildON architecture

Universal Building API





- Standardised and well-defined interface to facilitate access to different pilots' data
- Read historical data stored via Repository
- Read real-time data and send control commands via DACM



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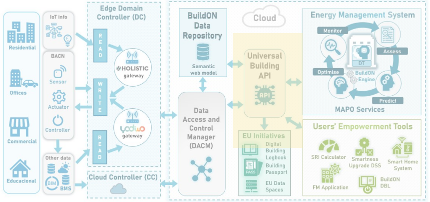
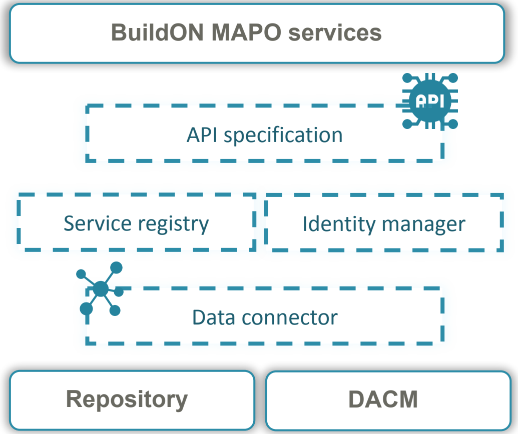
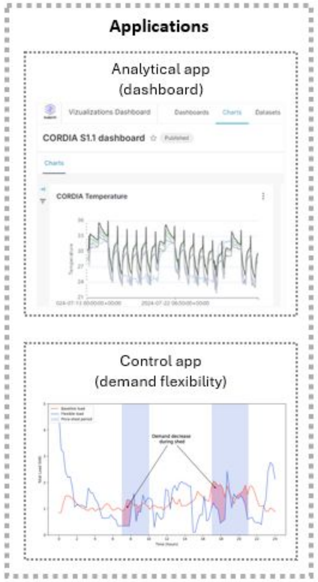
BuildON architecture



Universal Building API





- “App store" for MAPO services

Demonstration

Co-funded by
the European Union

For more information

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For BuildON:
buildon@live.ucl.ac.uk

Support and participating members of:

EBC
Energy in Buildings and Communities Programme

Acknowledgement: Members of the UCL Group K. Katsigarakis, G. Lilis, D. Mavrokapnidis, M. Wang

DigiBuild and BuildON project collaborators

BuildON

DigiBUILD

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LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY

RESEARCH TO MARKET SOLUTION

DATA-DRIVEN SMART BUILDINGS

WORKSHOP

Enhancing demand response and building management through AI-driven energy services

Efstathios Stamatopoulos (National Technical University of Athens)
Elissaios Sarmas (National Technical University of Athens)

dedalus DigiBUILD

www.sustainableplaces.eu

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INTRODUCTION

- **Energy transition**
  - *From fossil fuels to* ***renewable energy***
  - ***Sustainable*** *energy systems*
- **Data** and **AI-driven** energy services
  - Vast amounts of **data**
  - **Demand Response** and **Management Systems** in Buildings
- Technology's **Role**
  - AI as **enabler**
  - **Optimize** energy use in buildings
  - **Reduce GHG** emissions

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Challenges

Current Energy Consumption in EU's **Residential** and **Building Sector**

Demand for Energy Flexibility

Need for Smart Building Solutions

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DEDALUS and DigiBUILD

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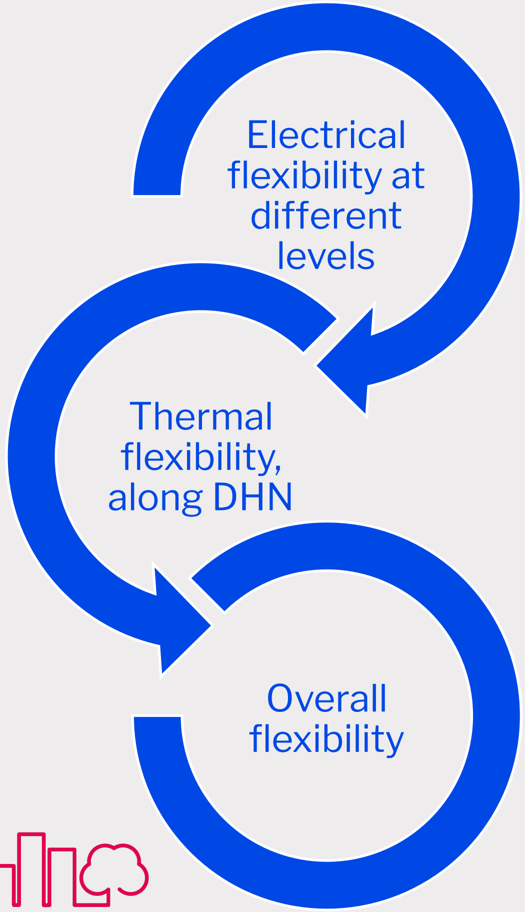

Flexibility modeling for data-driven residential DR

- Building-level
- District level
- Virtual cluster of buildings
- Cross-commodity scenarios

DigiBUILD

AI-based data-driven services for the built environment

- Energy Profiling, Benchmarking and Forecasting
- Energy resource Management
- Enhanced Comfort and Well-being
- Renovation roadmaps
- Climate resilient buildings

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Aggregated Flexibility

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Issue without Device-Specific Data

- Lack of detailed device-specific information and data makes it difficult to identify and quantify flexibility within a building.

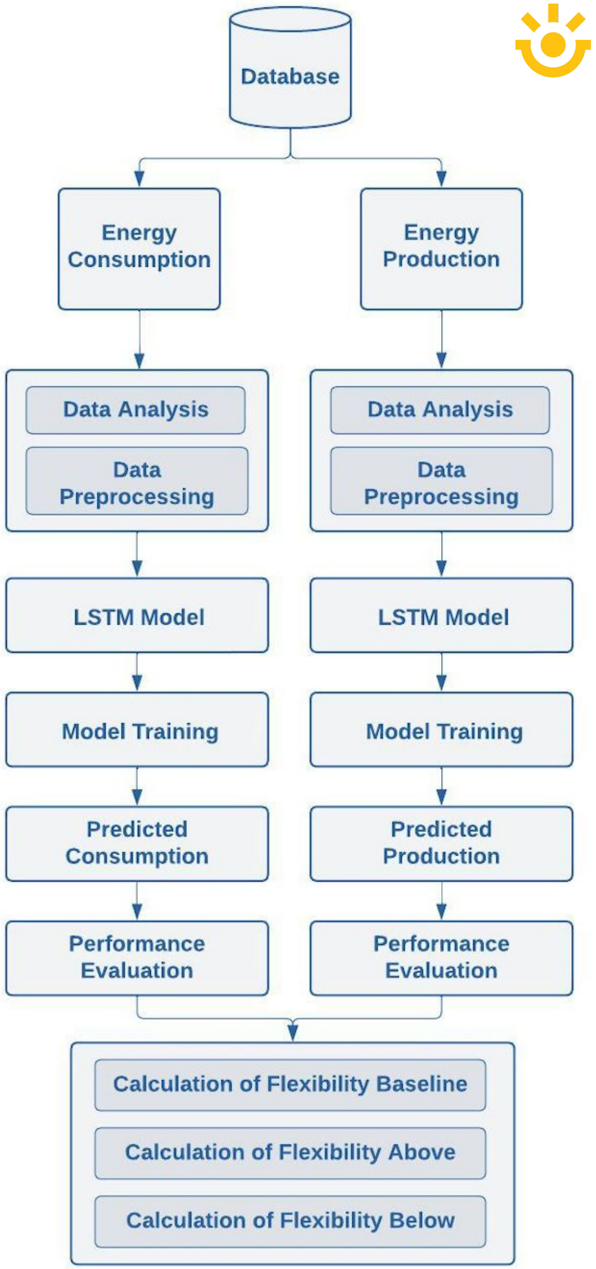
Solution

- Develop a hypothetical approach to construct an aggregated flexibility baseline load using building-level data.
- This baseline approximates electricity consumption and production in the absence of specific DR events.

Methodology Overview

Steps:

1. **Energy Prediction Model:** Forecast energy consumption and production using a Long Short-Term Memory (LSTM) model.
2. **Flexibility Definition:** Establish a baseline for expected energy patterns, including maximum and minimum flexibility.
3. **Comparison with Baseline:** Identify deviations between predicted values and baseline to determine flexibility.



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Data Collection

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Building:

- Residential building in Wiener Neustadt, Austria.
- The building consists of two floors and for each floor there is a dedicated photovoltaic (PV) system supplying electricity.

Dataset:

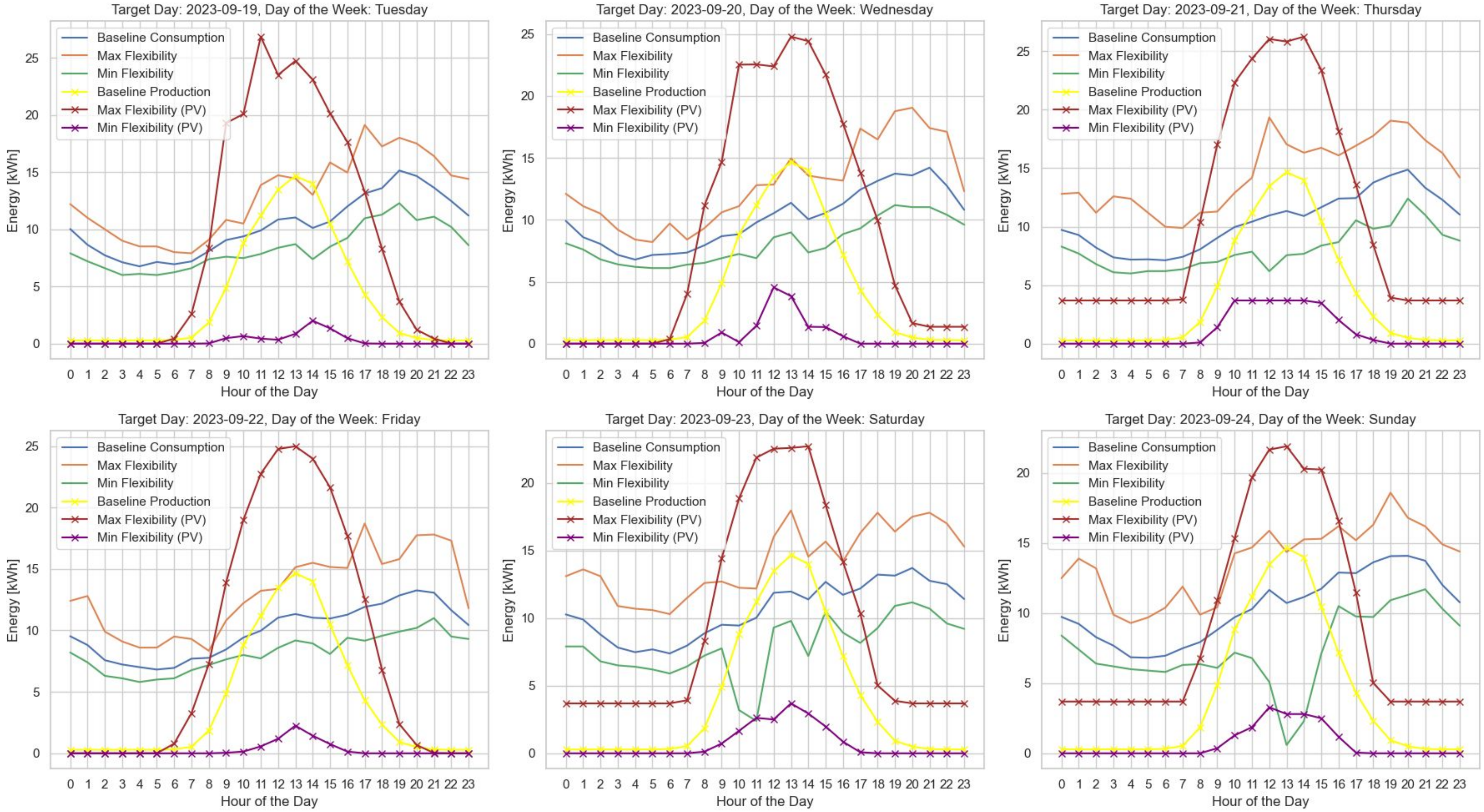
- Energy consumption data
- PV production data

Duration:

- Two years of hourly data

Weekday Analysis

- Analysis for each day of the week to understand daily patterns.



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Prediction Analysis

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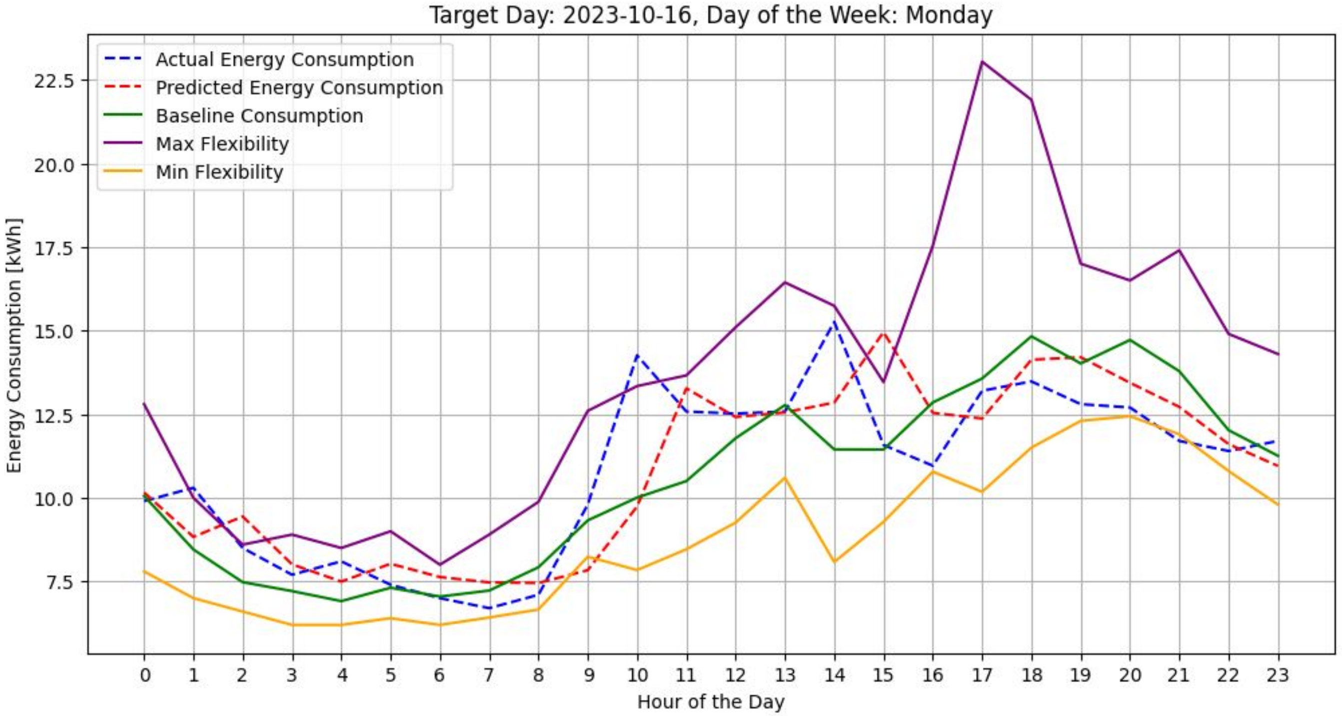
- Visual comparison of predicted values with baseline and flexibility levels.

Baseline Calculation:

- Weekday analysis
- Establish a reference baseline by calculating the average energy consumption and production for each hour for all the corresponding weekdays over the past 30 days.
- This baseline represents the expected normal operating conditions without any demand response events.

Flexibility Levels:

- Weekday analysis
- Determine the potential range of flexibility by identifying the maximum and minimum energy consumption and production values for each hour for all the corresponding weekdays over the same 30-day period.
- These levels indicate the upper and lower bounds within which energy adjustments can be made, highlighting the building's potential for DR participation.



Flexibility Estimation (1/2)

- Calculation of Energy Flexibility Indicators (EFIs) for each hour of the day

EFIs for Consumption

$$EFI_{up,con}[h] = \frac{Flexibility_{max,con}[h] - Baseline_{con}[h]}{Baseline_{con}[h]} * 100\%$$

$$EFI_{down,con}[h] = \frac{abs\left(Flexibility_{min,con}[h] - Baseline_{con}[h]\right)}{Baseline_{con}[h]} * 100\%$$

EFIs for Production

$$EFI_{up,pro}[h] = \frac{Flexibility_{max,pro}[h] - Baseline_{pro}[h]}{Baseline_{pro}[h]} * 100\%$$

$$EFI_{down,pro}[h] = \frac{abs(Flexibility_{min,pro}[h] - Baseline_{pro}[h])}{Baseline_{pro}[h]} * 100\%$$

Flexibility Estimation (2/2)

- Split the day in time intervals suitable for DR strategies and calculate EFIs for these time intervals

	Peak consumption (hours)	Off Peak consumption (hours)
Peak Production (hours)	A	B
Off Peak Production (hours)	C	D

$$EFI_{peak,peak\ up} = \frac{\sum_{h \epsilon A}(EFI_{up,con}[h])}{\#A},$$

A: $hour\ \epsilon\ peak\ consumption\ \cap\ peak\ production$

$$EFI_{offpeak,peak\ up} = \frac{\sum_{h \epsilon B}(EFI_{up,con}[h])}{\#B},$$

B: $hour\ \epsilon\ off\ peak\ consumption\ \cap\ peak\ production$

$$EFI_{peak,offpeak\ up} = \frac{\sum_{h \epsilon C}(EFI_{up,con}[h])}{\#C},$$

C: $hour\ \epsilon\ peak\ consumption\ \cap\ off\ peak\ production$

$$EFI_{offpeak,offpeak\ up} = \frac{\sum_{h \epsilon D}(EFI_{up,con}[h])}{\#D},$$

D: $hour\ \epsilon\ off\ peak\ consumption\ \cap\ off\ peak\ production$

$$EFI_{peak,peak\ down} = \frac{\sum_{h \epsilon A}(EFI_{down,con}[h])}{\#A},$$

A: $hour\ \epsilon\ peak\ consumption\ \cap\ peak\ production$

$$EFI_{offpeak,peak\ down} = \frac{\sum_{h \epsilon B}(EFI_{down,con}[h])}{\#B},$$

B: $hour\ \epsilon\ off\ peak\ consumption\ \cap\ peak\ production$

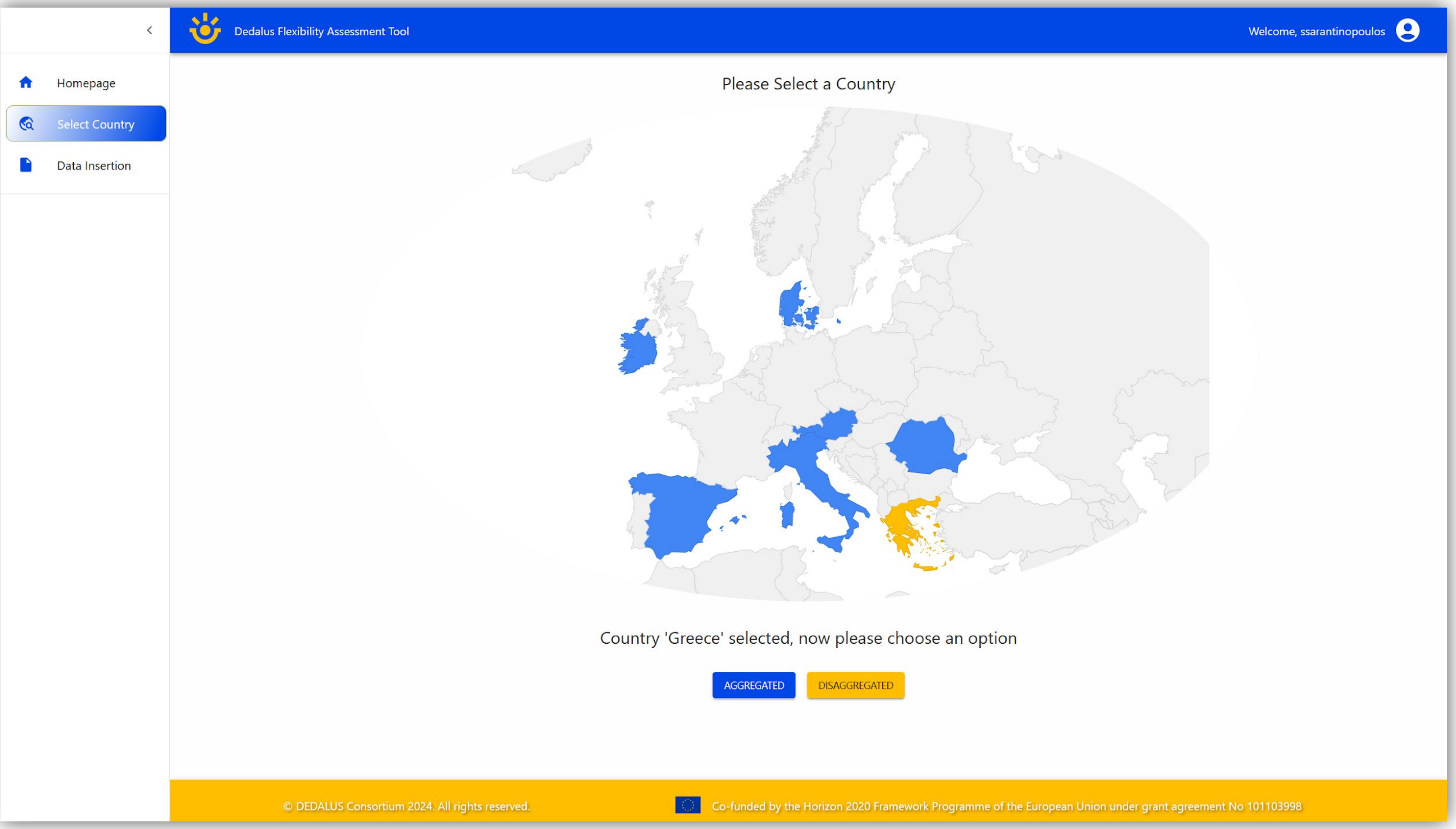
$$EFI_{peak,offpeak\ down} = \frac{\sum_{h \epsilon C}(EFI_{down,con}[h])}{\#C},$$

C: $hour\ \epsilon\ peak\ consumption\ \cap\ off\ peak\ production$

$$EFI_{offpeak,offpeak\ down} = \frac{\sum_{h \epsilon D}(EFI_{down,con}[h])}{\#D},$$

D: $hour\ \epsilon\ off\ peak\ consumption\ \cap\ off\ peak\ production$

Flexibility Assessment Tool



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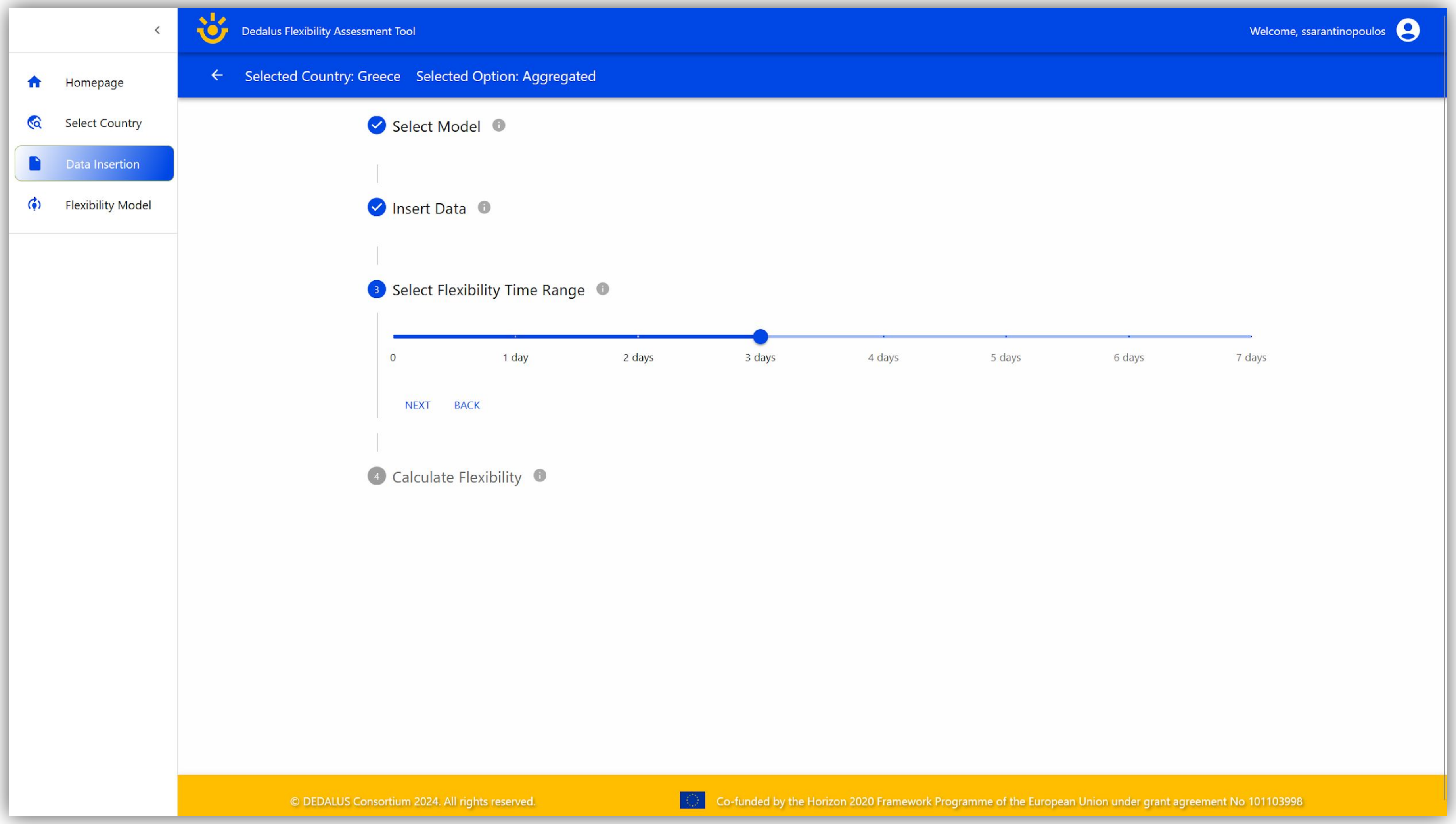
Flexibility Assessment Tool



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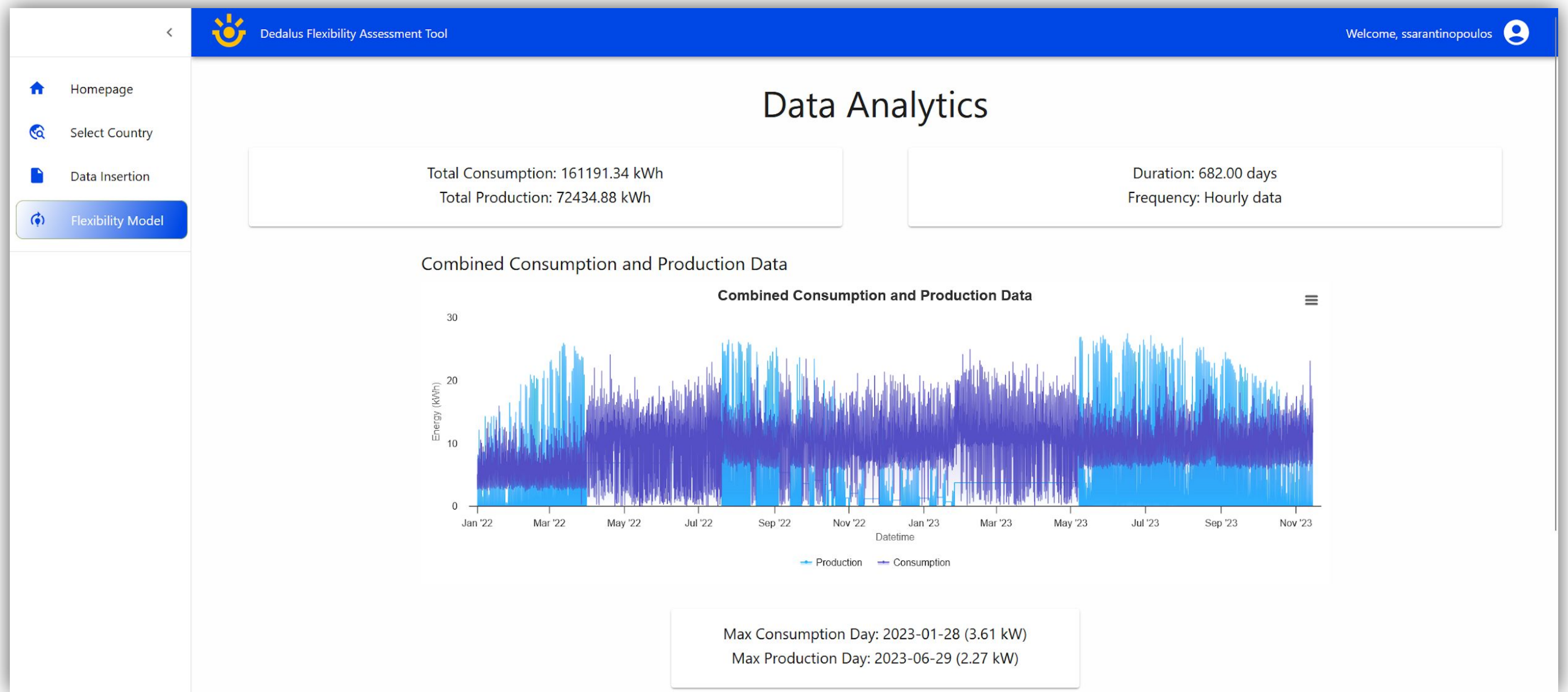
Flexibility Assessment Tool



While the model is training, he is presented with some data analytics on the uploaded dataset.

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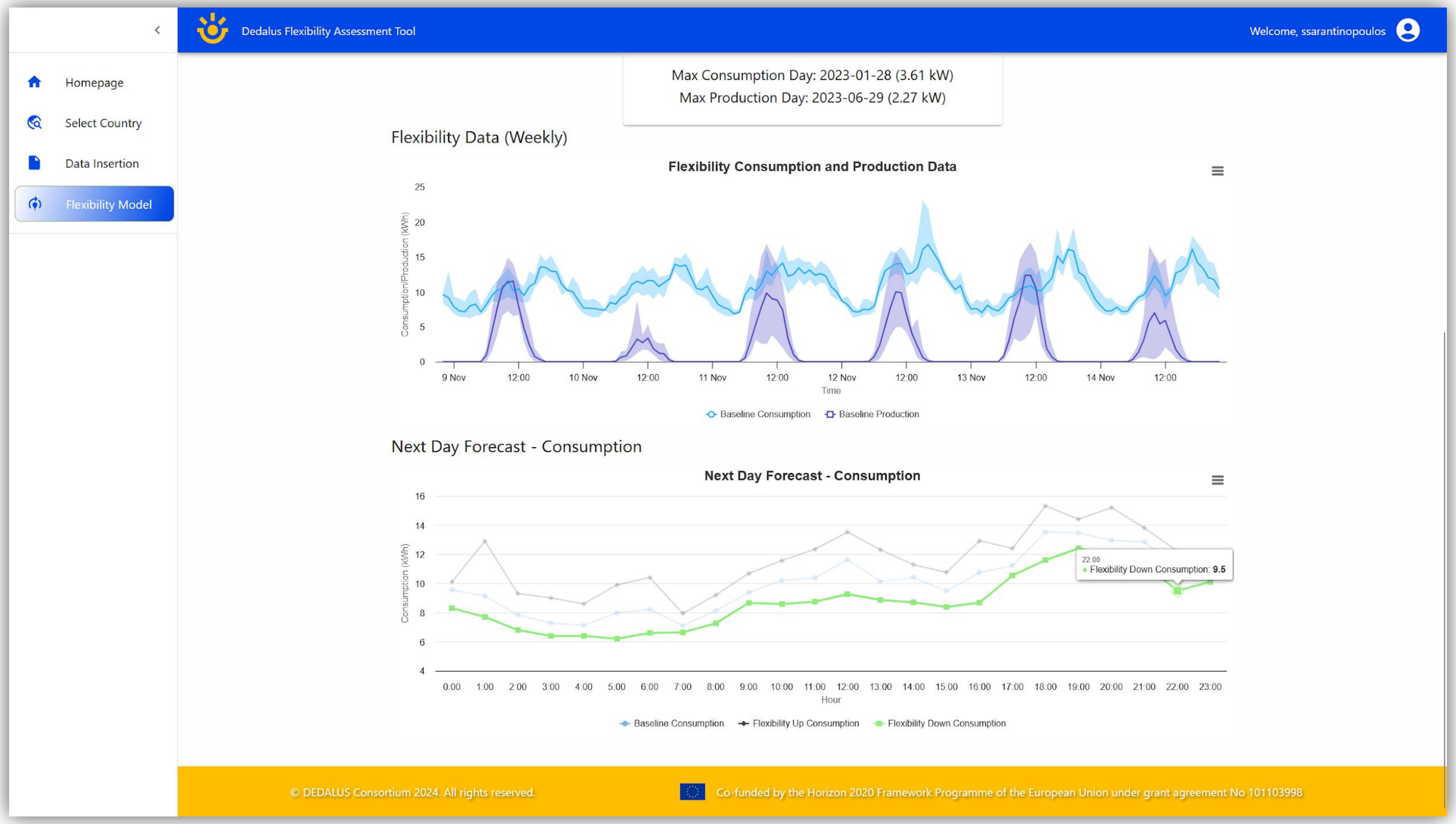
Flexibility Assessment Tool



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NILM (Non-Intrusive Load Monitoring)

Disaggregation of the total household energy consumption into individual appliance usage without requiring intrusive sensors on each device.

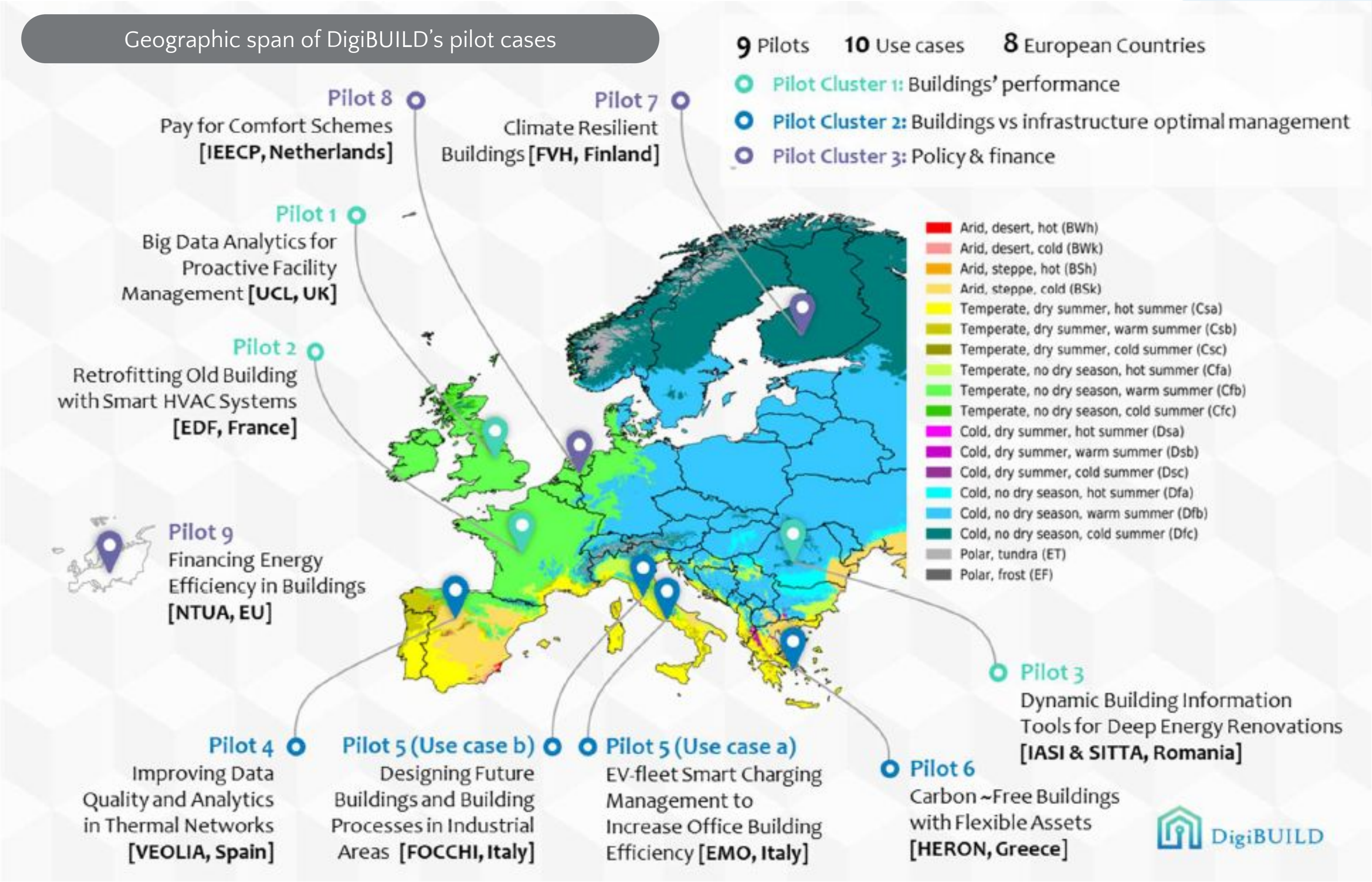
- **Models Used:** Factorial Hidden Markov Model (FHMM), Combinatorial Optimization (CO).

- **Identification of Flexible Devices**

		Appliances							
	Houses	TV	A/C	Dish Washer	Washer Machine	Washer Machine / Dryer	Dryer	EV	Freezer
Number	28	29	23	10	19	3	3	2	1

Enhancing Building Management through services for better-informed decision making

- AI-Based Services for finer-grained Energy **Profiling** and **Forecasting**
- Data-driven services for Energy Recourse **Management**
- Data-Driven Energy & Non-Energy Services for **Enhanced Comfort and well-being**
- Data-driven services **for Renovation Roadmaps** and **Energy Efficiency Financing**
- Services supporting Decision-Making under Uncertainty for **Efficient and Climate Resilient Buildings**



DigiBUILD

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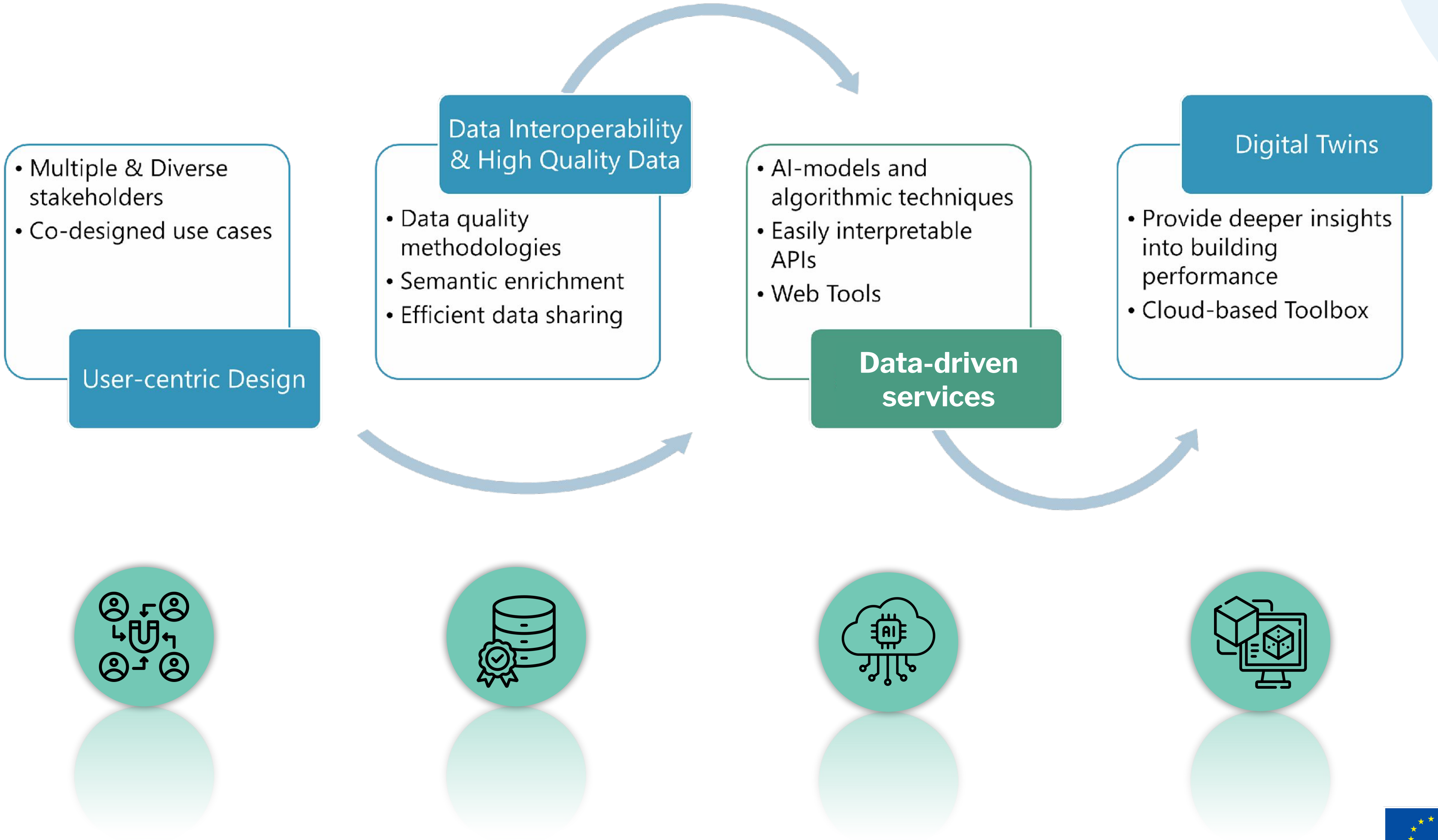
Services' Role in DigiBUILD

DigiBUILD



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AI-based services for finer grained energy profiling and forecasting

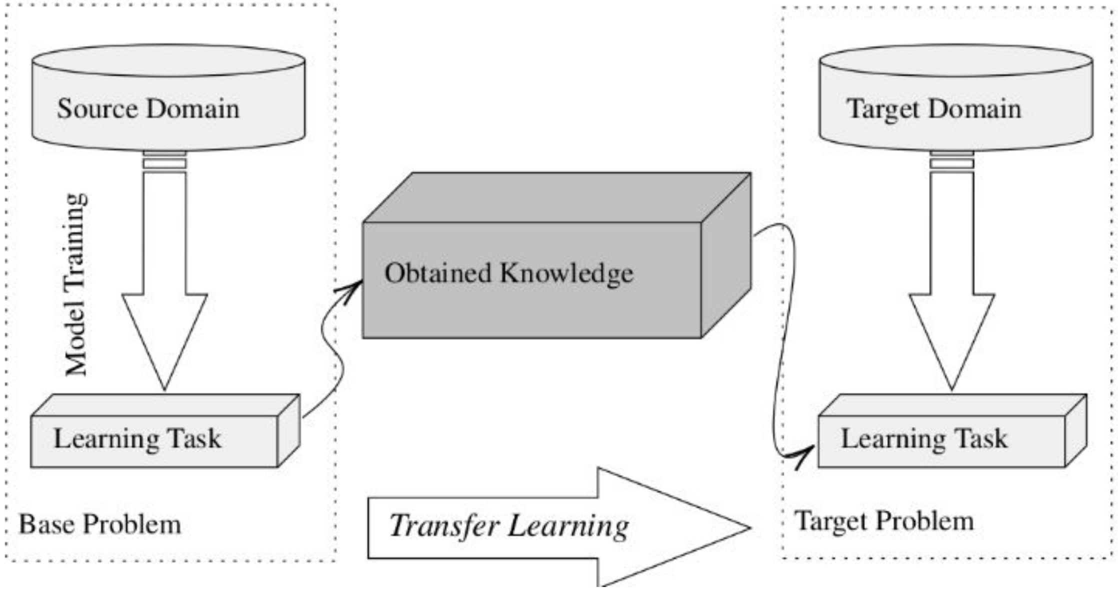
DigiBUILD

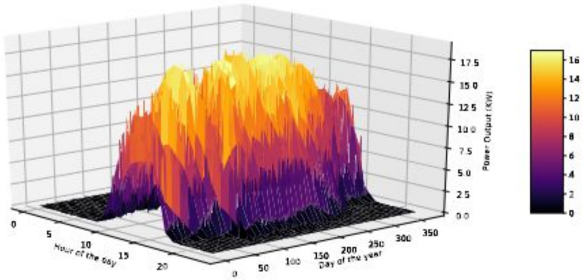
Objectives:

- Building Demand Forecasting
- Advanced monitoring and Benchmarking
- RES Forecasting

Tools:

- ✔ ML Algorithms
- ✔ Neural Networks
- ✔ Transfer Learning
- ✔ Incremental Learning

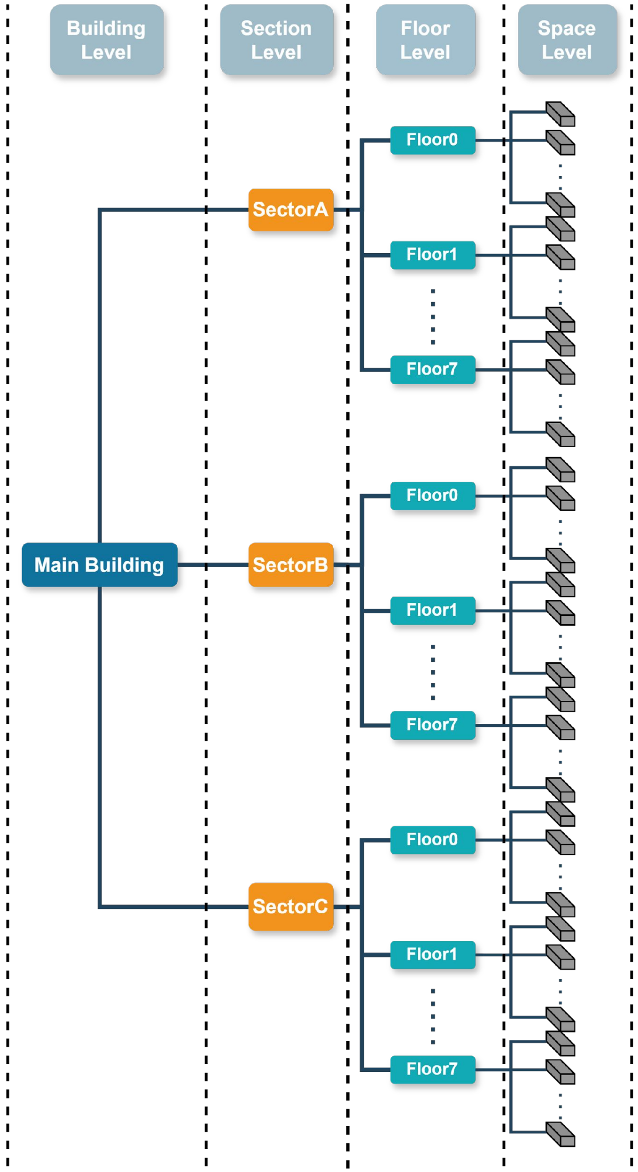




AI-based services for finer grained energy profiling and forecasting

MLP NN Hierarchical Forecasting

- Hierarchical-level segmentation
  - Handles **irregular time series data** effectively
  - Adaptable to **dynamic environments**
- Advantages
  - Great **balance** between **accuracy** and **efficiency** in training time and resources.
  - **Better insights and decision-making** for energy management in complex buildings



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AI-based services for finer grained energy profiling and forecasting

DigiBUILD

Energy Efficiency and HVAC Units Replacement in Office Buildings

- Scalable approach
  - **User-friendly** web-app
  - **Integrated** with BMS
- Monitoring & Benchmarking
  - Model **User behavior** and **occupancy patterns**
  - Real-time data **monitoring** and **visualization**
- Replacements Recommendations
  - **Economic returns** and **energy savings**

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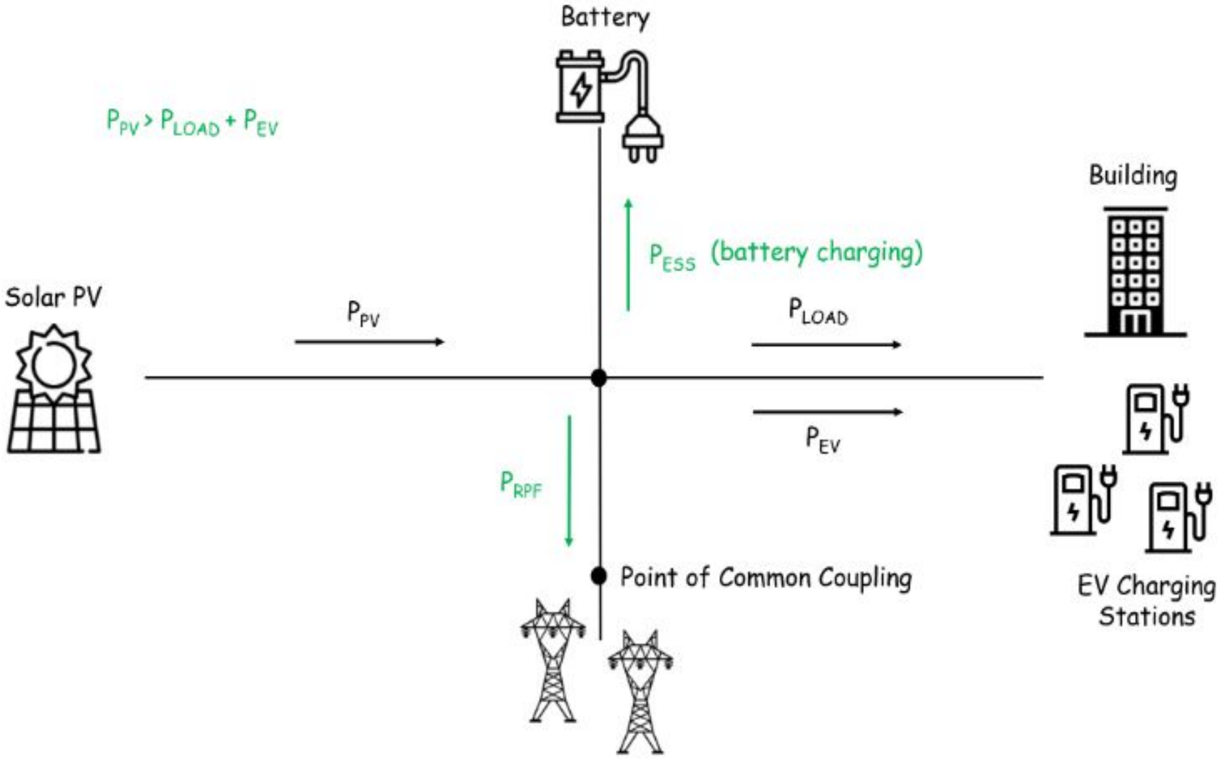
Data-driven services for energy resources management

DigiBUILD

The Smart Grid Example



Objectives:

- Flexibility Management
- Optimal Management of Flexible Loads
- District Heating Management
- E-mobility

Tools:

- ✔ Reinforcement Learning
- ✔ Gradient Boosting
- ✔ Optimization Algorithms
- ✔ Heuristic Algorithms

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Data-driven services for energy resources management

Energy forecasting

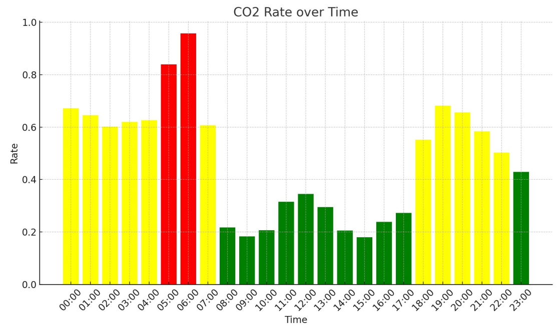
- LightGBM
- Reinforcement Learning

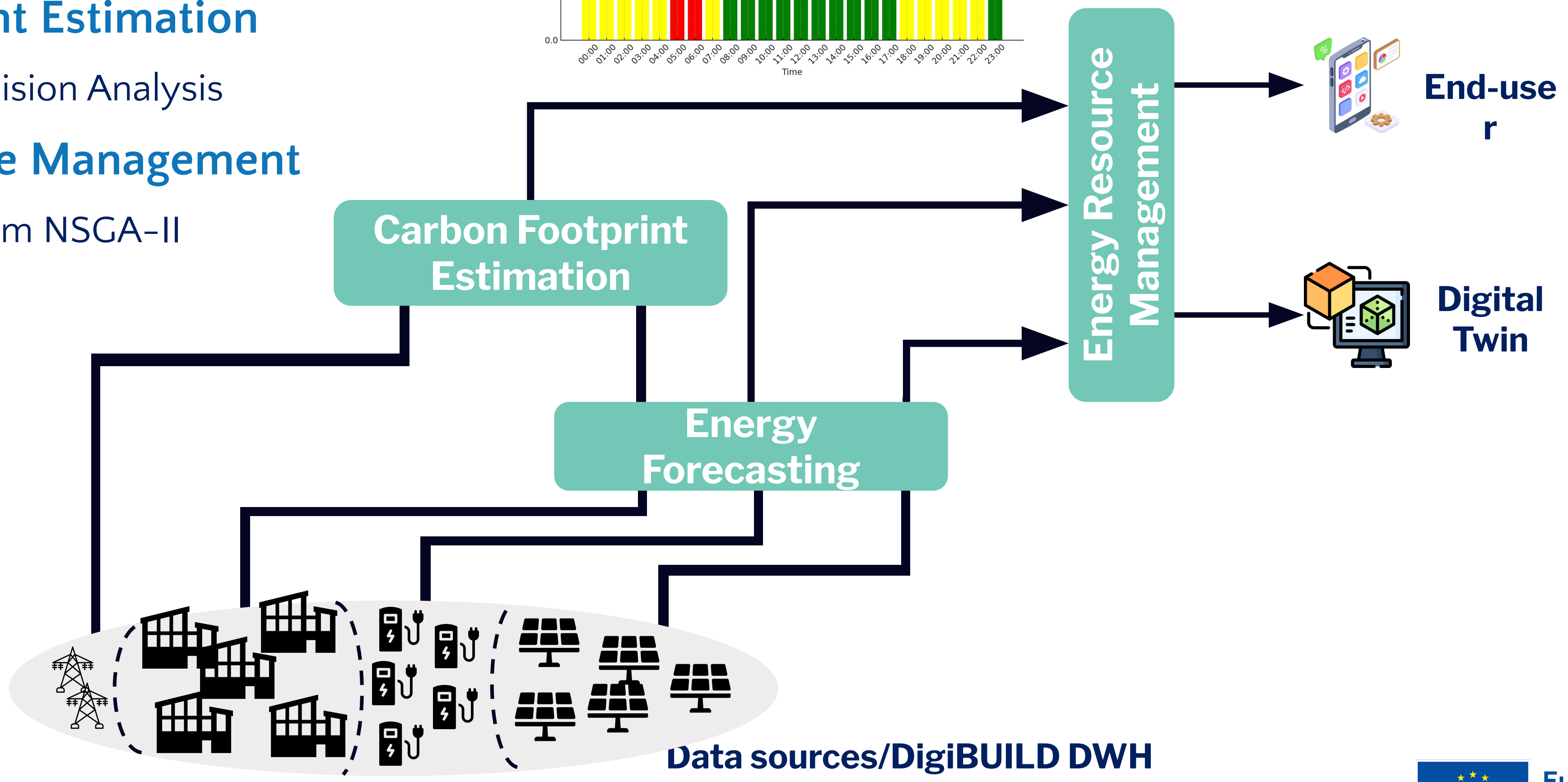
Carbon Footprint Estimation

- Multicriteria Decision Analysis

Energy Resource Management

- Optimised custom NSGA-II





DigiBUILD

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Decision-making under uncertainty tools for efficient and climate resilient buildings

DigiBUILD

- ❑ Accurate Evaluation of Climate Resilience
- ❑ Comprehensive Understanding of Building Vulnerabilities
- ❑ User-Friendly Analytical Tool

- ✓ Innovative and Detailed Scoring System
- ✓ Location-Specific Assessment
- ✓ Intuitive Web-Based Tool

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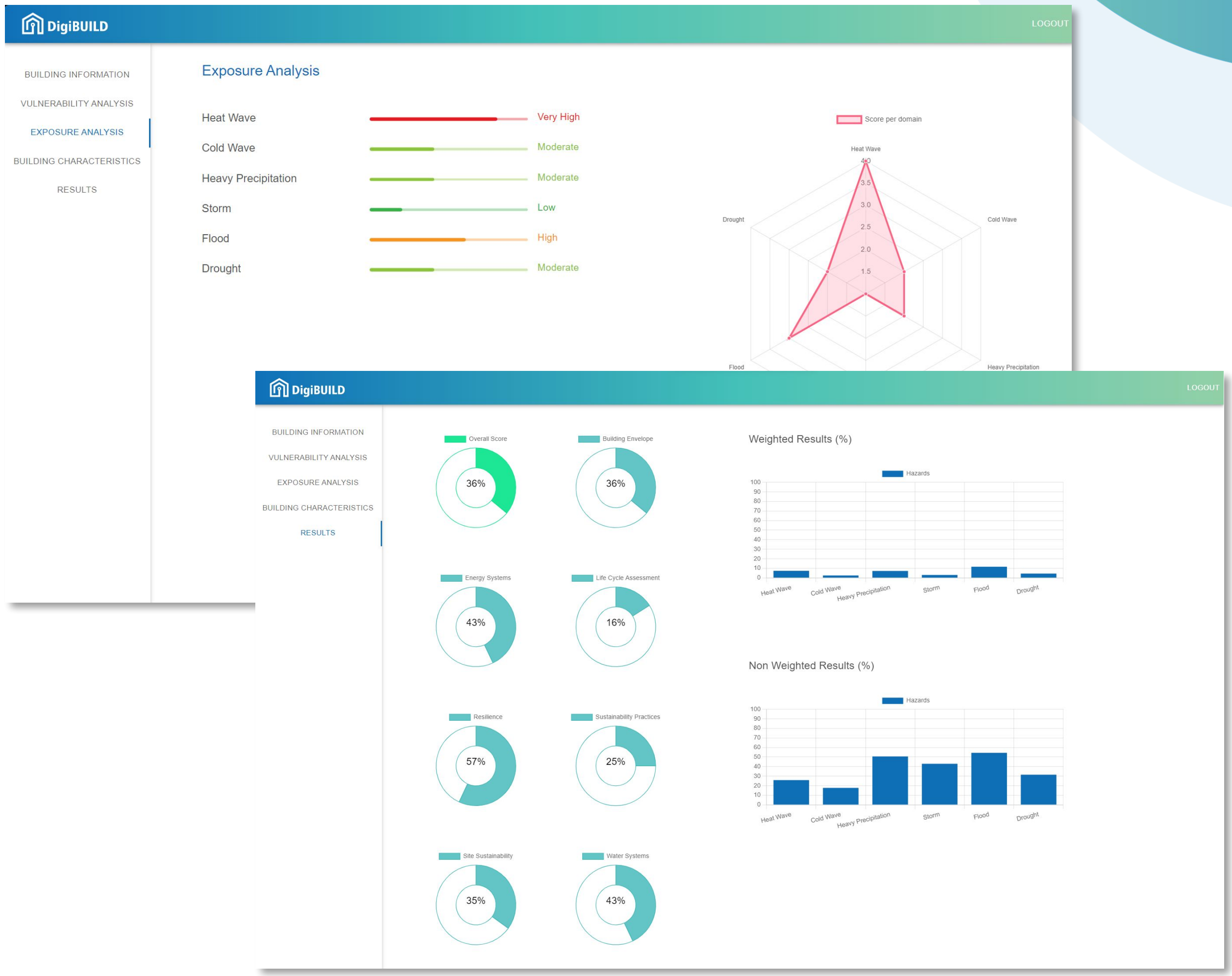
Decision-making under uncertainty tools for efficient and climate resilient buildings

DigiBUILD

- ✔ Assesses a building's ability to **anticipate, prepare for, respond to, and recover** from climate events.
- ✔ A **dynamic weighting system** based on climate exposure was developed, allowing for **location-specific** resilience assessments.
- ✔ Evaluates **vulnerability** in different domains of **buildings' components** (energy systems, building envelope, water systems, etc.)



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KEY TAKEWAYS

- **AI-driven energy services** optimize energy use, cut costs, and enhance sustainability.
- **Smart building solutions** improve energy flexibility, resilience, and occupant comfort.
- EU projects like **DigiBUILD** and **DEDALUS** are pioneering the future of energy management by leveraging AI to tackle energy challenges in buildings.
- Adopting these innovations is critical for achieving the EU's **2050 zero-emission building stock** target and enhancing resilience.

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FUTURE IMPACT

- **Scaling smart technologies** will be crucial in achieving climate and energy goals.
- AI and data-driven solutions will revolutionize **energy management**, leading to more resilient and adaptive buildings.
- **Policy makers** and regulations play a vital role in accelerating the adoption of these innovations.
- The **next decade** will be pivotal in accelerating the adoption of these innovations across the EU.

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LIST

R2M RESEARCH TO MARKET SOLUTION

DATA-DRIVEN SMART BUILDINGS

WORKSHOP

Thank you!

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MODERATE

Marketable Open Data Solution for Optimized Building-related Energy Services

Leveraging shared knowledge to boost data-driven workflows

Services for Advanced Energy Efficiency

25.9.2024 - Workshop

Cristian Pozza

Eurac Research

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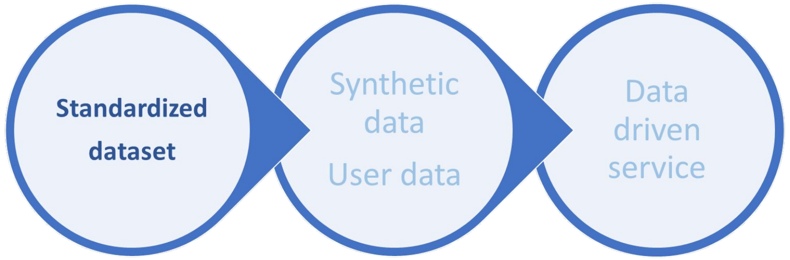
This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101069834. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA

Drivers

- Needs:
  - Data collection, Standardization (previous presentation)
  - Complete, trusted high quality datasets
  - Reliable data-driven services
  - Interoperability

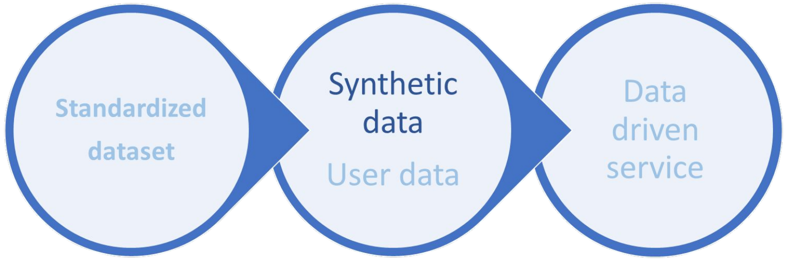
- Advanced data-driven services are there
- Still barriers are in:
  - sharing data with services
  - integrating services in organizations' workflows

MODERATE Approach



1. Define a sw pipeline
   - Data collection, processing, standardization
   - Synthetization and enrichment
   - Interoperable data-driven services
2. Validate on real case studies
3. Make the pipeline adoptable by new stakeholders for their business, assets and needs
4. Share openly, to enable replication and adaptation to specific case

Sharing data with services



- In many situations, sharing data is an essential step:
  - Intra-company, i.e. mktg
  - External developers
- …but confidentiality issues are a barrier

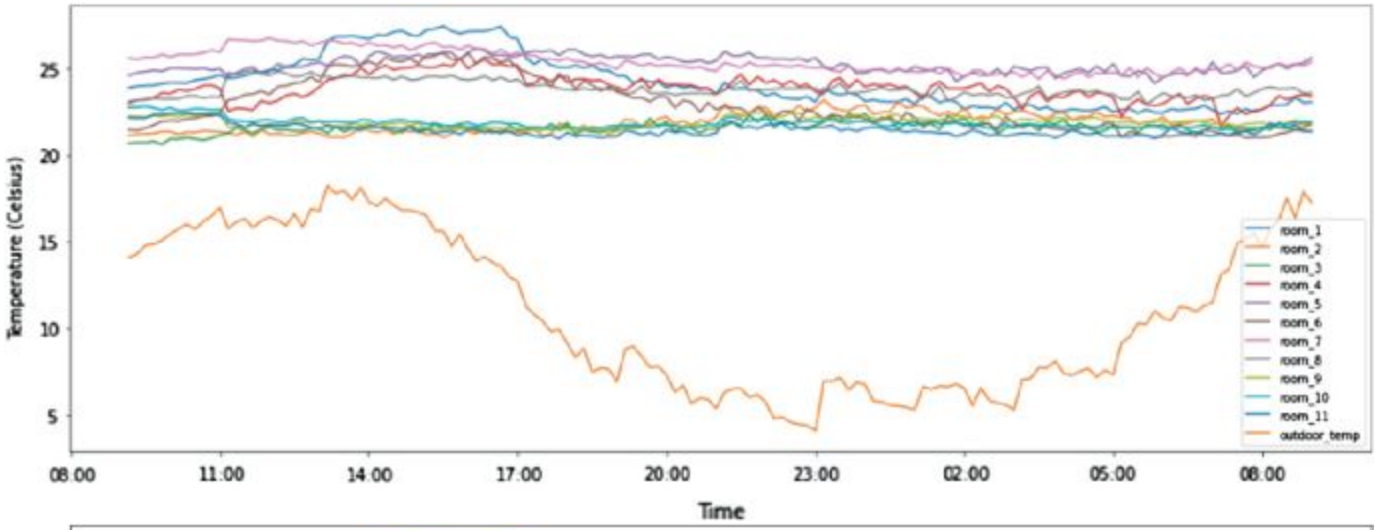
- To this end, data synthetization provides:
  - Scalability, bias reduction, variety & volume
  - Cost savings
  - Enhancing ML, integration with real data
  - Privacy, data protection, facilitate storage and sharing
- …but skills, effort, time needed

Data synthetization and sharing

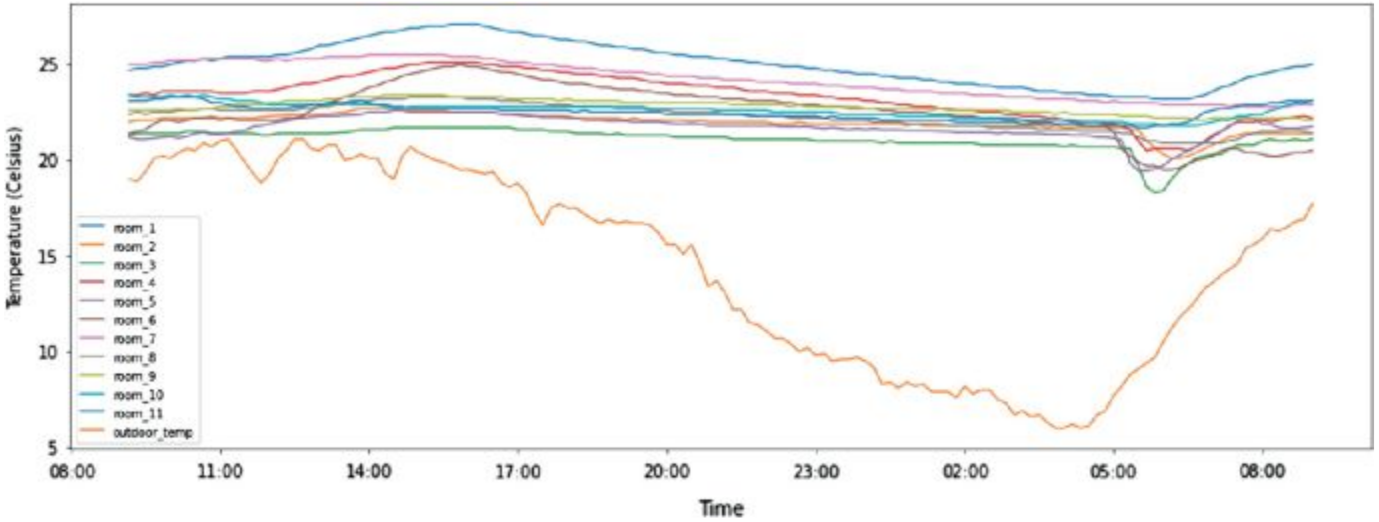
- By a pipeline, ML models can be trained using different generative algorithms (GAN, conditional diffusion model, …) and validated

- Making it possible to generate complete, coherent, high-quality synthetic datasets
  - Energy, IEQ and other relevant parameters
  - Static and dynamic data
  - Different level of data aggregation

Example (GAN)



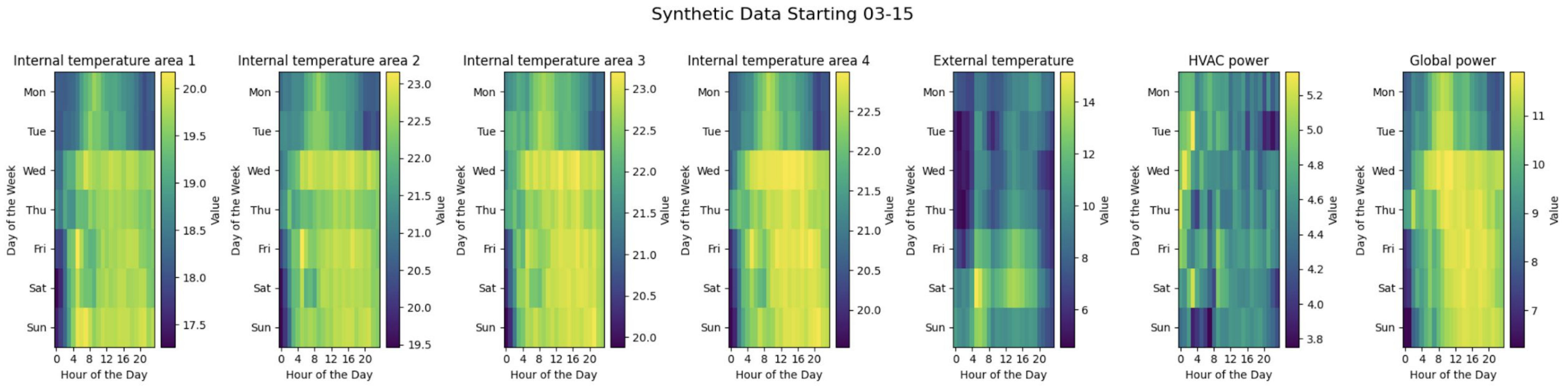
REAL DATA

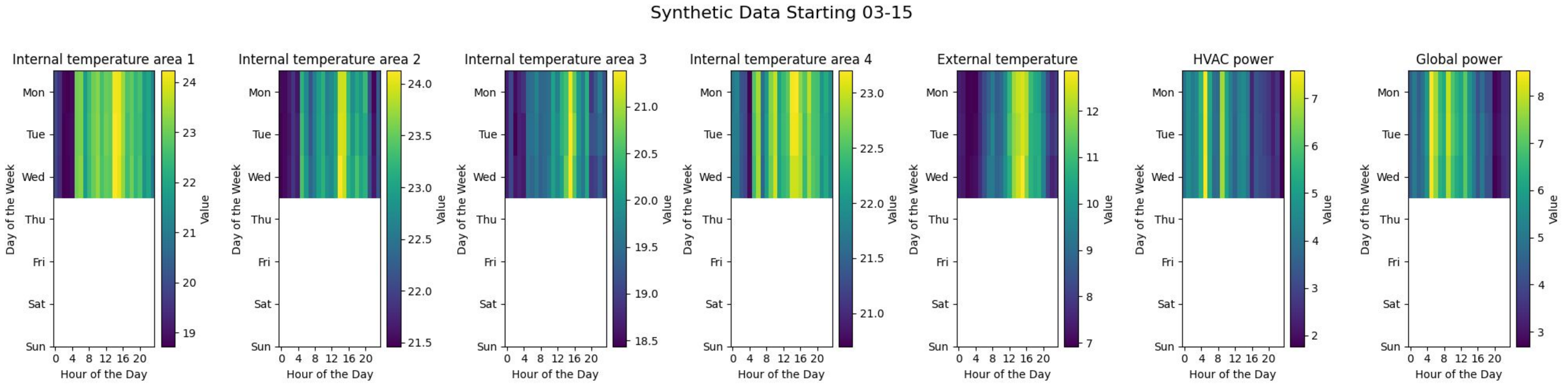


SYNTHETIC DATA

[10.1007/978-3-031-47909-0_7]

Example (CDM)


Synthetic Data Starting 03-15
Internal temperature area 1
Internal temperature area 2
Internal temperature area 3
Internal temperature area 4
External temperature
HVAC power
Global power
Day of the Week
Hour of the Day
Value
Mon
Tue
Wed
Thu
Fri
Sat
Sun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Internal temperature area 3
Internal temperature area 4
External temperature
HVAC power
Global power
Day of the Week
Hour of the Day
Value
Mon
Tue
Wed
Thu
Fri
Sat
Sun

Can we make on-demand generator of synthetic data?

- Not really, because the generation depends on the input data and on the purpose for the model
- And a key priority when generating synthetic data is preserving the privacy of sensitive information while maintaining high utility in services

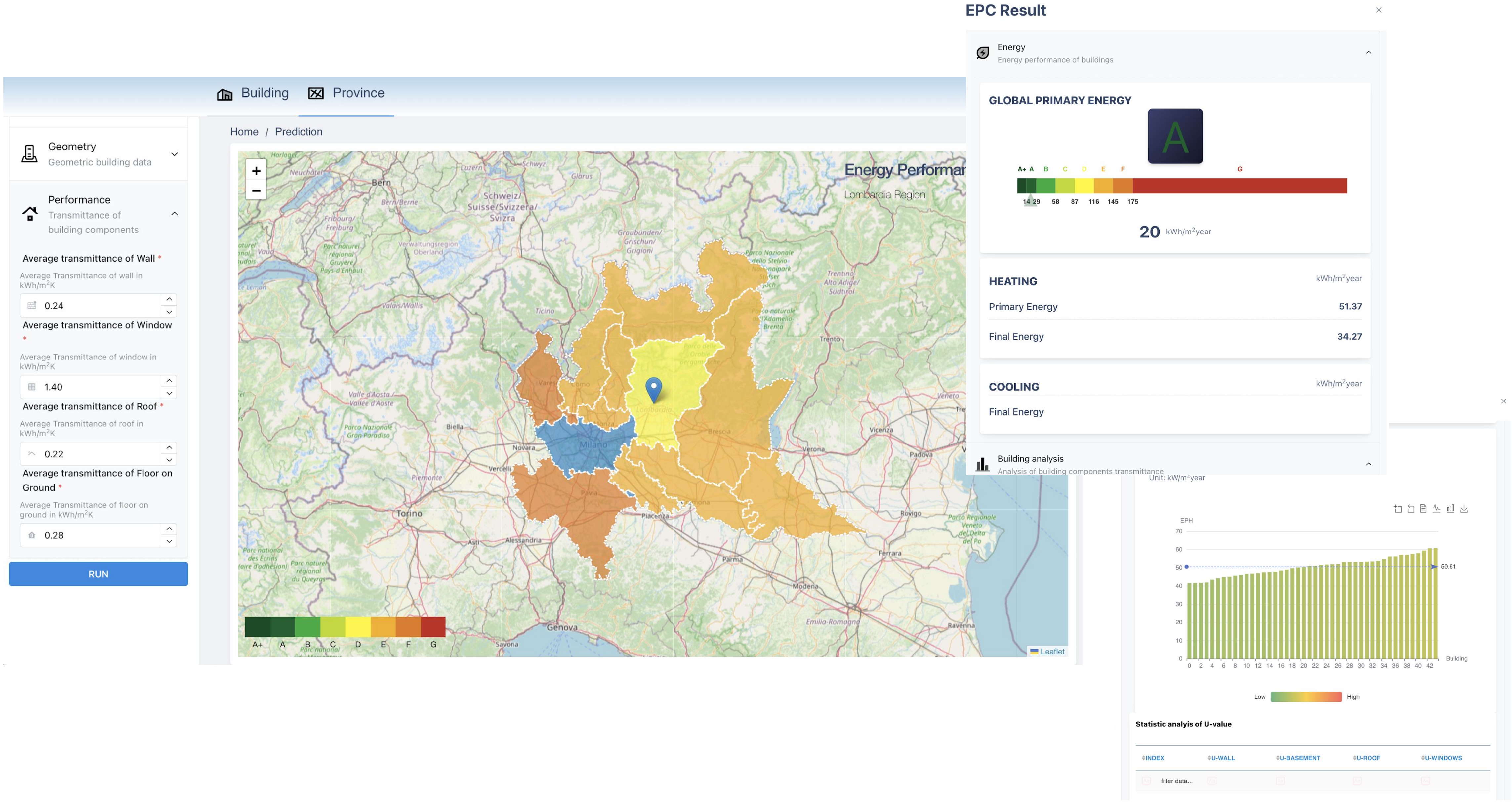
- …but you can:
  - Use MODERATE pipelines and see them in action
  - Simply take MODERATE OS codes and documentation, then DIY

How predictive models can be improved

- AIM: identify a model that is able to predict the performance of building using a large EPC dataset?
- PROBLEM: high performance buildings (CLASS A, A+ - old measurement scale) represent very low percentages compared to the entire dataset:
  1) Class A buildings : 3%
  2) Class A+ buildings: 0.5%.
- SOLUTION: Synthetize EPC of A and A+ classes using CTGAN*, generate 300,000 EPC in classes A and A+, -> integrate dataset as training in a NN model to predict building performance

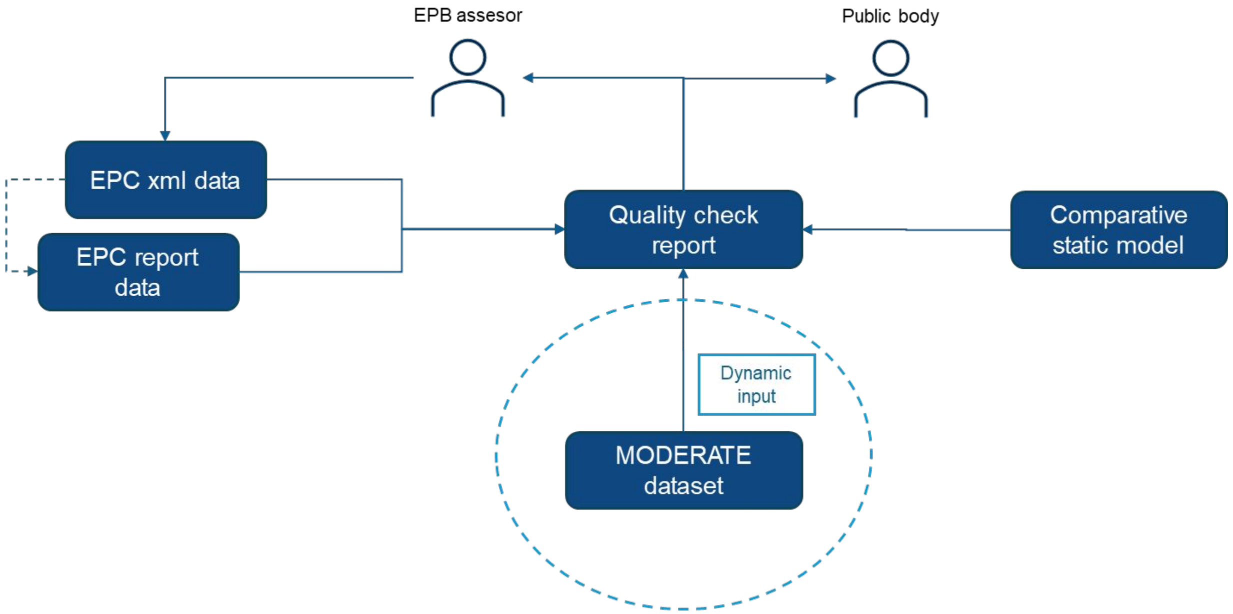
* Modeling Tabular data using Conditional GAN, NeurIPS 2020 conference

How predictive models can be improved



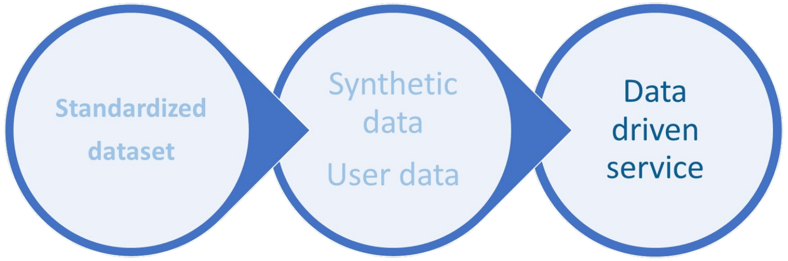
How quality checking of EPC can be improved

- Static models that are compared with the EPC introduced by the user



- EPC can also be compared with a synthetic dataset shared from public bodies
  - Cross-referencing with a comprehensive dataset
  - Greater adaptability to changing conditions
  - More accurate comparisons with real-time data

Data-driven services



- **Fault detection and forecasting**
- Energy system optimization
- ECM planning tool
- Solar PV tool
- Local Energy Communities
- M&V tool
- **Benchmarking**, geo-clustering
- De-risking for EE projects
- **EPC quality** and harmonization

Examples: 3rd party service provided

Time series-based energy benchmarking

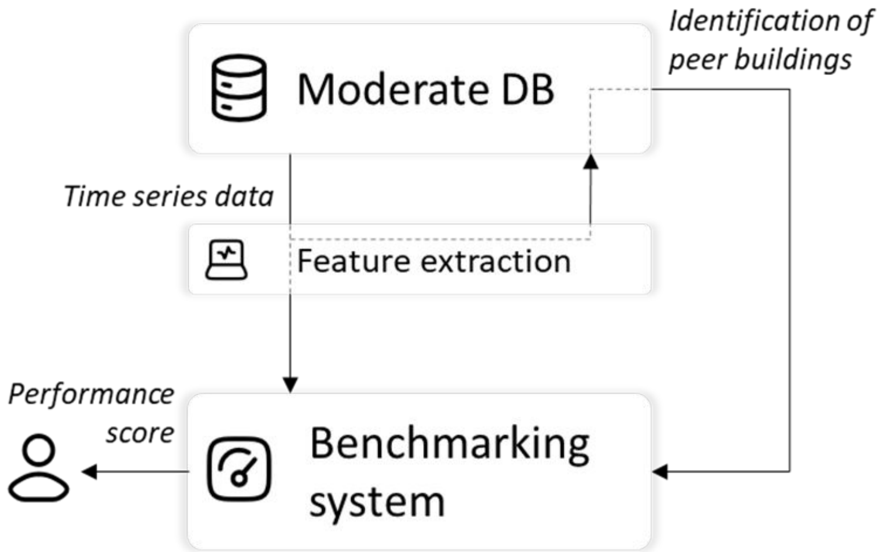
What challenges does this service address?

- Static and pre-defined classes of comparison

Poor results since buildings in the same end-use category are heterogeneous and electric consumption is driven by different variables.

- Use of aggregated data such as bills

This prevents understanding the causes of sub-optimal performance.



- Dynamic identification of similar buildings

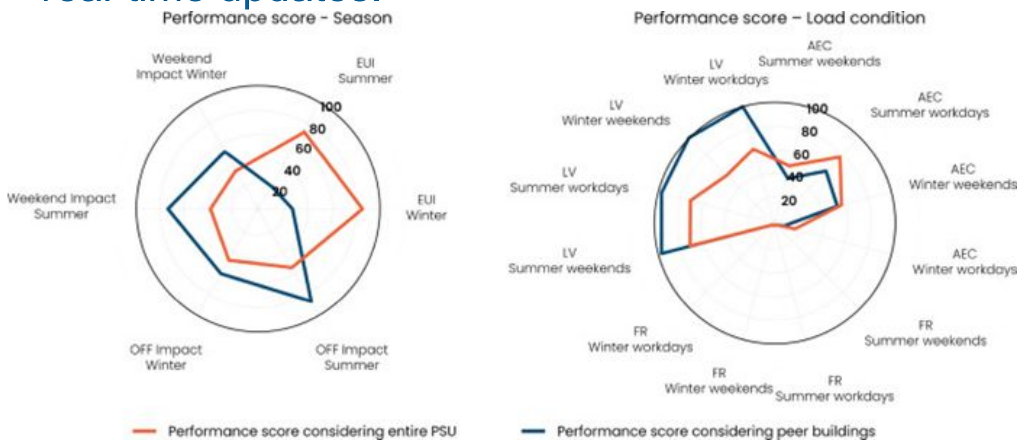
Identification of the set of buildings against which compare a new building considering feature extraction processes and data analytics techniques

- Use of time series data for operational KPI calculation

Load shape pattern frequency, anomaly rate, load volatility, operational schedule efficiency

- Real-time benchmarking

Promptly identification of sub-optimal performance with real-time updates.



Piscitelli, M. S., Giudice, R., & Capozzoli, A. (2024). A holistic time series-based energy benchmarking framework for applications in large stocks of buildings. Applied Energy, 357, 12255.

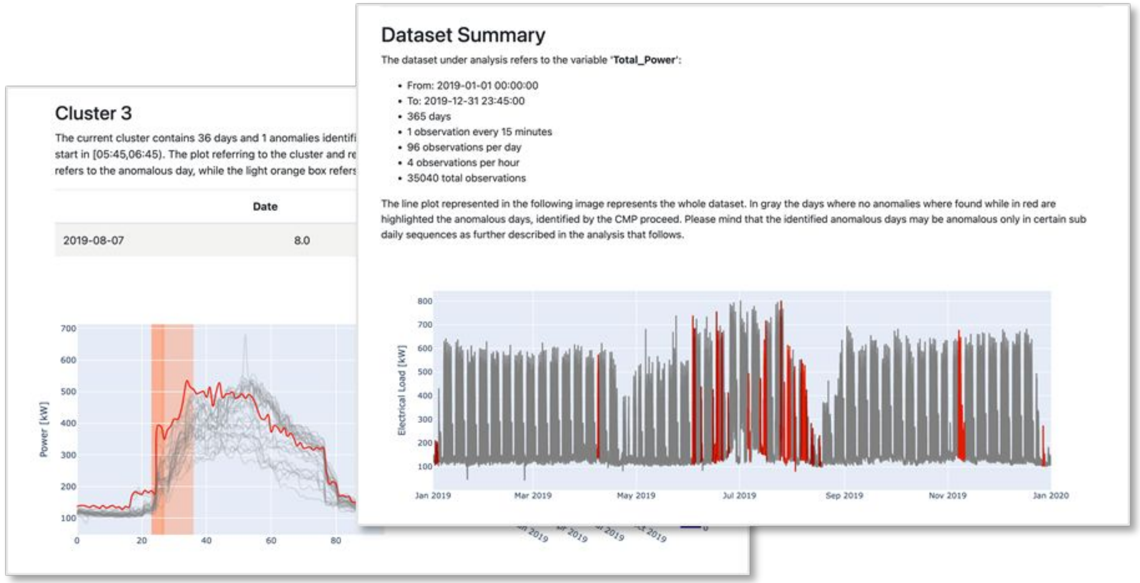
Examples: 3rd party service provided

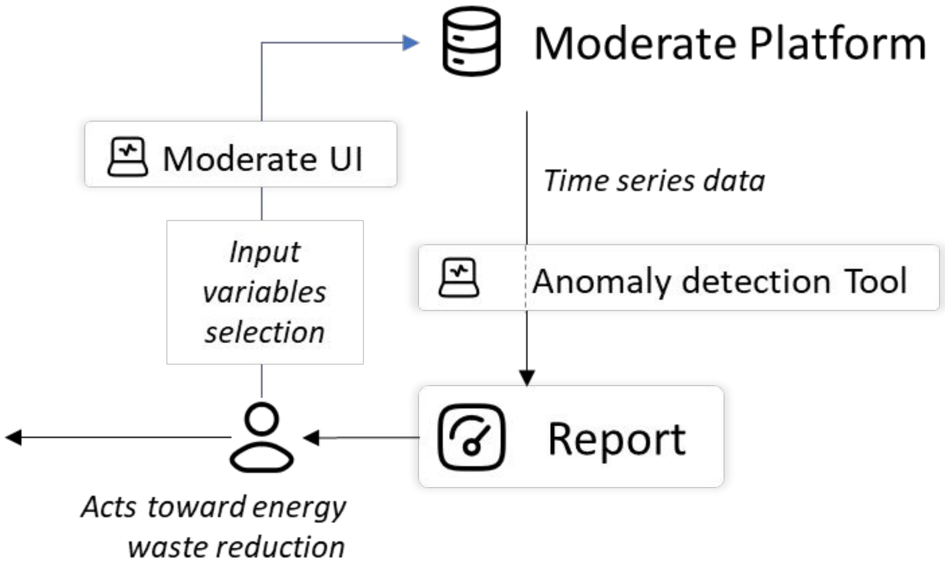
Anomaly detection on building electrical load timeseries

What challenges does this service address?

- Usually performed on single dataset owned by the user
- The algorithm is not publicly available and the process not replicable on other datasets

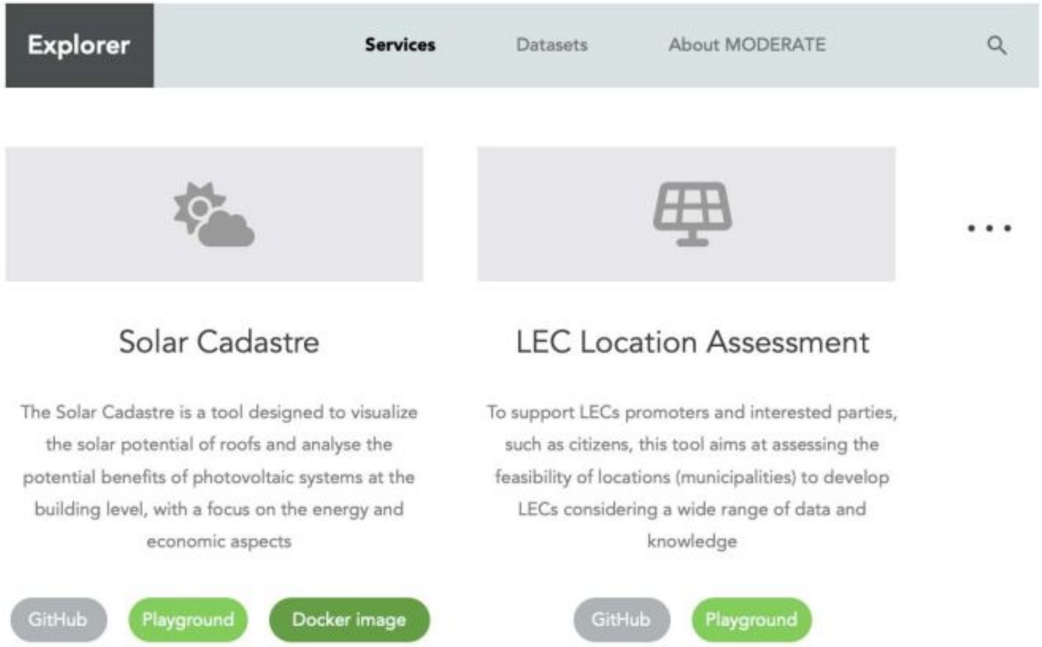
- Opportunity to develop and deliver a standard process that is replicable across different buildings
- Offers an open testbed to perform anomaly detection according to user inputs on diverse buildings end uses





MODERATE marketplace

- All open datasets, services and sw pipelines at hand
- Programming environment (playground)
- Test-before-invest and Support to companies



Key takeaways

- Open datasets and data-driven services for energy and building sector
- A collaborative environment to boost services with realistic data
- Find out ML models and techniques for data synthetization on our communities on GitHub and Zenodo

- **Marketplace launch: Q1/2025**
- Want to contribute with your codes/data/services? Contact us

eurac research

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Politecnico di Torino

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REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

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synavision Perfect Building Performance

MODERATE

Marketable Open Data Solution for Optimized Building-related Energy Services

Thank you!

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101069834. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA

DATA-DRIVEN SMART BUILDINGS
dedalus WORKSHOP
Data-driven Residential Energy
Carrier-agnostic Demand Response Tools and
Multi-value Services
25 September 2024, 14:00 – 17:30

DEDALUS Ontology: Demand response and flexibility modelling for interoperability

José L. Hernández* & Susana Gutiérrez, CARTIF
Marzia Mammina, Luca Vitale & Alessandro Rossi, Engineering

This project has received funding from European Union's Horizon Europe Research
and Innovation programme under the Grant Agreement No 101103998

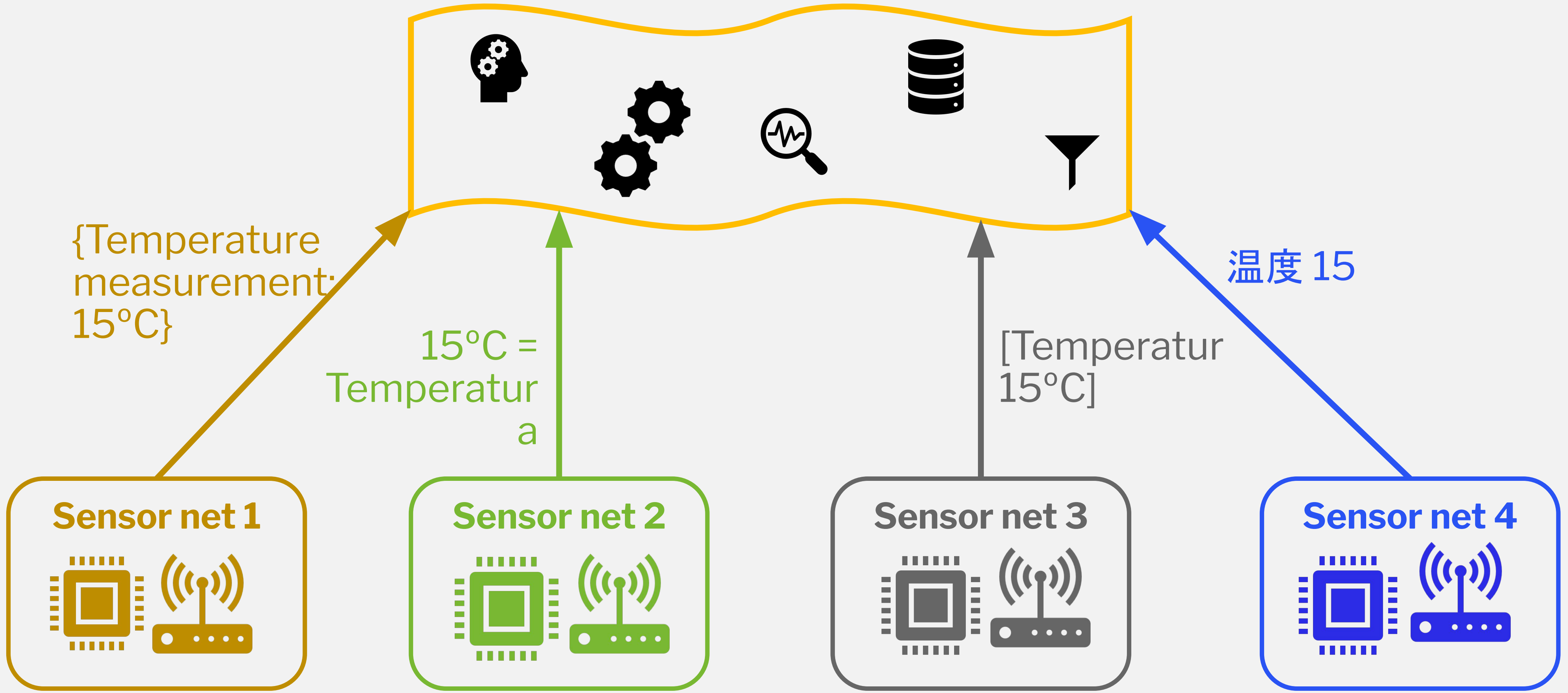
SUSTAINABLE PLACES 2024

Content of the presentation

SUSTAINABLE PLACES 2024

- Problem formulation: Interoperability challenges
- DEDALUS Methodology
- State of the art
- DEDALUS architecture
- DEDALUS ontology
- Use of the ontology
- Conclusions

Problem formulation



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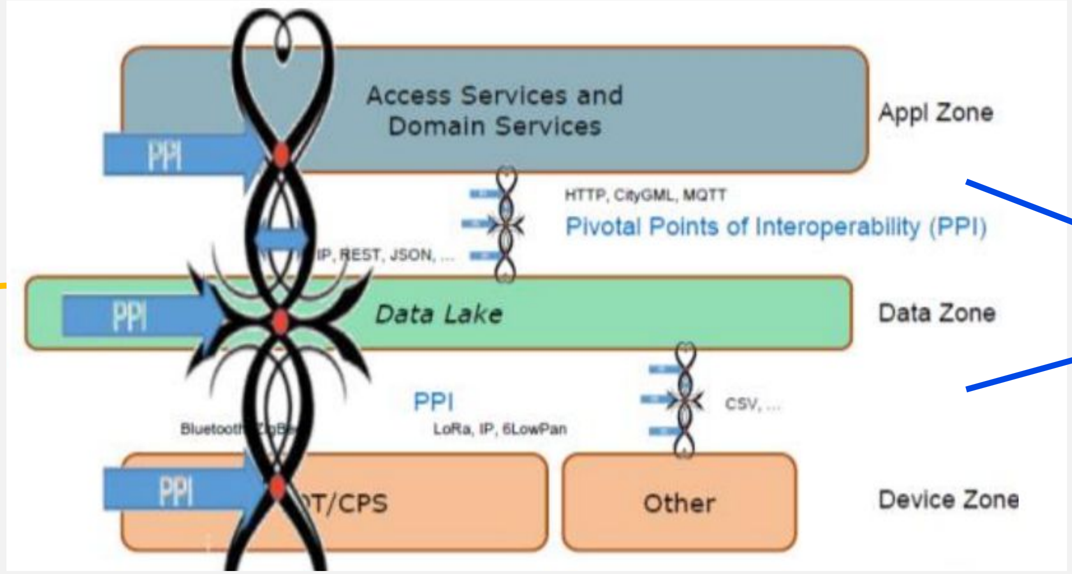
Problem formulation



Foundational interoperability: Northbound and Southbound

Semantic interoperabilit y

And also...
Structural interoperability

Problem formulation

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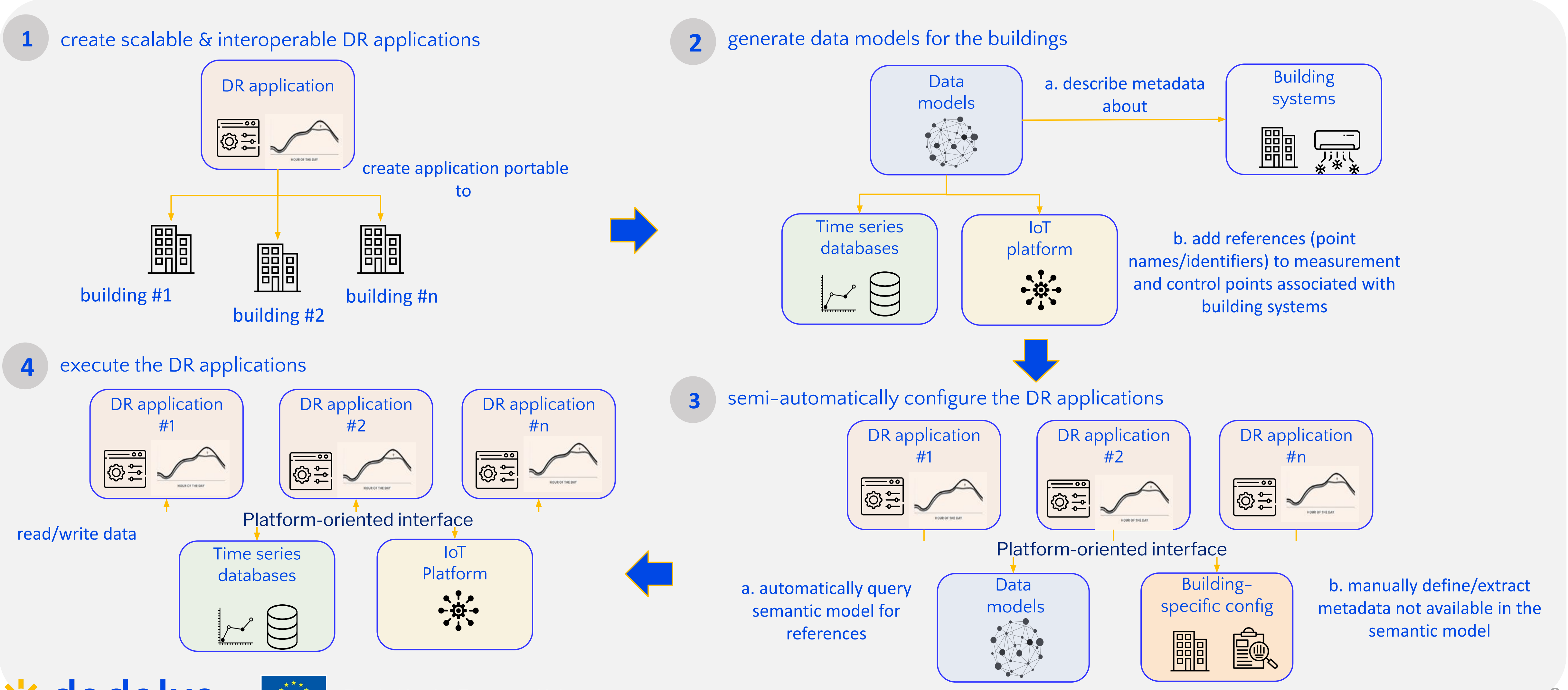
- Open and/or standard protocols to gather data
- Open and/or standard protocols to share data
- Define data exchange structures
- Define languages and vocabularies

ONTOLOGY

Problem formulation



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Methodology

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State of the art

- SAREF
- OpenADR
- Brick
- dCO
- BIGG

Analysis

- Pros and cons
- Capabilities of the ontologies

Selection

- Most suitable ontology

Extend

- Select extensions to be used

State of the Art

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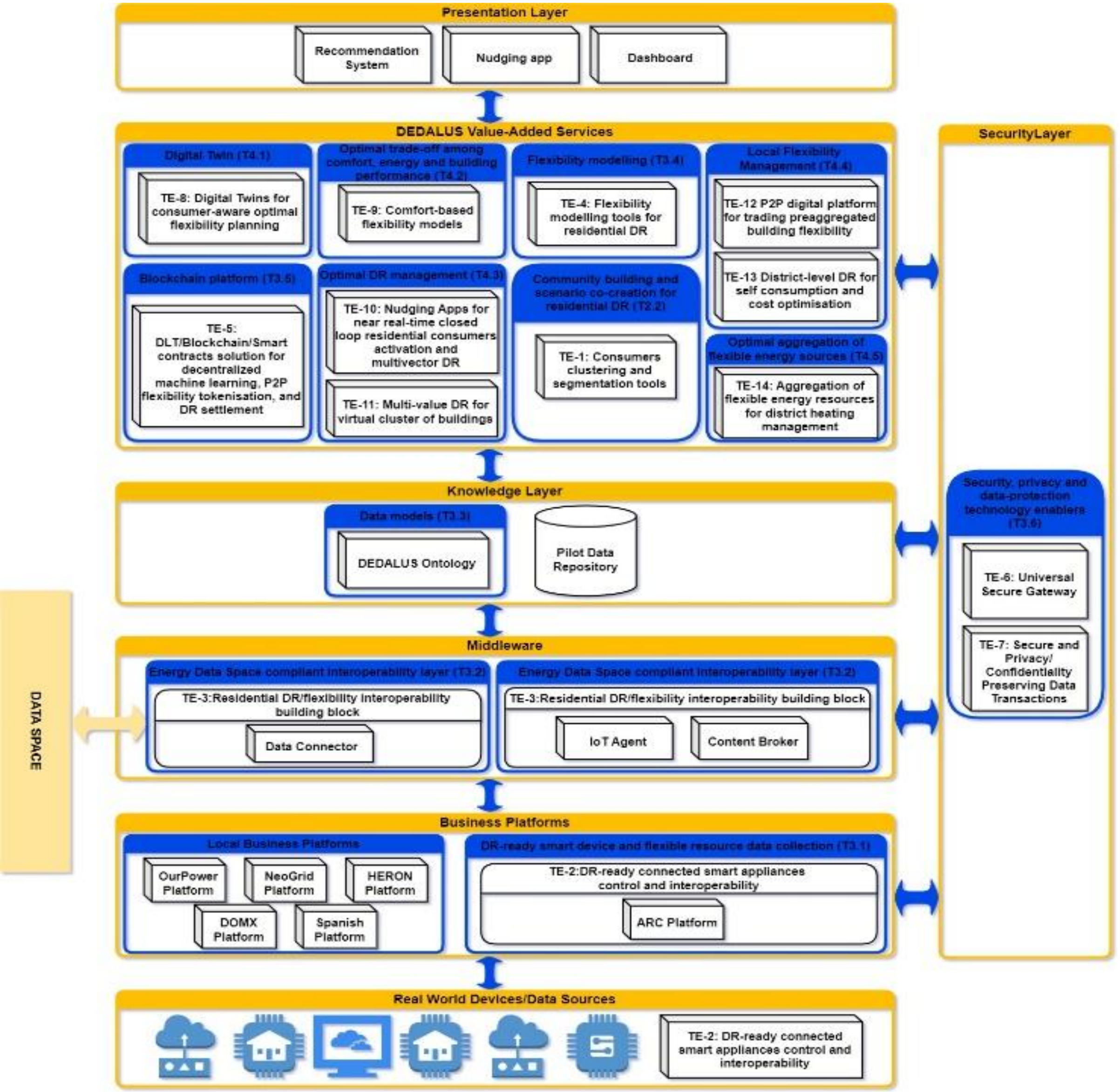
Ontology	Pros	Cons
SAREF	smart appliances, systems, meters and spaces. A lot of extensions are available.	Not covering flexibility
OpenADR	OpenADR protocol	other (more generic) concepts are missing.
Brick	Focused on buildings.	Other concepts are missing.
BIGG	Designed to represent multiple aspects of smart grid systems, based on SAREF, BOT, IFC…).	Big size, difficult to follow, focused on Energy Performance Certificates (although have extensions).

Architecture for an interoperable demand response



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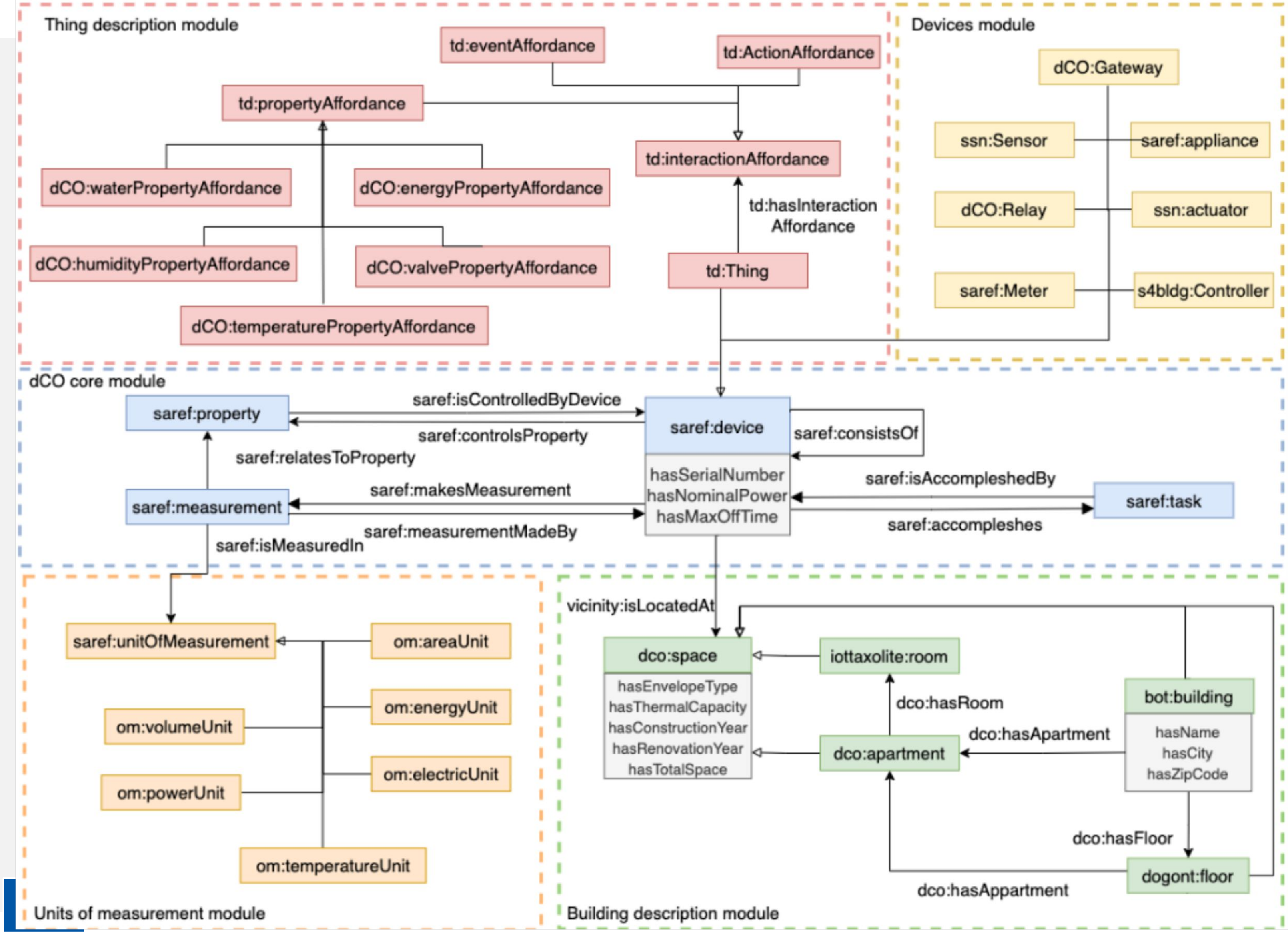
dCO based ontology



dCO based ontology – Matching entities

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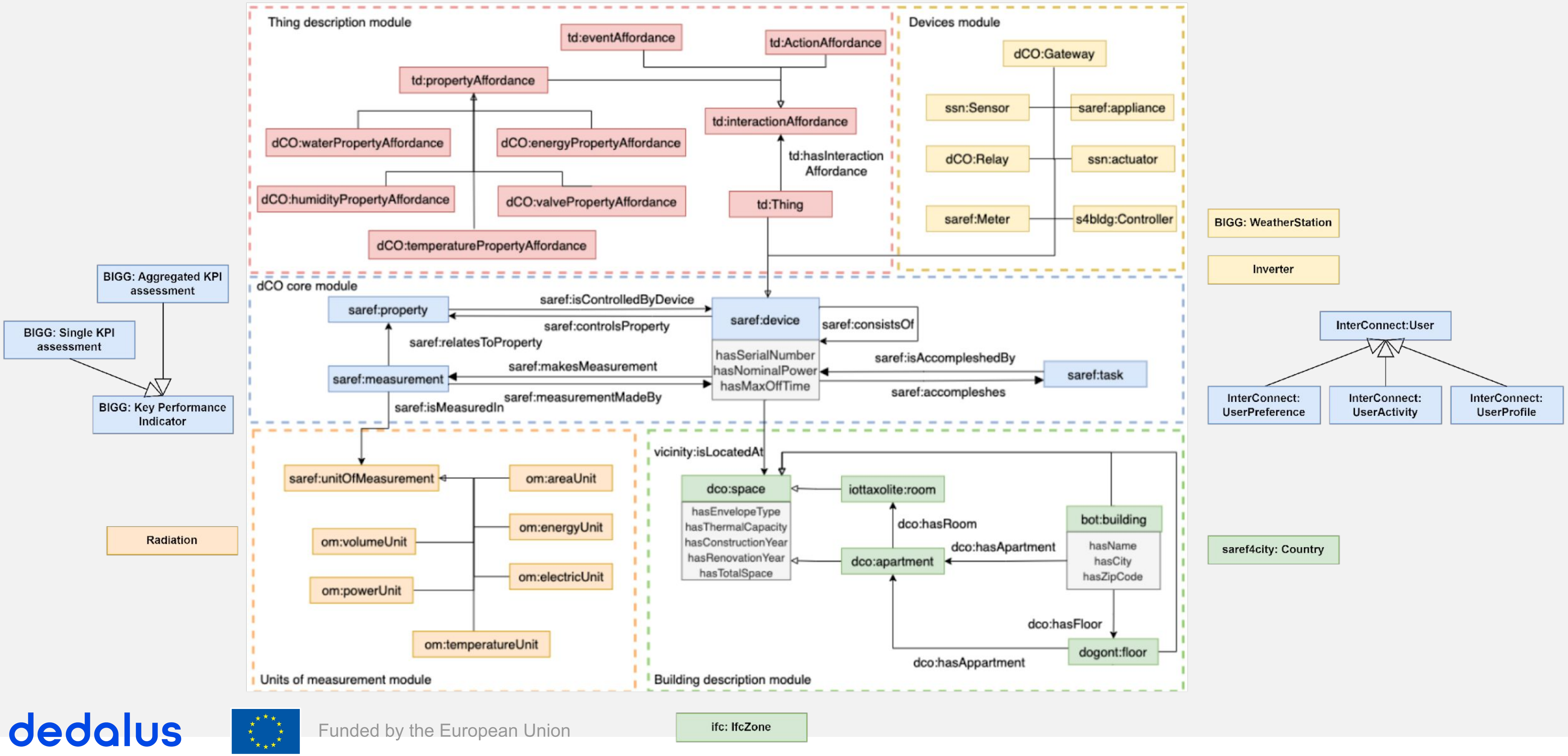
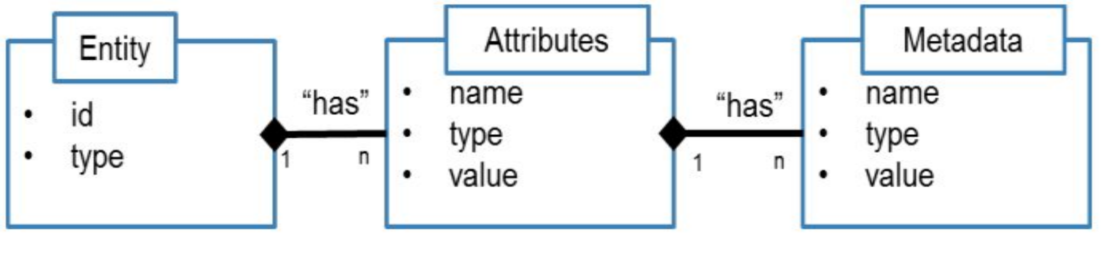
Thing description module	dco:PropertyAffordance	NO
	dco:EventAffordance	NO
	dco:ActionAffordance	NO
	dco:InteractionAffordance	NO
	dco:ThingDescription	NO
Devices module	dCO:Gateway	YES
	ssn:Sensor	YES
	dCO:Relay	YES
	saref:Meter	YES
	saref:Appliance	YES
	ssn:Actuator	YES
	s4bldg:Controller	YES
dCO core module	dco:Device	YES
	dco:Service	YES
	dco:property	YES
	dco:measurement	YES
Units of measurement module	saref:unitOfMeasurement	YES
	om:volumeUnit	NO
	om:powerUnit	YES
	om:areaUnit	YES
	om:energyUnit	YES
	om:electricUnit	YES
	om:temperatureUnit	YES

Building structure module	dco:Space	YES
	dco:Room	YES
	dco:Building	YES
	dco:Apartment	YES
	dco:Stairway	NO
	dco:Storey	YES
Power, electricity and heating flow module	dco:Hub	YES
	dco:Storage	YES
	dco:Producer	YES
	dco:Consumer	YES
Energy flexibility module	dco:Slice	NO
	dco:FlexOffer	YES
	dco:Schedule	YES
	dco:FlexOfferProfileConstraint	YES
	dco:FlexOfferTariffConstraint	NO

dCO based ontology – Extensions

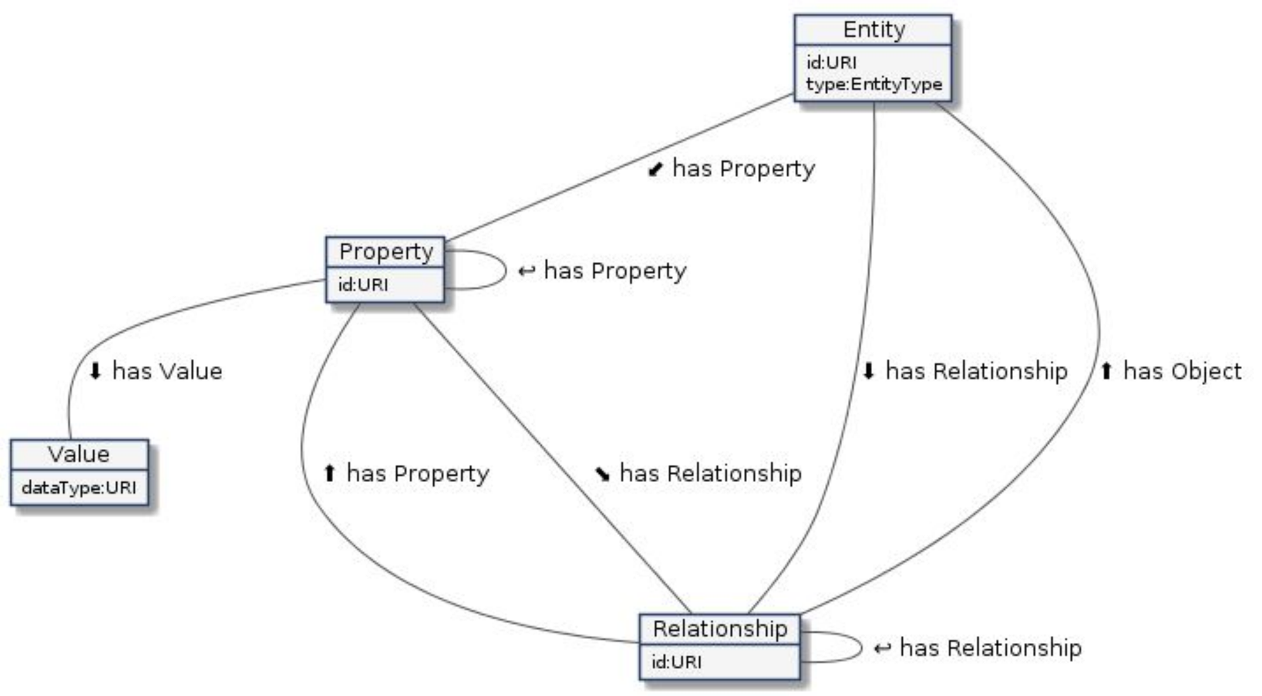


DEDALUS ontology – How using it



NGSIv2 information model

NGSI-LD
information model



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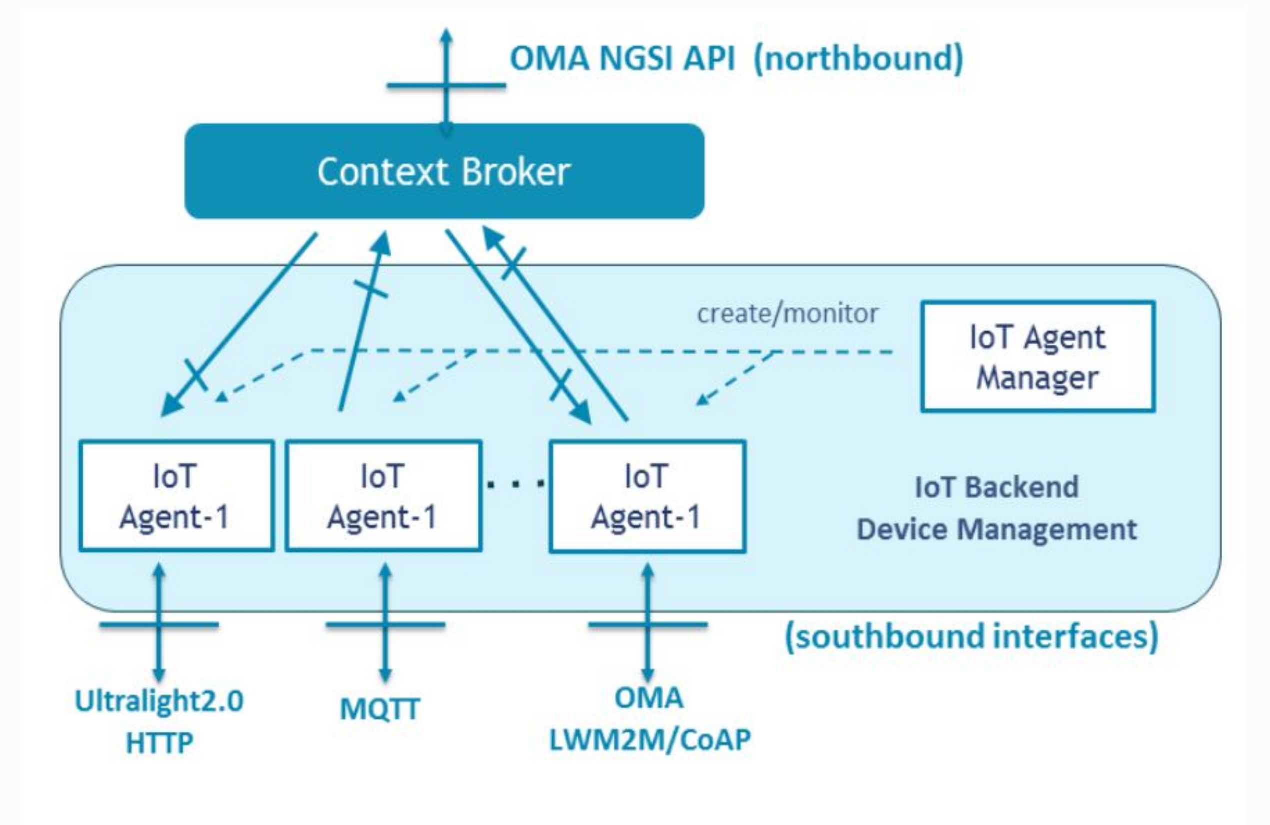
DEDALUS ontology – How using it



IoT NGSI agents

Custom agent to represent DEDALUS ontology

Conclusions

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- Interoperability is key
- Demand response and flexibility not yet fully explored
- Data management and sharing
- Making data accessible

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Data-driven Residential Energy Carrier-agnostic Demand Response Tools and Multi-value Services

José L. Hernández
josher@cartif.es

Thank you!

DATA-DRIVEN SMART BUILDINGS

WORKSHOP

25 September 2024, 14:00 – 17:30

European Convention Center, Luxembourg & Online (Hybrid)

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Data-driven Residential Energy
Carrier-agnostic Demand Response Tools and
Multi-value Services

Utilizing Social Sciences Framework for New Service Development in Advanced Energy-Efficient Buildings

25/09/2024 → Sustainable Places Conference, Luxembourg

Christine Gritsch – Blueprint Energy Solutions

SUSTAINABLE PLACES 2024

This project has received funding from European Union's Horizon Europe Rese
and Innovation programme under the Grant Agreement No 101103998

DEDALUS's Overarching Project Goal

Goal: Deploy a social, technological, and business framework to design and demonstrate an SSH-driven, multi-value, energy carrier-agnostic Demand Response (DR) ecosystem.

Focus: Optimize and manage automated DR in residential buildings.

Social Arm: Structured through the Social Science Framework (SSF)

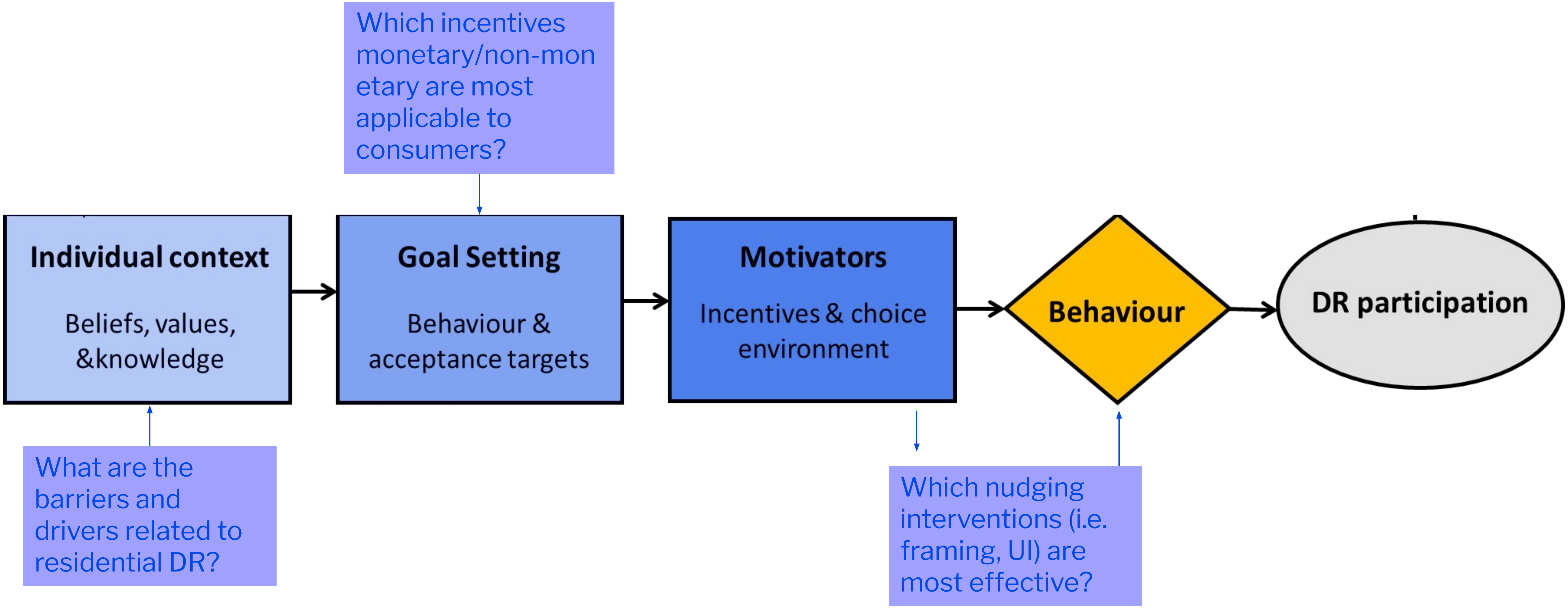
Key Insight Areas:

- Behavioral change theories
- Motivation and behavioral economics
- Foundational pillars: Individual Context, Goal Setting, and Motivation

Objective: Bridge theoretical frameworks and applications to foster end-user engagement in DR

Social Science Framework

Social Science Framework



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Applying Social Science Framework

Social Science Framework	Co-creation activities	SSH methodology
Individual context Beliefs, values, knowledge	Segmentation questionnaire	Persona definition
Goal Setting DR behaviour & acceptance targets	Barriers & drivers workshop activity	Q-methodology
Motivation Incentives and choice environment	Nudging workshop activity	User testing Make Exercises
	Incentives workshop activity	Focus group Scenario analysis

Workshop Methodology

- Designed workshops to assess factors within SSF regarding end users. Activities included:
  - Q-Method to assess barriers and drivers to DR participation
  - Ranking task to assess relative importance of incentives for DR participation
  - Nudging activity to assess motivations & preferences regarding tools and services
- Output:
  - Understanding user motivation, preferences & needs
  - Recommendations for broader engagement strategy
  - Learnings & best practices for engaging end users

Dedalus pilot sites

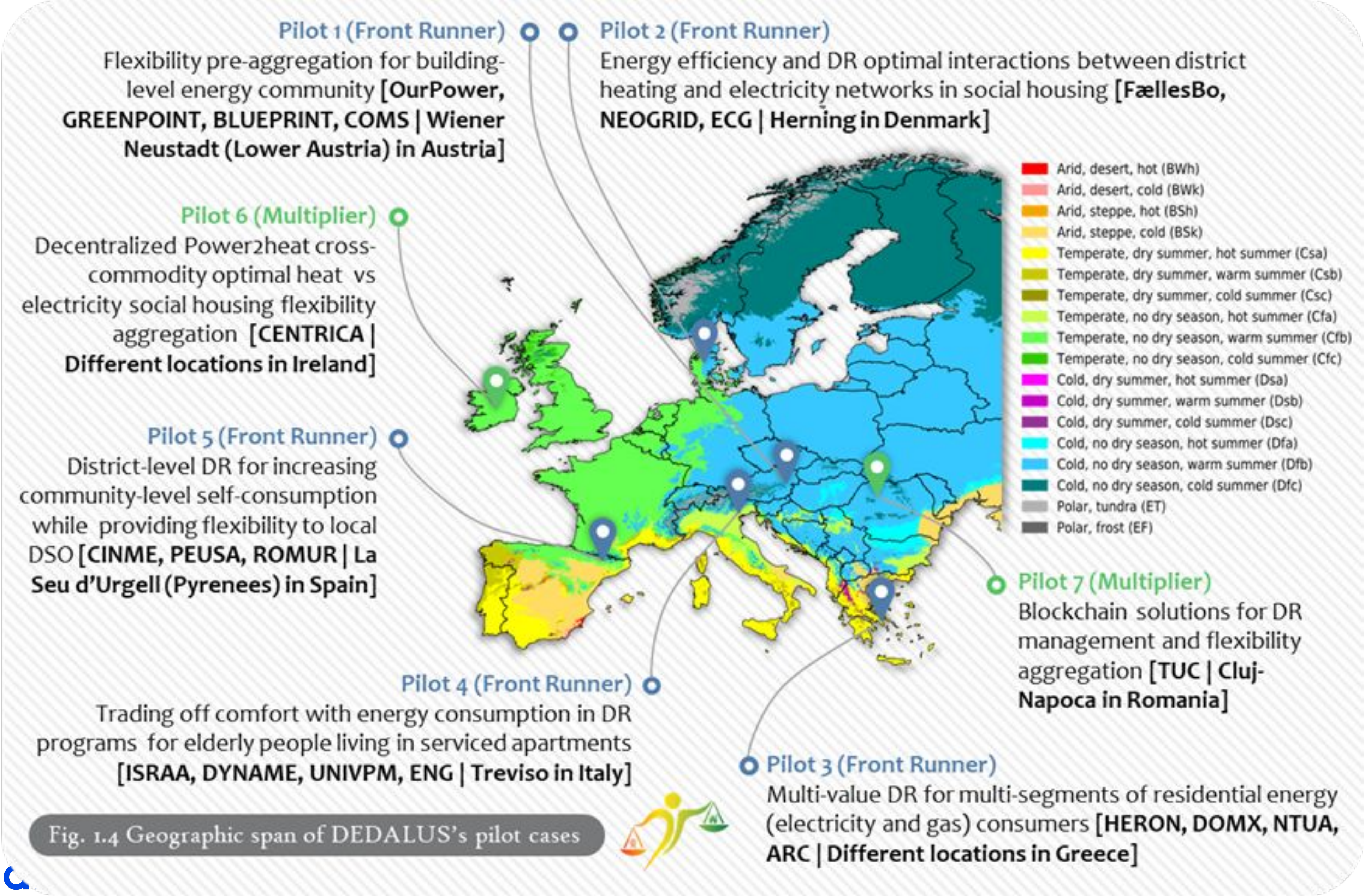
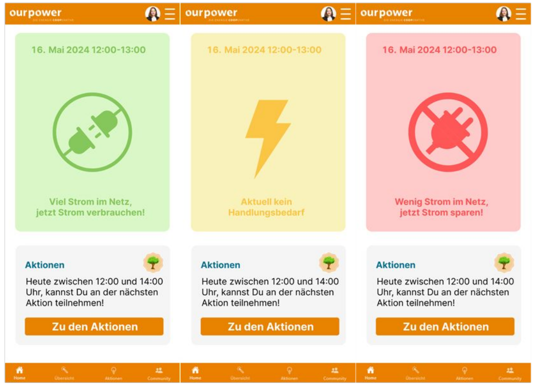
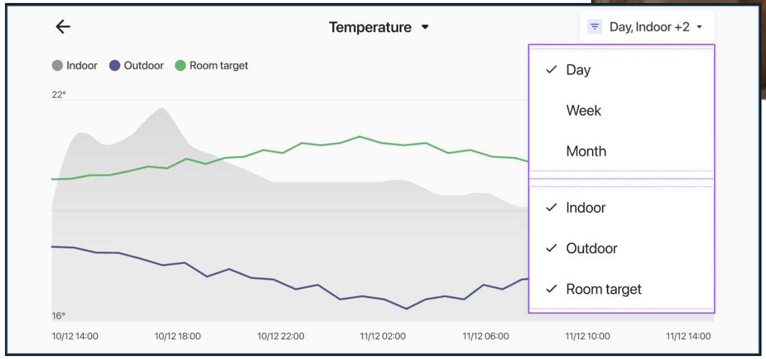


Fig. 1.4 Geographic span of DEDALUS's pilot cases

Completed workshops





Analysis

- Relative importance of incentives
- Motivations, profiles & needs
- Feedback on APPs

Ranking scores

Ranking	Incentive
1	**Recognition & Rewards**: Public acknowledgement for participation in newsletters, on websites, or at community events.
2	**Social Benefits**: Inclusion in a community of like-minded individuals who are interested in sustainability and energy conservation.
3	**Community Contributions**: The satisfaction of contributing to a community goal, such as reducing the local carbon footprint.
4	**Environmental Impact**: Regular reports on the environmental impact of participants' actions, such as carbon emissions saved.
5	**Gamification**: Participation in energy-saving challenges or competitions with leaderboards and progress tracking.
5	**Enhanced control & autonomy**: The ability to manage and monitor energy consumption in real-time through apps or online dashboards.

User motivation profiles

-3	-2	-1	0	1	2	3
3. No point saving energy if it makes living uncomfortable	5. More inclined to join DR if neighbours also join	9. Lacks info to make informed decision about DR	6. Feels social pressure to appear environment conscious	1. Would compromise comfort to participate in DR	8. Understands how DR works & the benefits	11. Comfortable using smart devices & APPs
	12. Lack info on DR participation & environment	10. Energy programs are hard to understand	15. Needs to trust personal info will not be shared	7. Saving energy is discussed within social circle	4. Likes technology that can be personalised	
		2. Home comfort is more important than saving energy	16. Important to understand energy data use	13. Would not participate without customisation option		
			14. Important to see how DR impacts environment			

APP feedback

Participant Comments:

- Respective preview for money savings plot (along with the existing consumption illustration, for example in a different tab)
- Daily and weekly report as well (currently we have only the monthly plot)
- We should highlight the "savings' bar, instead of the consumption bar
- Notifications to the end-users to be able to view their weekly consumption bar (for example) or even mail notifications with an overall preview of their consumption
- To add the indication (kWh) in the top left corner
- Re-adjustment of the bar preview, for example, to illustrate the consumption of January in the middle instead of the left corner
- Different representations, for example, only of the percentage savings per month/week/day

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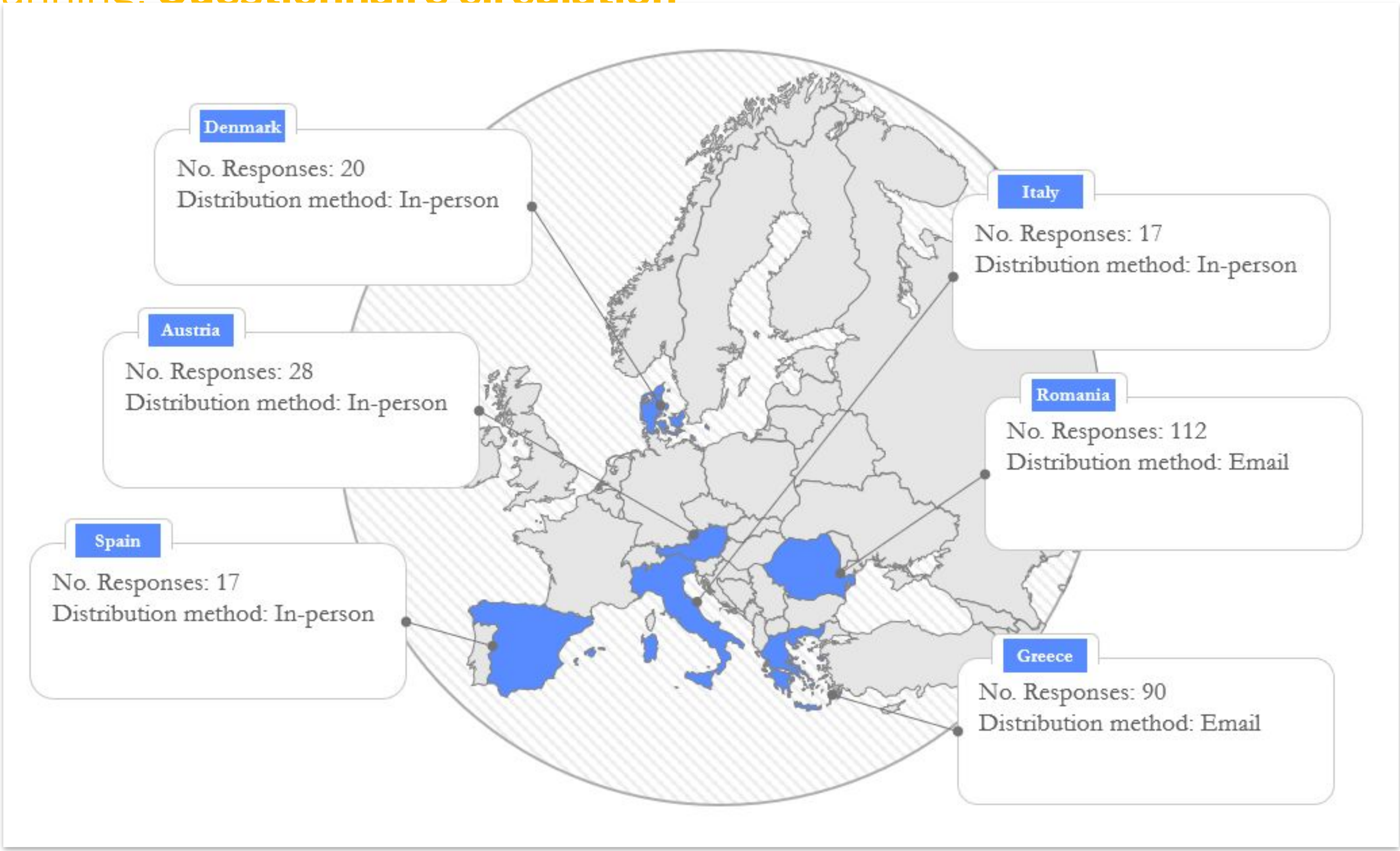
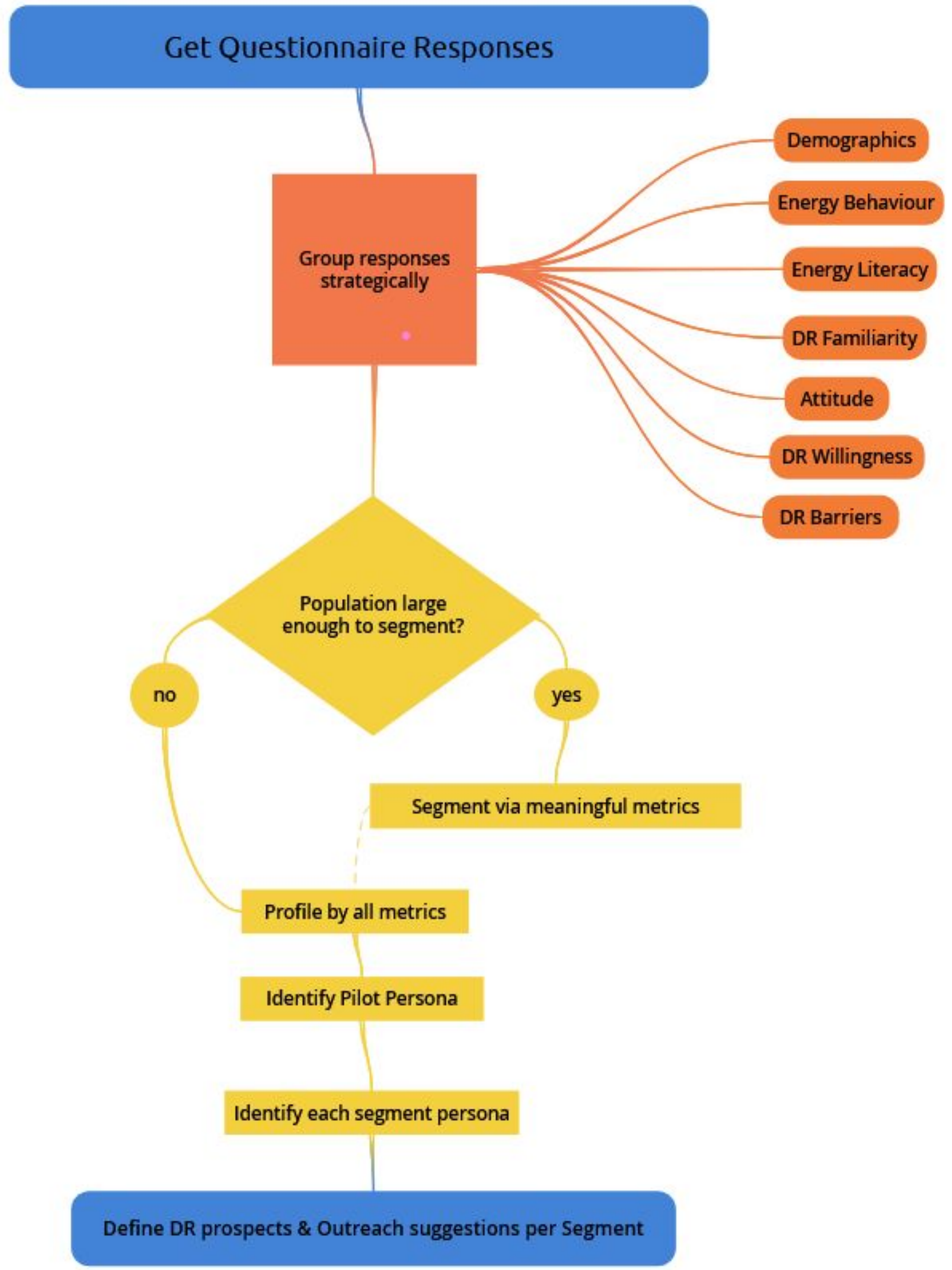
Consumers segmentation and clustering of buildings for optimal DR planning: **Questionnaire circulation**



Questionnaire Segmentation - Flow chart

Analysis approach

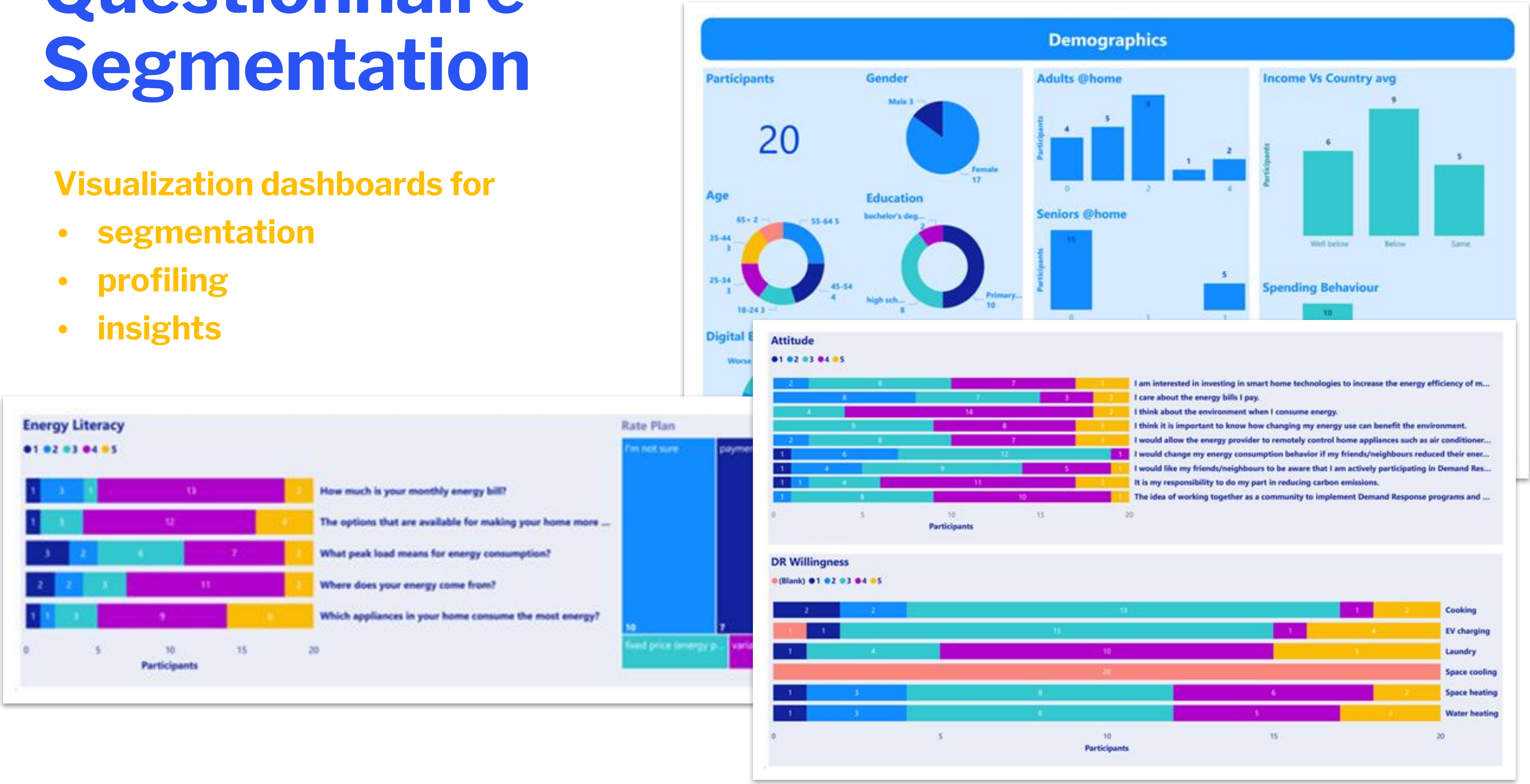
- Collect Questionnaire Responses
- Group Responses strategically in Categories that assist the analysis
- If the population is large enough, proceed with respondent segmentation in meaningful groups
- Profile a persona per Pilot and per Segment by presenting its dominant answer for each question
- Draw insights to tailor the outreach campaign per



Questionnaire Segmentation

Visualization dashboards for

- segmentation
- profiling
- insights



Questionnaire Segmentation

Pilot Persona profile example

Each bubble relates to a question category

Conclusions

- Provided insight into the motivations, profiles & needs
- Knowledge on effective incentives
- Feedback on APPs
- Recommendations for increasing consumer engagement and social acceptance
- Recommendations Common project themes & best practices

DR Incentives: Common Themes
High Value of Community and Social Benefits
Environmental Impact
Low Interest in Gamification
Recognition and Rewards

Barriers and Drivers: Common Themes	
Information and Understanding	•***Barrier***: A significant barrier across all workshops was the lack of information.... •***Driver***: Many users across pilot sites are knowledgeable....
Customization and Technology:	•***Barrier***: For some, discomfort with smart devices and applications... •***Driver***: The ability to customize energy preferences and settings...
Trust and Data Privacy	•***Barrier***: Trust issues... •***Driver***: Transparent information about data management...
Comfort vs. Energy Saving	•***Barrier***: Comfort at home was a critical factor... •***Driver***: Participants who were flexible and willing to compromise on comfort ...

Impact on Technical Outcomes

- **Enhanced Software Architecture:**
  - The integration and analysis of social science goals has led to a more responsive and user-centered software architecture.
- **Technology Enablers:**
  - Specific technology enablers were enhanced and focused to support social science objectives, such as improved user engagement.
- **AI-Driven Service Design:**
  - Social science insights guided the development of AI-driven services, ensuring they meet user needs and foster engagement effectively.

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Data-driven Residential Energy Carrier-agnostic
Demand Response Tools and Multi-value
Services

Thank you!

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This project has received funding from European Union's Horizon Europe Research and Innovation programme under the Grant Agreement No 101103998

District heating energy management system for smart building energy use

José L. Hernández*, CARTIF
Pablo Marcos & Javier Martín, VEOLIA
Ignacio de Miguel & Fredy Vélez, Universidad de Valladolid

DigiBUILD

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DATA-DRIVEN SMART BUILDINGS
WORKSHOP

25 September 2024, 14:00 – 17:30

European Convention Center, Luxembourg & Online (Hybrid)

[TECHNOLOGY CENTRE] 30 CARTIF ANNIVERSARY

23/09/2024

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Table of contents

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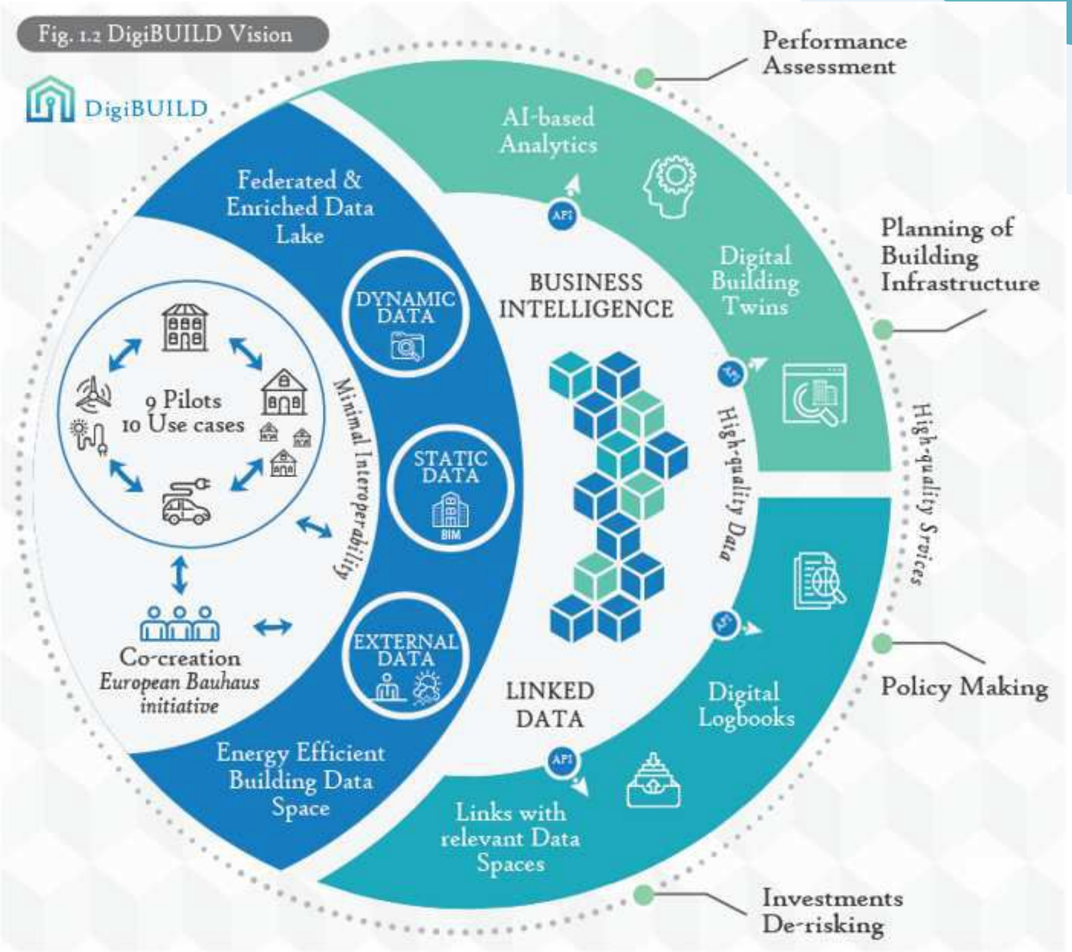
Background

DigiBUILD – Vision and approach

DigiBUILD is aligned with the European Strategy for data and contribute to the development of an **Energy Efficient Building Data Space**

Cocreation methodologies (according to the European Bauhaus initiative) are applied

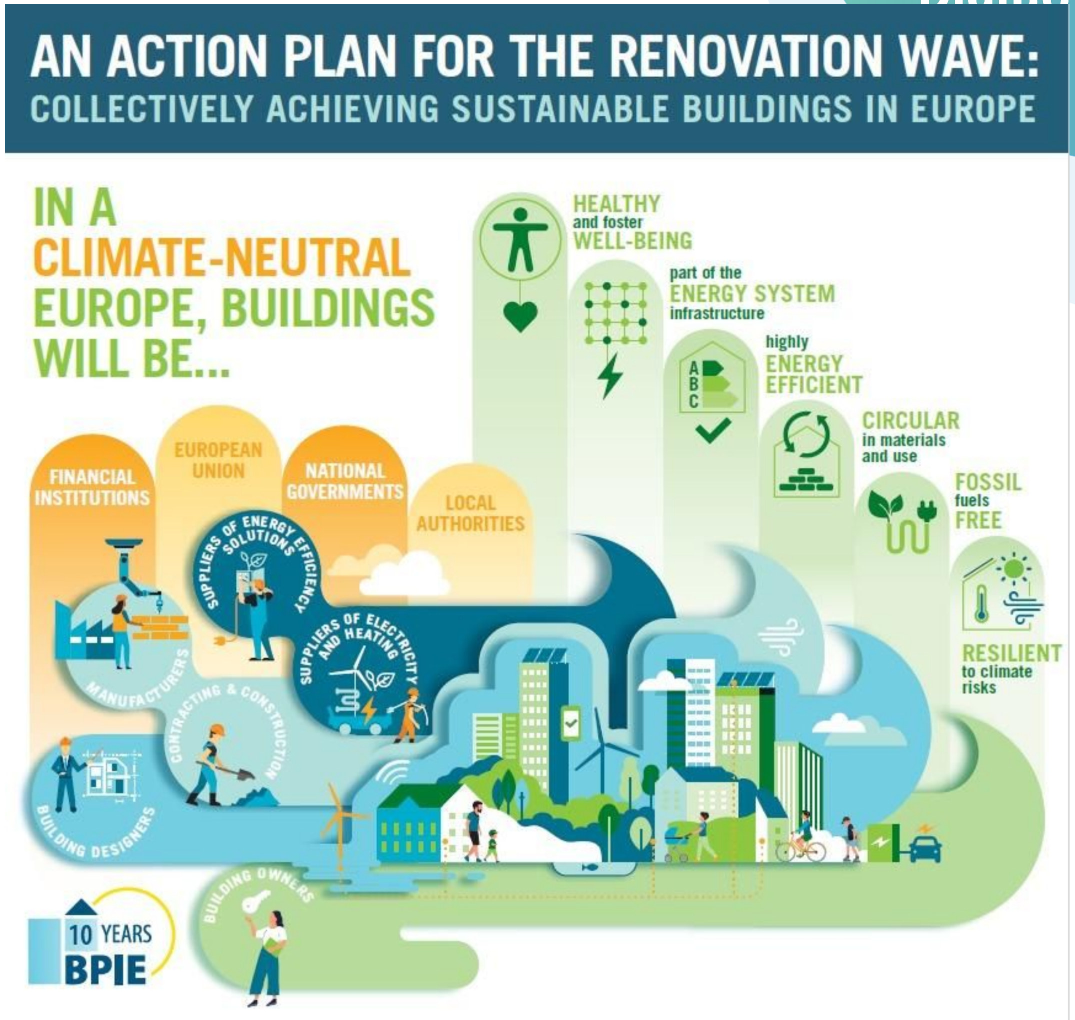
Gather and manage data in a proper and adaptable way (namely not to mobilise thousands of data but only the necessary data), in order to drive more robust, improved and **consistent monitoring of building stock energy performance**



Background

Europe building stock challenges

- Energy-efficient buildings through the Renovation Wave Strategy
- District heating plays important role in EU
- Optimisation techniques



Background

Current optimization approaches

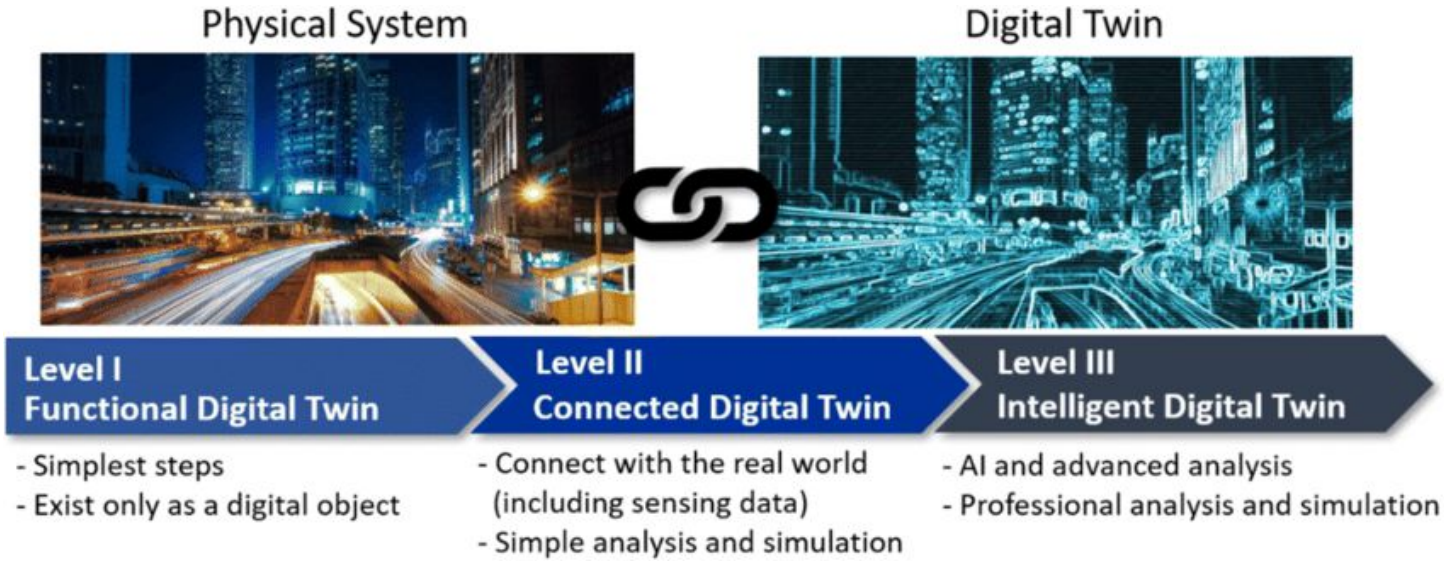
- Treated as isolated silos
- Wighted sum functions
- Mathematical formulation
- Complex AI algorithms

Our approach

- Grey-box approach
    - Physics + data
- Reduction of computational load
- Simplified by an hybrid data-driven model

Digital twin definition

- *"A digital twin is a **virtual representation** of an object or system designed to reflect a physical object accurately. It spans the object's lifecycle, is updated from **real-time data** and uses **simulation, machine learning and reasoning** to help **make decisions**"* [1]



[2]

[1] https://www.ibm.com/topics/what-is-a-digital-twin

[2] Kang, Ji-Soo & Chung, Kyungyong & Hong, Ellen. (2021). Multimedia knowledge-based bridge health monitoring using digital twin. Multimedia Tools and Applications. 80. 1-16. 10.1007/s11042-021-10649-x.

Digital twins definition

They allow to...

- Simulate different conditions
- Optimise the operation
- Visualise the current status of the network
- Understand behavioral patterns (historical data)
- Forecasting energy resources

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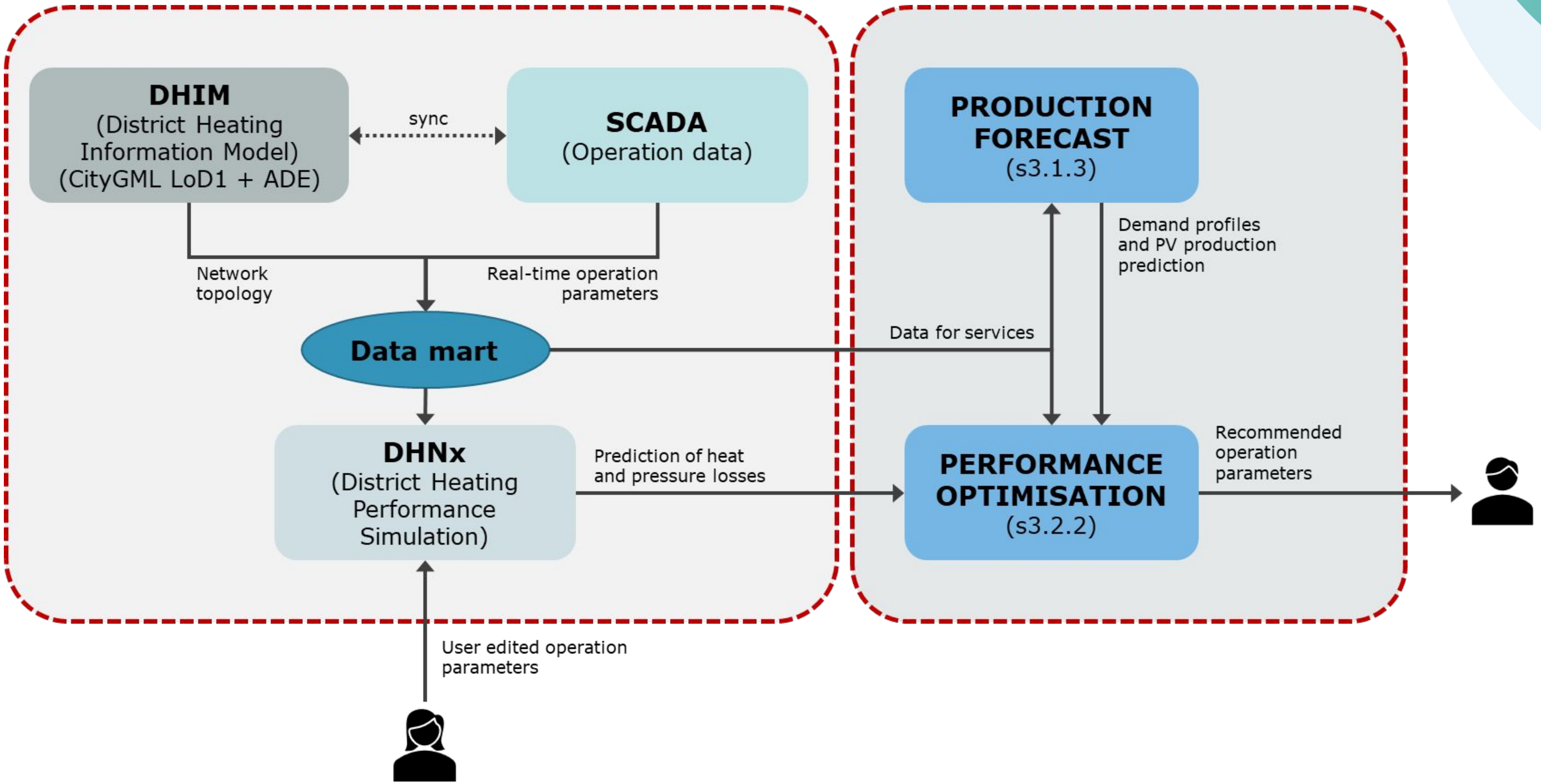
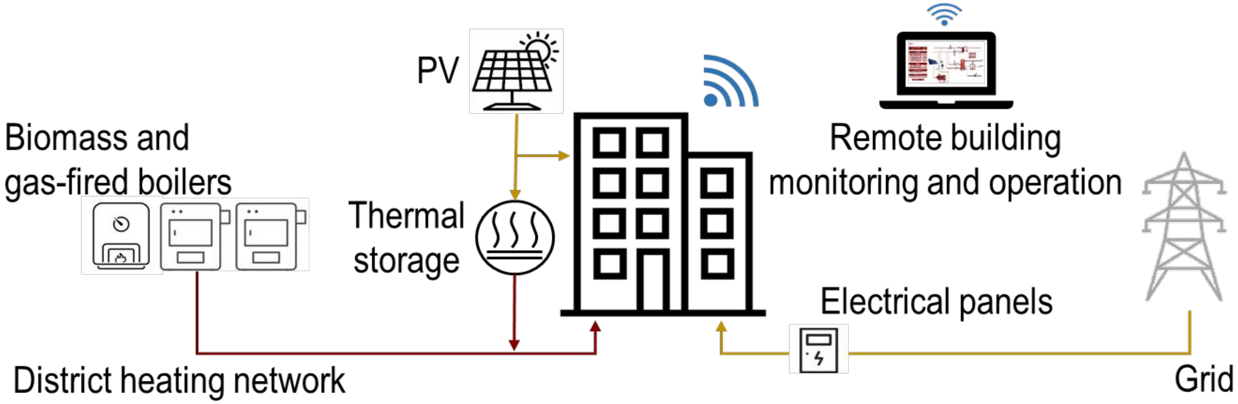
Digital twin approach

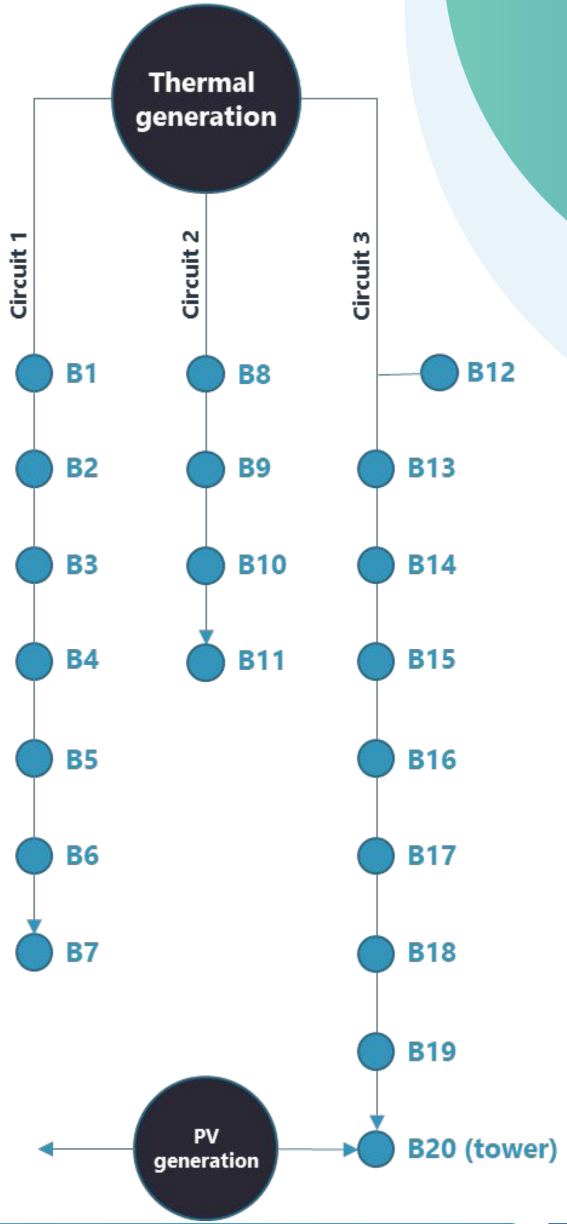


Application case

Application case



- **Demand nodes** (20 buildings w/ one substation each):
  - 1 tower + 19 blocks: substation w/ storage, interchanger and pumping
- **Production nodes** (boilers' room + PV façade):
  - Boilers' room: 3 boilers + variable flow pumping system
  - PV façade: PV panels in tower
- **Distribution system** (3 circuits):
  - Circuit 1: 7 blocks
  - Circuit 2: 4 blocks
  - Circuit 3: 1 tower + 8 blocks



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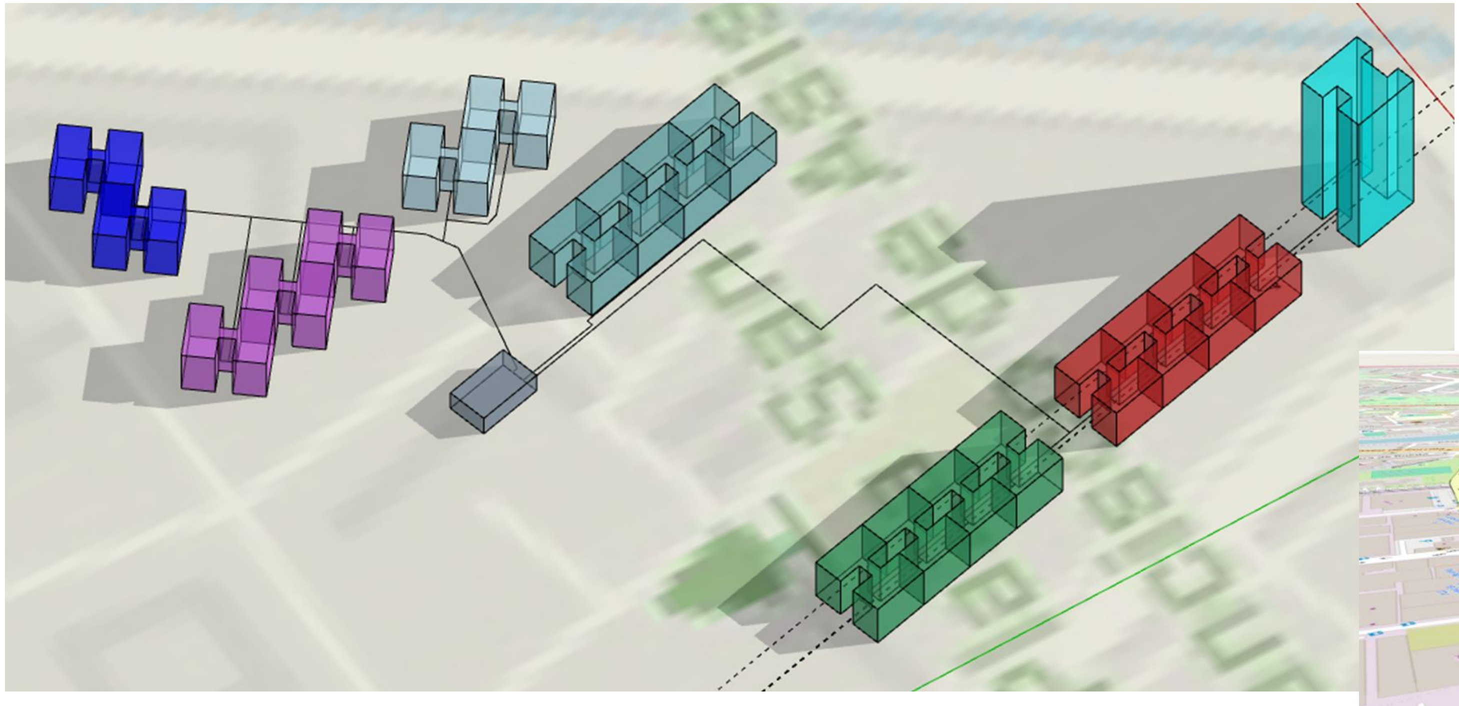
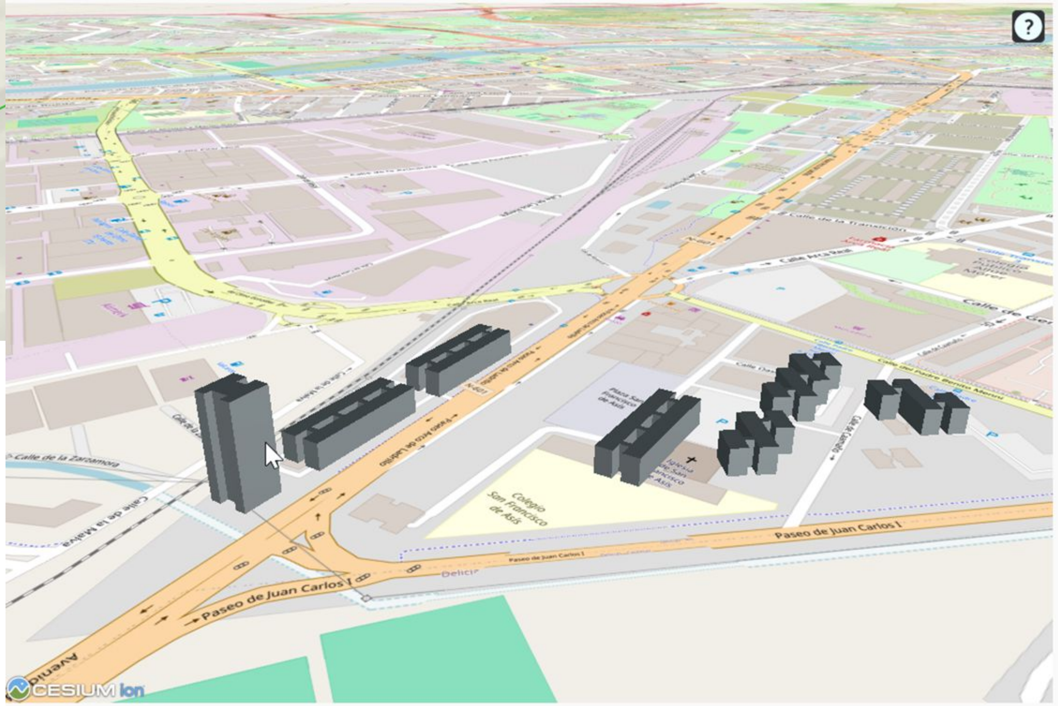
Application case





Preliminary results

DigiBUILD

Home
Optimization
History

Username
log out

SIMULATION RESULTS

Element	Heat losses (W)	Pressure losses (Pa)
circuit1	4968.49	5602.29
circuit2	4974.30	7594.14
circuit3	4963.34	4432.21
producers-0-forks-0	11293.01	411.69
forks-0-consumers-0	1806.56	16974.97
forks-0-consumers-1	1806.56	16974.97

Element	Circuit 1 inlet temp (°C)	Circuit 2 inlet temp (°C)	Circuit 3 inlet temp (°C)	Circuit 1 return temp (°C)	Circuit 2 return temp (°C)	Circuit 3 return temp (°C)
producers-0	130.00	130.00	130.00	118.26	118.52	118.03
forks-0	129.31	129.41	129.22	118.88	119.05	118.74
consumers-0	129.09	129.22	128.97	119.09	119.22	118.97
consumers-1	129.09	129.22	128.97	119.09	119.22	118.97

Boiler circuit	Pump power (W)
circuit1	3.92

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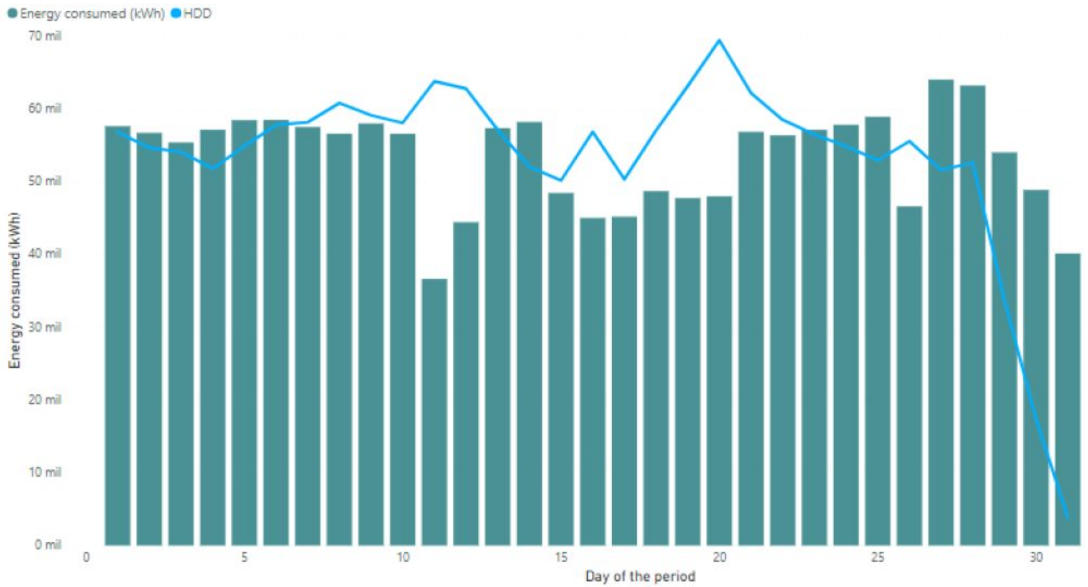
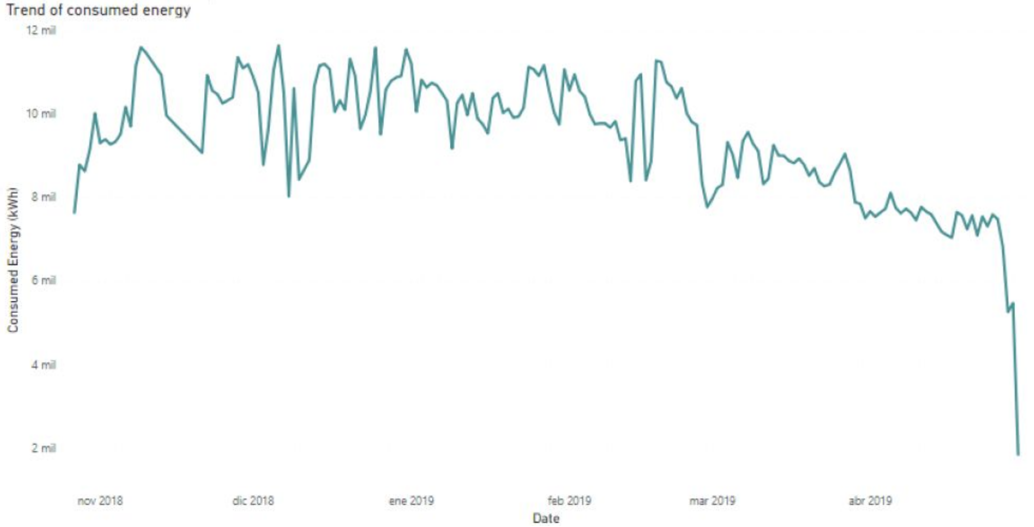
Preliminary results





$$Energy = 0.00036737 \times HDD + 10.7763$$

$$0.00036737 \times HDD + 10.7763 = Flow \times Cp \times (Tin - Tret)$$

$$Qp = k \times (Tin - Tground)$$

Original set-point	Average new set-point
87ºC	81.43ºC

Std	Energy savings (considering losses)
1.43	88 MWH (over 1.6 GWH) □ ~5%

DigiBUILD

Conclusions

- Digital twin as a way for the optimization of energy resources
- Application of AI is enhanced by using contextual data
    - Grey-box approaches
- Potential for improvements in the energy management
- Need of infrastructure digitalization
- Users should be the core

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Thank you!

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SUSTAINABLE PLACES 2024

AI-based analytics and control services to monitor, assess, predict and optimise building performance

Sofía Mulero-Palencia, CARTIF

CARTIF BuildON

Contents

1. Motivation

Building stock status

40% energy consumption	**75%** non-compliant buildings
36% emissions	be standing in 2050

(EC, 2020)

▲ in electricity demand from 23% to 30-31%1 by 2030 (ENTSO-E, 2020)

-0.5%/year for space heating consumption

+1.3%/year for electrical appliances consumption (households)

Opportunity

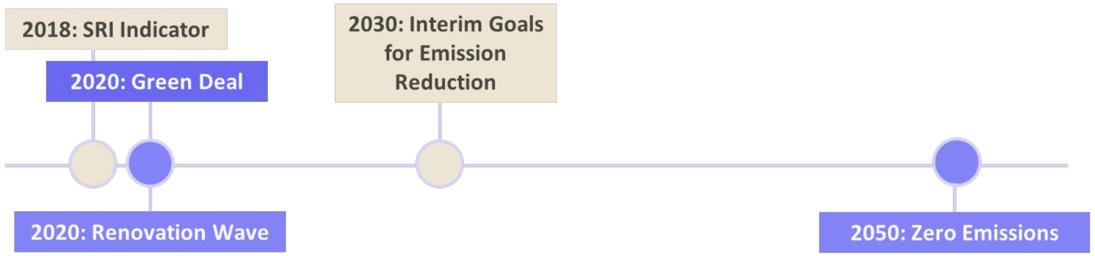
Significant potential for energy efficiency improvements

Challenge

Renovations often not feasible due to legal and financial barriers

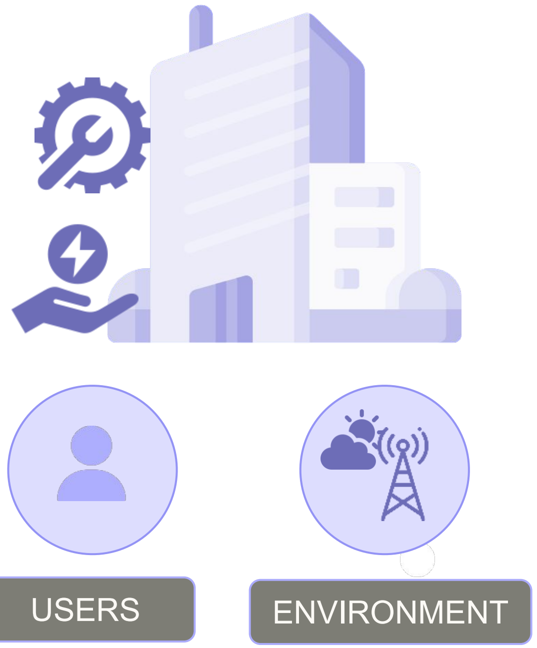
DIGITALISATION

European Initiatives roadmap



2. Smart Building Technologies

SMART BUILDING



BARRIERS

SOCIAL ASPECTS

- Lack of **user-friendly** solutions
- Technological **knowledge gap**

HARMONISATION

- Need for seamless integration of SW and HW
- Relevance of interoperability and standardisation

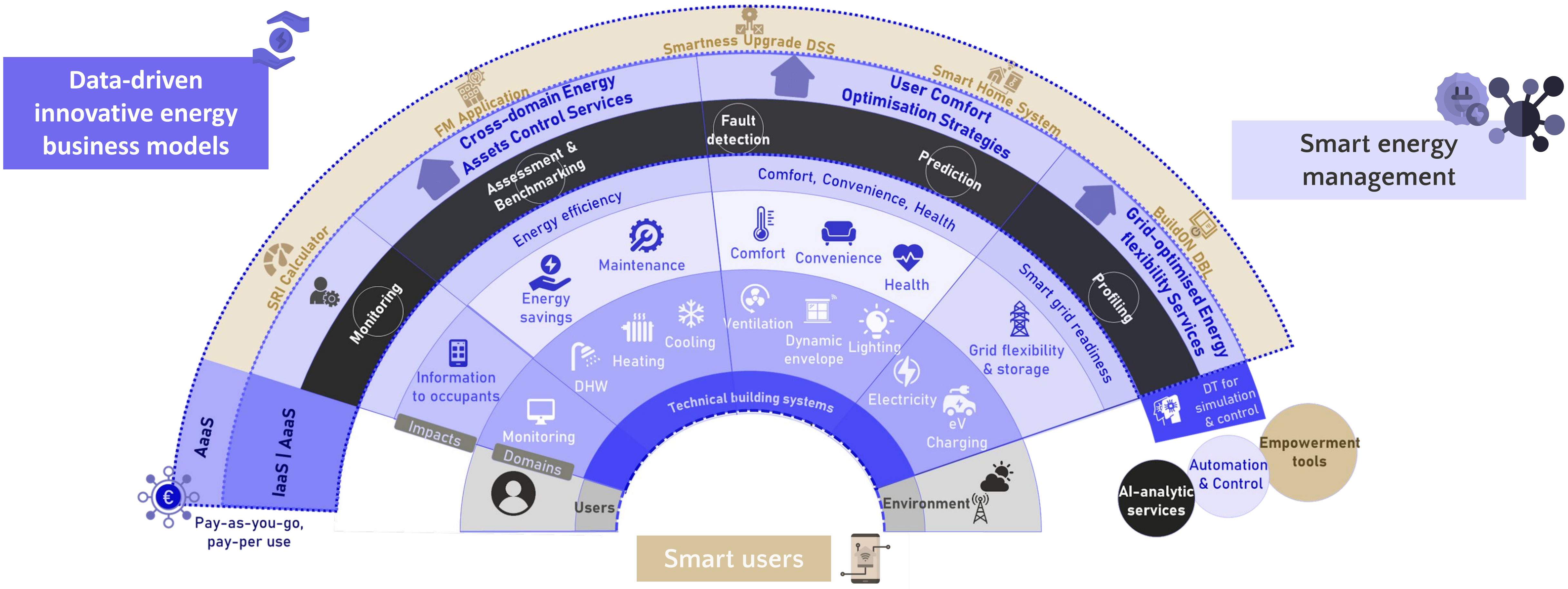
INTEGRATION NEW TECHNOLOGIES

- AI/ML for energy management and optimisation
- Digital Twins for real-time monitoring and control

1. MOTIVATION | 2. SMART BUILDING TECHNOLOGIES | 3. THE SMART TRANSFORMER TOOLBOX | 4. MAPO SERVICES | 5. CONCLUSIONS

3. The Smart Transformer Toolbox

SUSTAINABLE PLACES 2024



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BARRIERS

- SOCIAL ASPECTS
- HARMONISATION
- INTEGRATION NEW TECHNOLOGIES

Data-driven innovative energy business models
BUSINESS

User-friendly tools to empower users towards more efficient energy use
SOCIAL

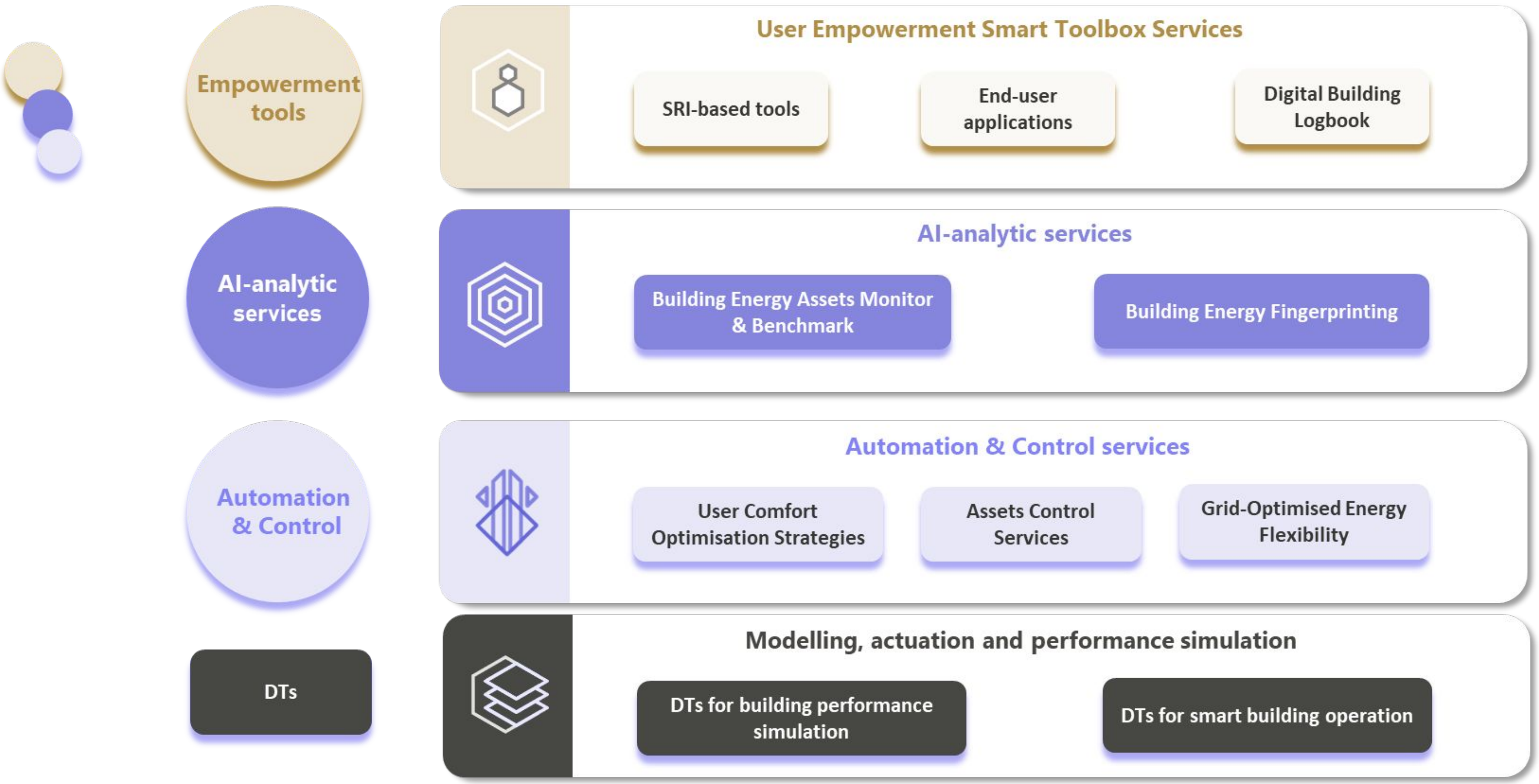
IoT Edge-Cloud interoperable framework for building data exchange and operation
TECHNICAL

Smart energy management system: MAPO analytics and optimisation services
TECHNICAL

Digital Twins for building performance simulation and smart building operation
TECHNICAL

3. The Smart Transformer Toolbox

SUSTAINABLE PLACES 2024



MAP Services for Monitoring, Assessment and Prediction capabilities

O services for energy optimisation

4. MAPO services

1 HOW TO IMPACT ON THE BUILDING

- Integration of advanced technologies
- Increased levels of automation
- Increased levels of Smart Readiness
- Adaptability to the needs of stakeholders and the environment

2 HOW TO FOSTER WIDESPREAD ADOPTION

- Technology harmonisation, resource sharing > archetypes
- **Standardised** solutions

4. MAPO services

1

SRI IMPROVEMENT

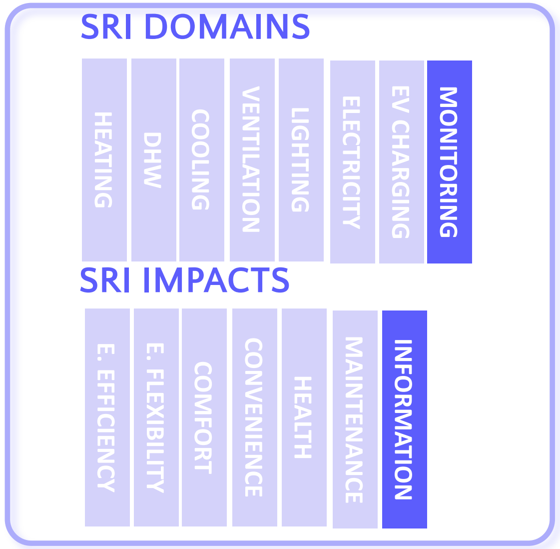
SRI DOMAINS	HEATING 34% 29% | 37%	DHW 29% 28% | 30%	COOLING 11% 0% | 18%	VENTILATION 7% 0% | 12%	LIGHTING 50% 42% | 56%	ELECTRICITY 26% 32% | 22%	EV CHARGING 14% 21% | 9%	MON & CONTROL 45% 69% | 28%
SRI IMPACTS	E. EFFICIENCY 36% 35% | 36%	E. FLEXIBILITY 33% 46% | 24%	COMFORT 33% 24% | 40%	CONVENIENCE 40% 44% | 37%	HEALTH 36% 31% | 9%	MAINTENANCE 42% 23% | 55%	INFORMATION 53% 48% | 55%	

* GLOBAL
RESIDENTIAL | TERTIARY

AI-analytic services

Building Energy Assets Monitor & Benchmark
- Advanced visualisations: monitoring and building performance
- Benchmarking tailored to specific building categories

Building Energy Fingerprinting
- Building energy profiling
- Data-driven forecasting capabilities.
- Operation and maintenance for anomaly detection



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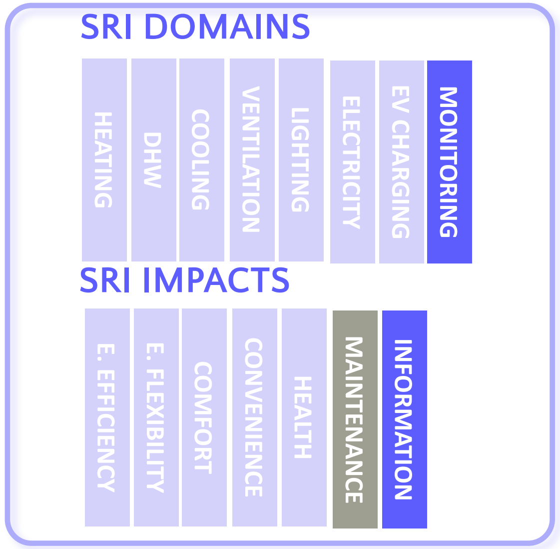

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4. MAPO services

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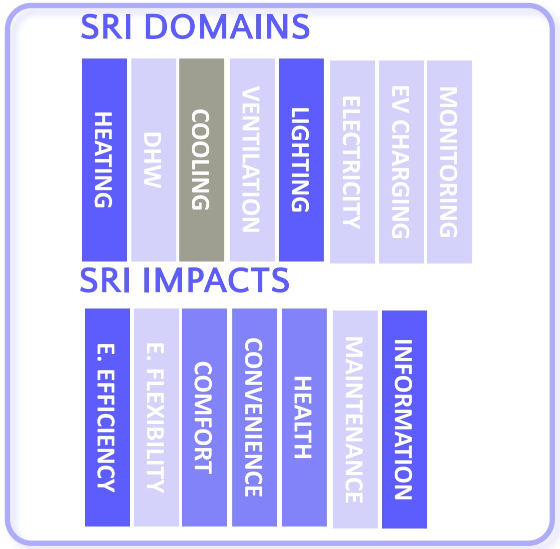
Automation and control services

Service	Description
User Comfort Optimisation Strategies	- Visual and IEQ comfort strategies for occupant wellbeing
Assets Control Services	- Energy assets control for H&C generation, enhanced management
Grid-Optimised Energy Flexibility	- Flexibility for occupants and grid congestion management



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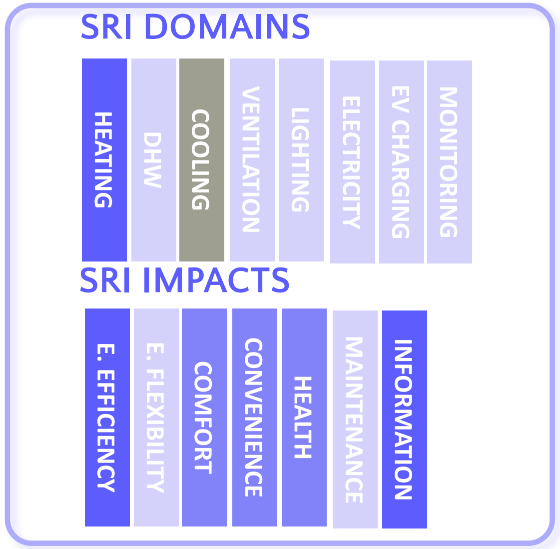

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4. MAPO services

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SRI DOMAINS

HEATING
DHW
COOLING
VENTILATION
LIGHTING
ELECTRICITY
EV CHARGING
MONITORING

SRI IMPACTS

E. EFFICIENCY
E. FLEXIBILITY
COMFORT
CONVENIENCE
HEALTH
MAINTENANCE
INFORMATION

4. MAPO services

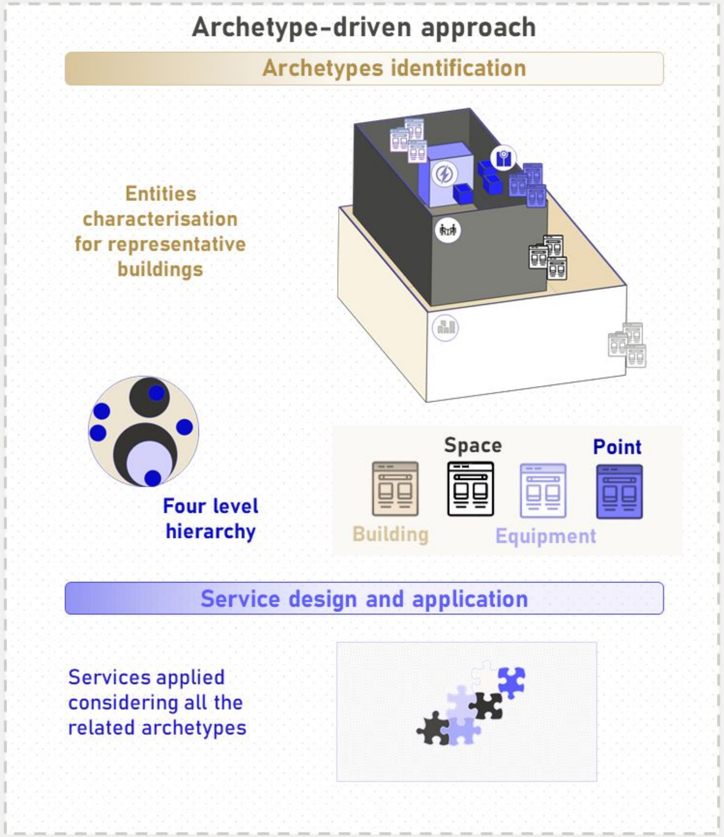
2

SUSTAINABLE PLACES 2024

HARMONISATION: ARCHETYPE-DRIVEN SERVICES

An archetype is a representative model capturing the essential characteristics and functionalities of energy assets within a specific domain

- **Tailored optimization:** efficient services customised for diverse building environments.
- **Scalable solutions:** adaptable across various configurations, ensuring wide applicability.
- **Dynamic adaptability:** robust solutions that adjust to evolving conditions and needs.



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CARTIF

Sustainable Places 2024: Sofía-Mulero Palencia, September 2024

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5. Conclusions

Overcoming barriers to Smart Buildings Technologies

- Foster **widespread adoption**
    - **Digitalisation** as a driver
    - Easy-to-use applications, enhanced participatory scenarios and training
    - Technology **harmonisation**, resource sharing
    - Increased levels of **automation**
    - **Adaptability** to evolving environment

- **Policies** promoting advanced automation and AI-based technologies
    - **Standardised** solutions

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SOFÍA MULERO-PALENCIA, CARTIF

SUSTAINABLE PLACES 2024
25 SEPTEEMBER 2024, LUXEMBOURG

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