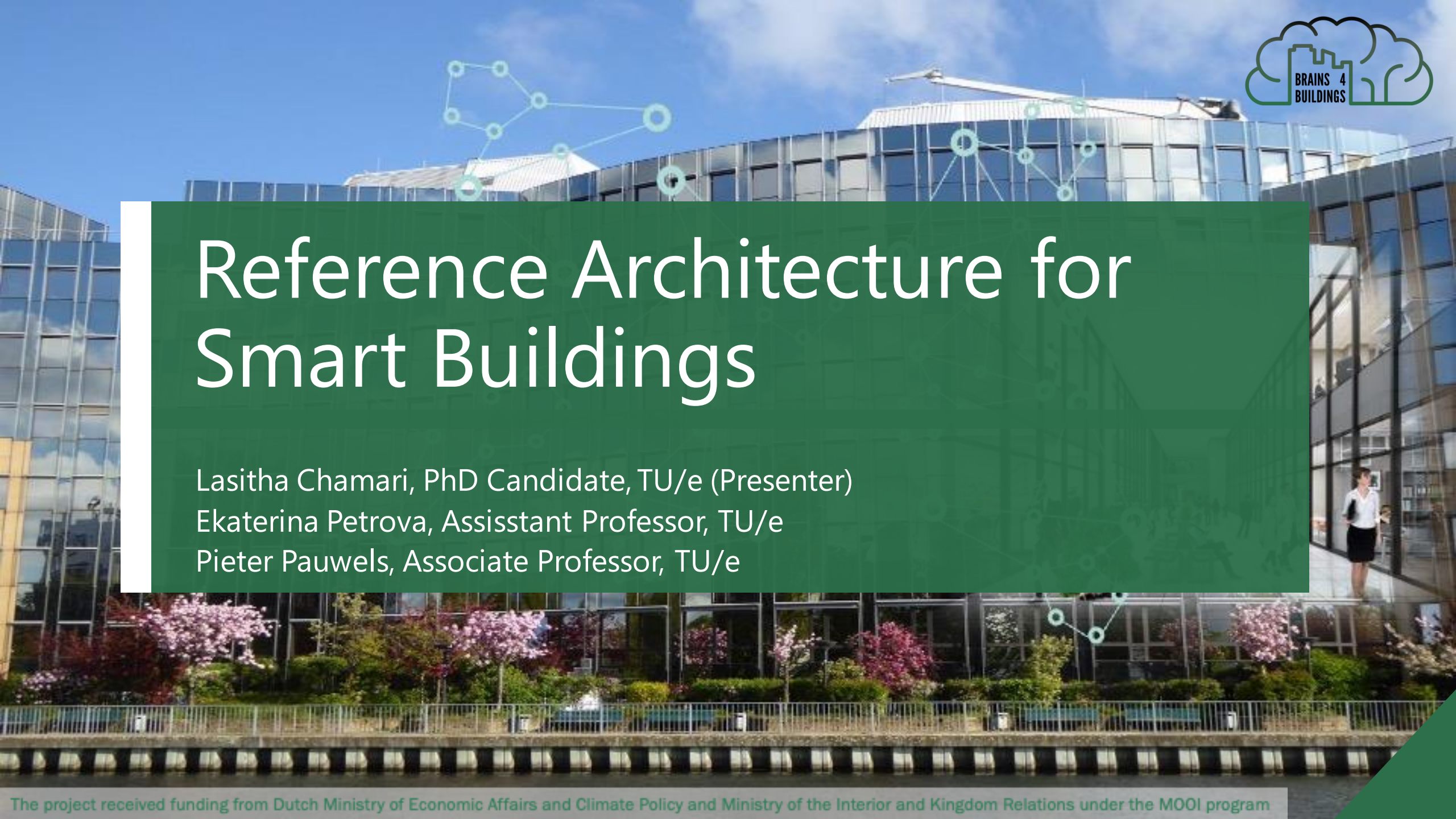


Reference Architecture for Smart Buildings

Lasitha Chamari, PhD Candidate, TU/e (Presenter)
Ekaterina Petrova, Assisstant Professor, TU/e
Pieter Pauwels, Associate Professor, TU/e

The project received funding from Dutch Ministry of Economic Affairs and Climate Policy and Ministry of the Interior and Kingdom Relations under the MOOI program

Webinar Outline

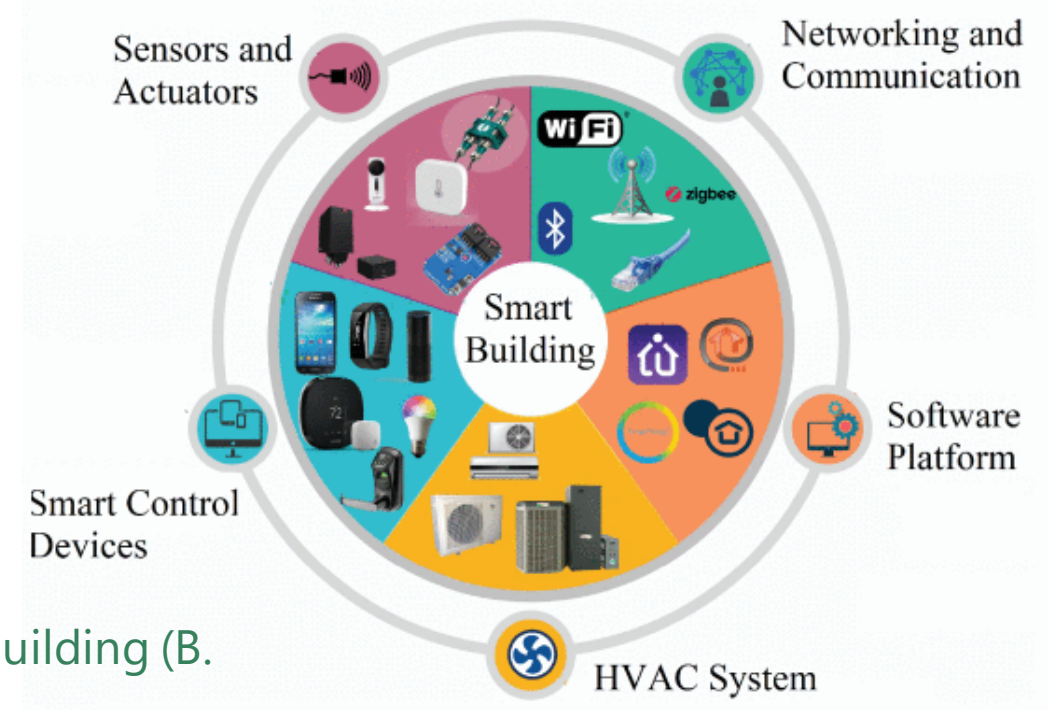
1. What makes a building “Smart”
2. The need for a Reference Architecture
3. A Reference Architecture for Smart Buildings
4. Implementation and use cases
5. Q & A

1. Smart Building

What makes it Smart

Smart Building

- Objectives –
  - Reduce energy cost
  - Reduce GHG emission
  - Improve self-sufficiency
  - Improve occupant comfort
- Incorporate various sensors, actuators, data-driven solutions, and automation
- Monitor and control a wide range of functions
  - HVAC, lighting, energy flexibility

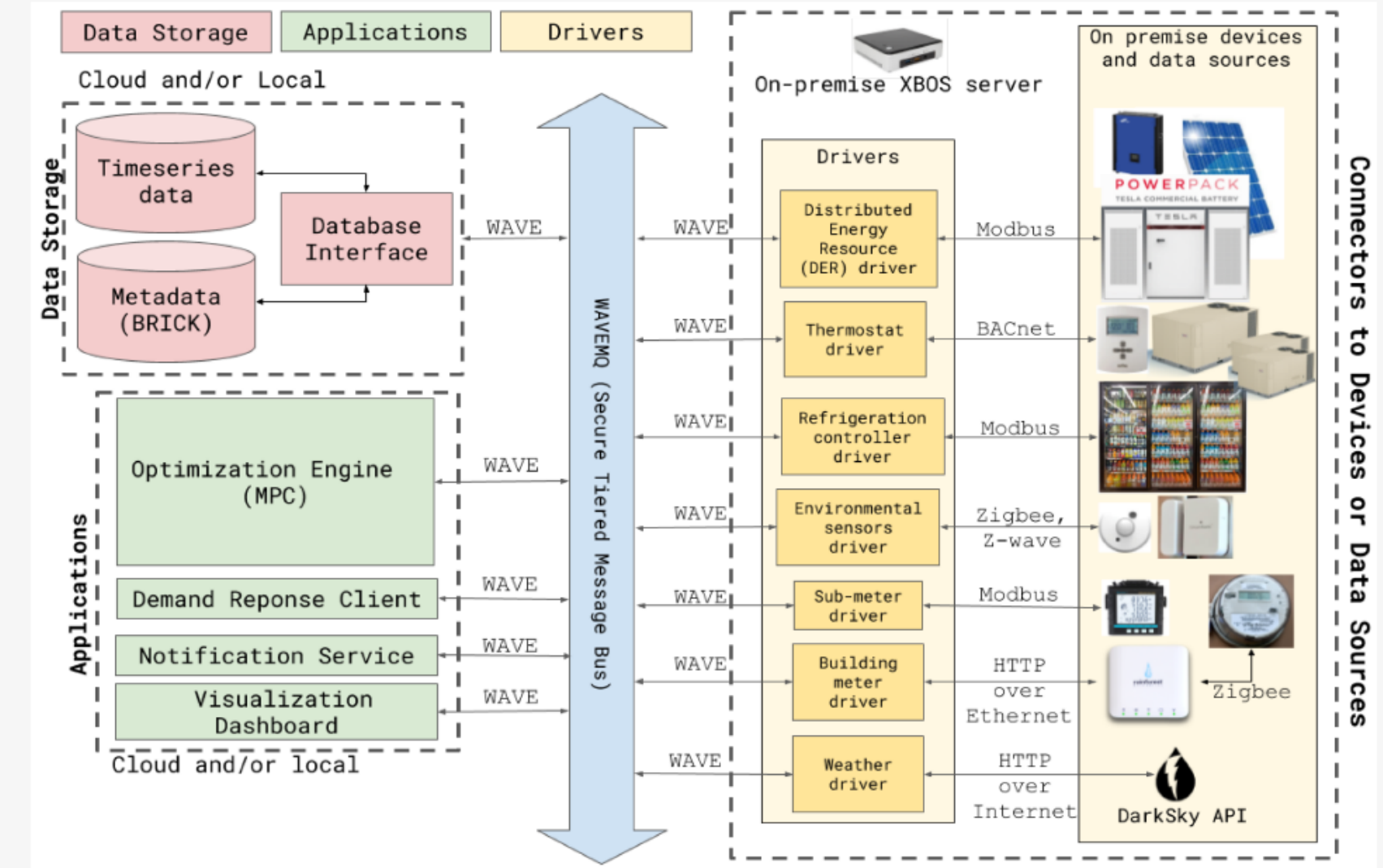


Components of a Smart Building (B. Qolomany et al., 2019)

Intelligent Controller example

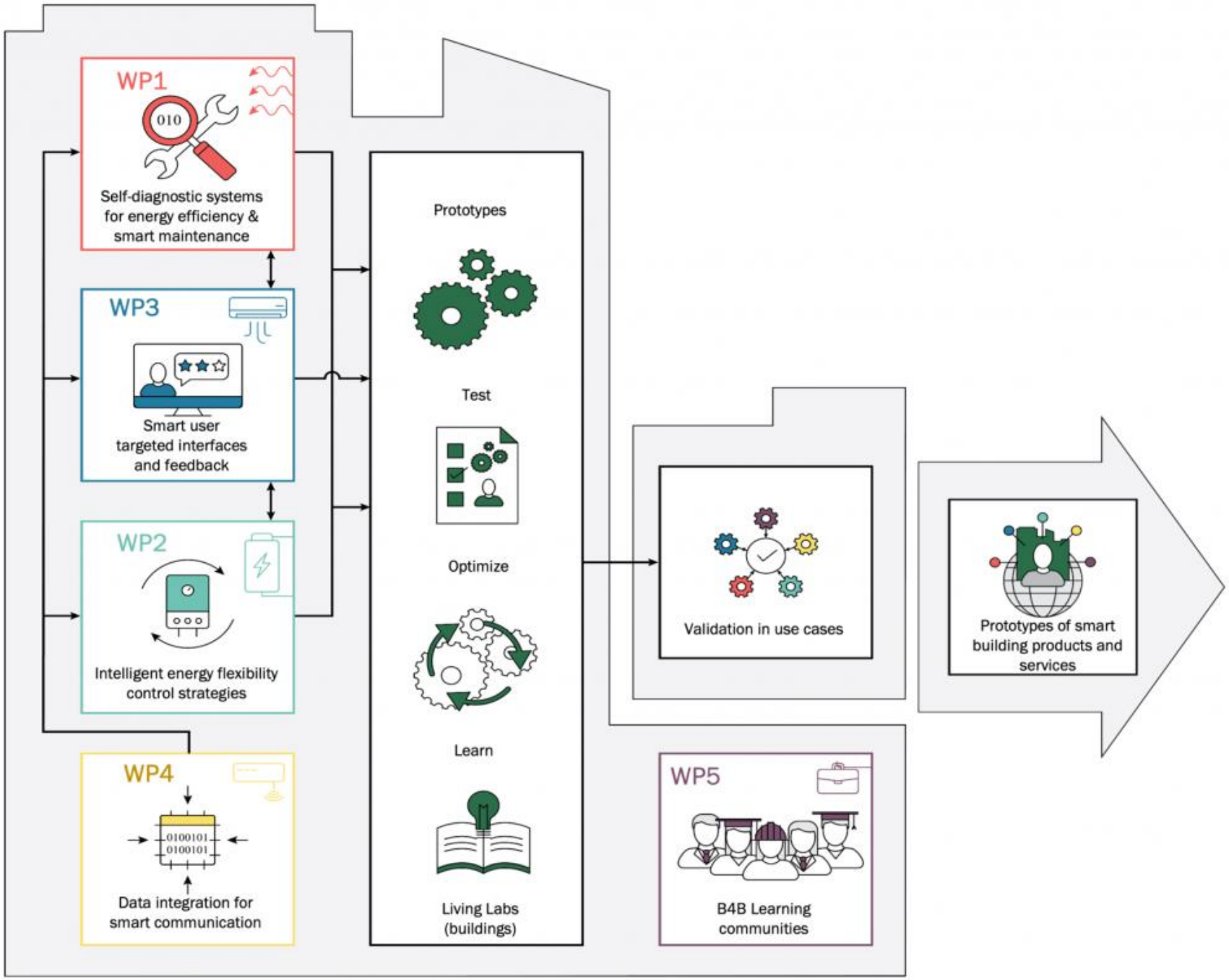
- Example of typical interactions between components of an MPC

- Data
- Metadata
- Systems and Controllers
- Communication



Solar + Optimizer System based on MPC (K. Prakash et al., 2020)

Brains4Buildir



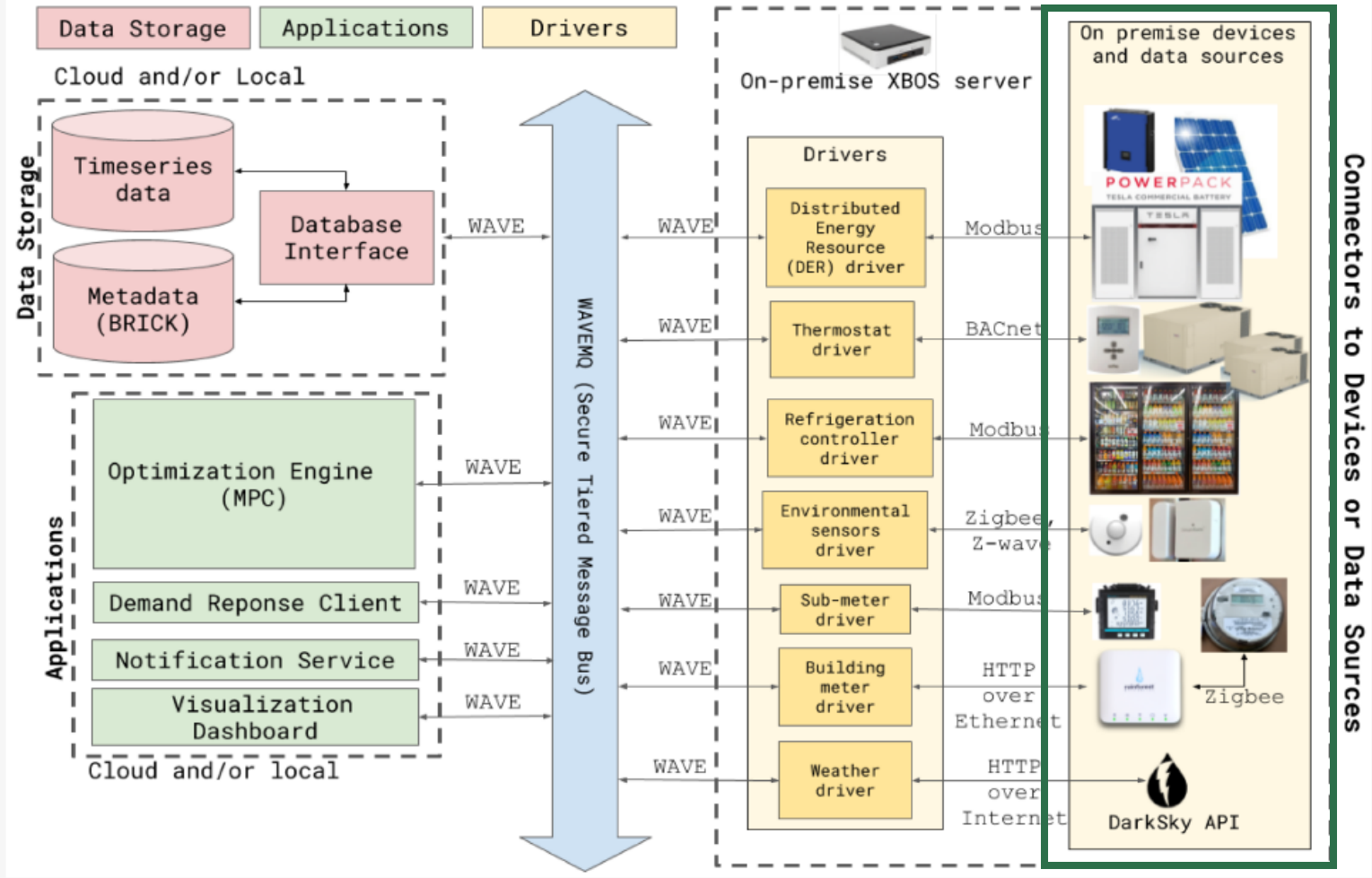
2. Reference Architecture

What's in it for Smart Buildings?

Why smart buildings need a well-defined architecture

- Limite ls
- Lack c integra
- Comp
- Docur instruc
- Lack o techno
- Lack c oints
- Inade ation
- Security vulnerabilities - exposing sensitive data sources to

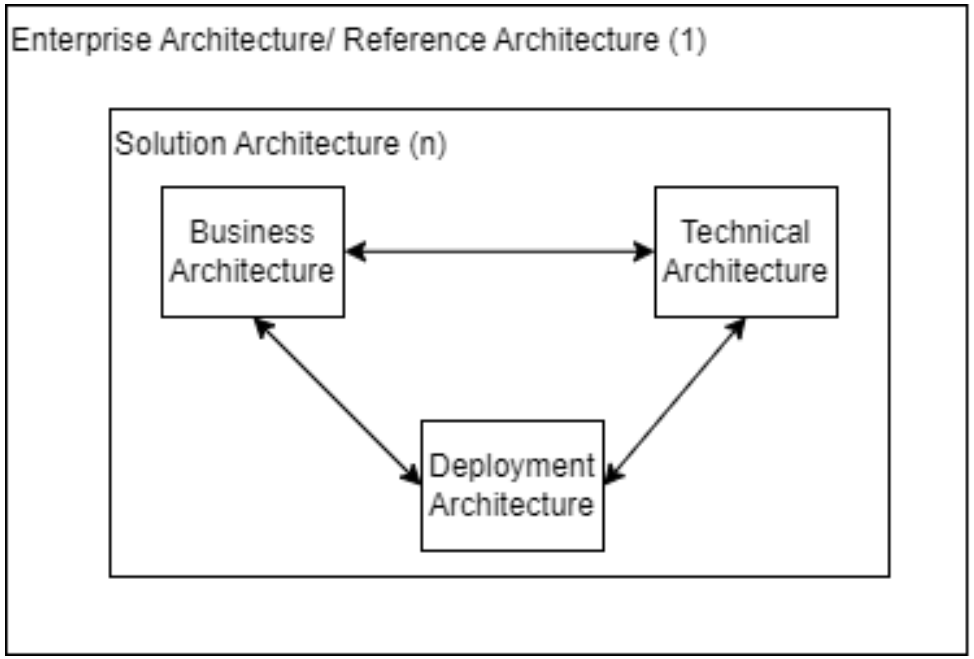
Figure 1. Software architecture diagram of the Solar+ Optimizer system.



Solar + Optimizer System based on MPC (K. Prakash et al.,2020)

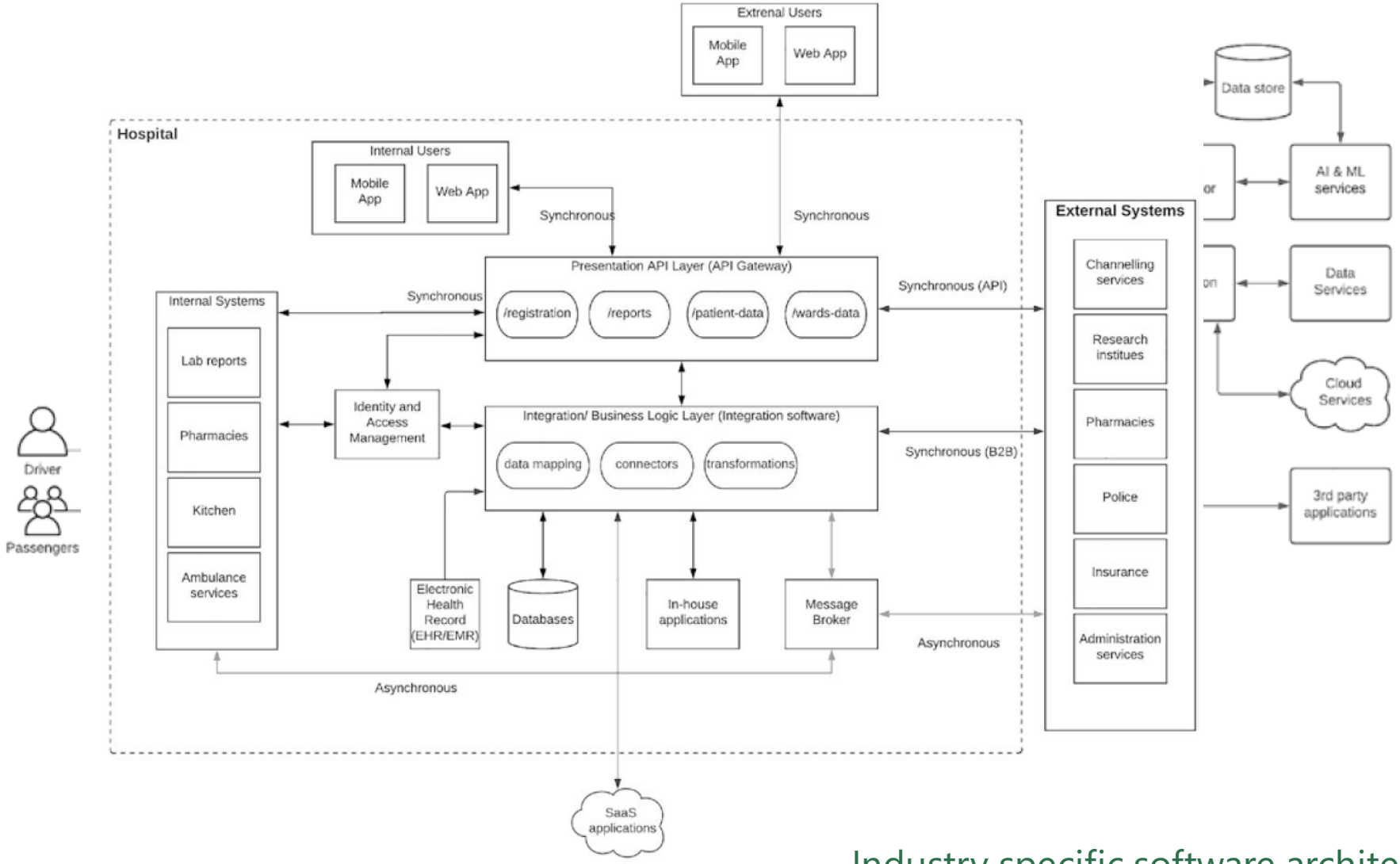
Reference Architecture

- Physical systems have stable architectures (buildings, bridges).
- Architecture - "The **structure of components, their inter-relationships**, and the principles and guidelines governing their design and evolution over time" (TOGAF standard, 10th edition)
- Reference Architecture – A blueprint to create architectures
- Re-usable, 1:n



Enterprise Architecture and Solution Architecture (C. Fernando, 2023)

Domain specific architecture-Edge computing



Industry specific software architecture patterns

3. A Reference Architecture for Smart Buildings

Creating a blueprint

How to get there?

- The 6 steps

1. Understand the smart building's requirements (data needs and requirements, Zachman Architecture Framework)
2. FRs and NFRs
3. Patterns/ Reference Architectures - Look for already available patterns in similar domains
4. Components - Burrow re-usable components and best-practices, add our own components and interactions tailored to use cases
5. Architecture description
6. Implementation

Functional requirements

FR1 Ingestion of time series data from heterogeneous systems

FR2 Processing and storage of large volumes of time series data

FR3 Processing and storage of contextual information (metadata)

FR4 Integrating metadata with the operational data

FR5 Interoperability among several existing devices, services, and applications

FR6 Real-time bidirectional communication ability

FR7 User-centered interfaces

Non-functional requirements

General NFRs – Performance, extensibility, security, reliability, and maintainability

NFR1 Reusability of components and services

NFR2 Add new services in a modular way

NFR3 Scalability to manage the increasing number of devices, data or services in the building

Architectural Pattern

Patterns are everywhere…

Domain specific architecture patterns

- Education
- Automotive
- Healthcare

Technology specific patterns

- Which pattern is the best?

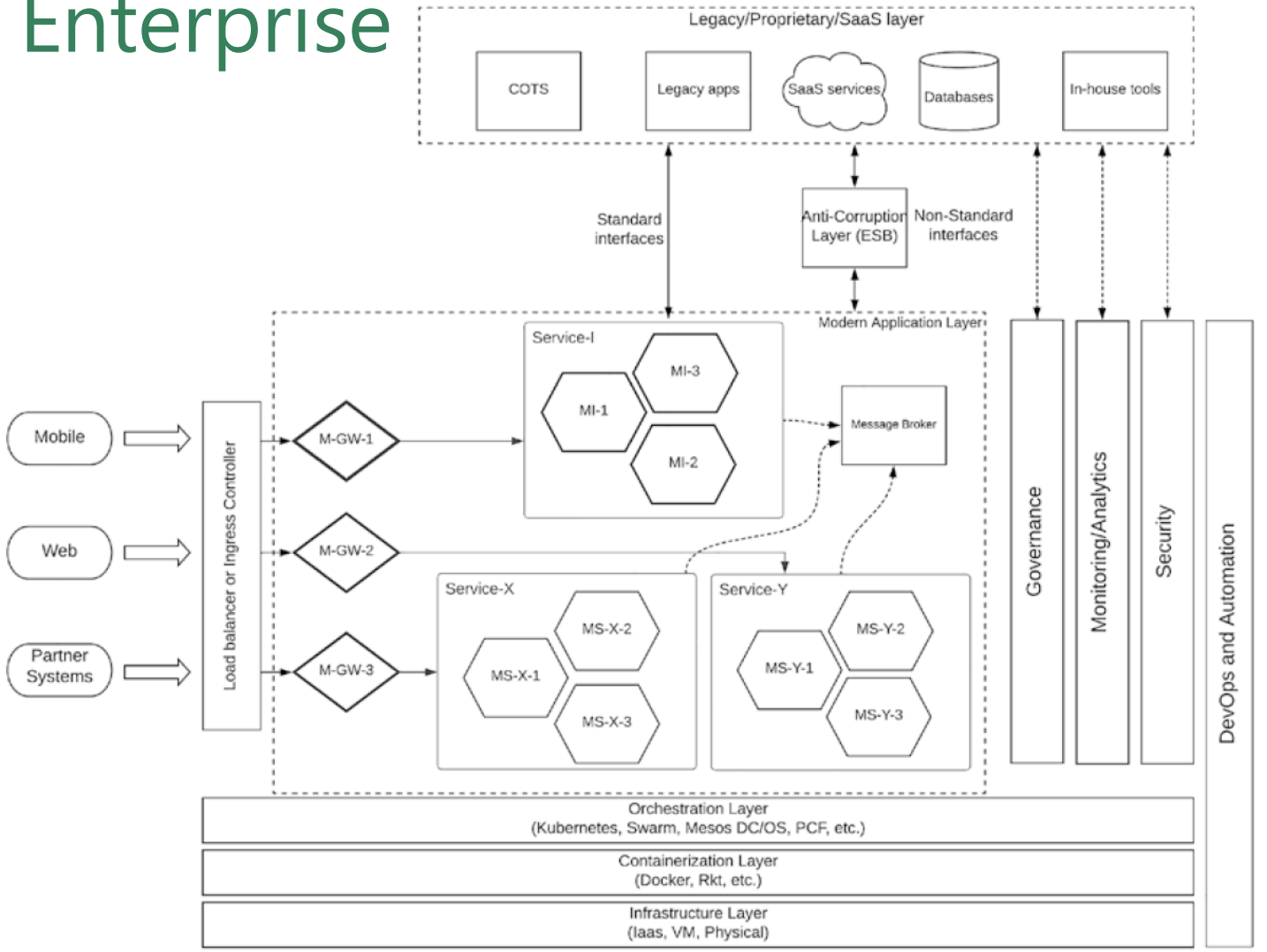
- Selecting a pattern for new services (e.g data driven applications, integration software)

	Layered	Microkernel	Event-driven	Microservices	Space-based
Partitioning	T	D/T	T	D	T
Overall cost	$	$	$$$	$$$$$	$$$$$
Agility	●	●●●	●●●	●●●●●	●●
Simplicity	●●●●●	●●●●	●	●	●
Scalability	●	●	●●●●●	●●●●●	●●●●●
Fault tolerance	●	●	●●●●●	●●●●●	●●●
Performance	●●●	●●●	●●●●●	●●	●●●●●
Extensibility	●	●●●	●●●●●	●●●●●	●●●

Figure A-1. Architecture styles rating summary

A summary of architecture style characteristics (M. Richards, 2022)

Brownfield Enterprise



Microservice based architecture pattern
(C. Fernando, 2023)

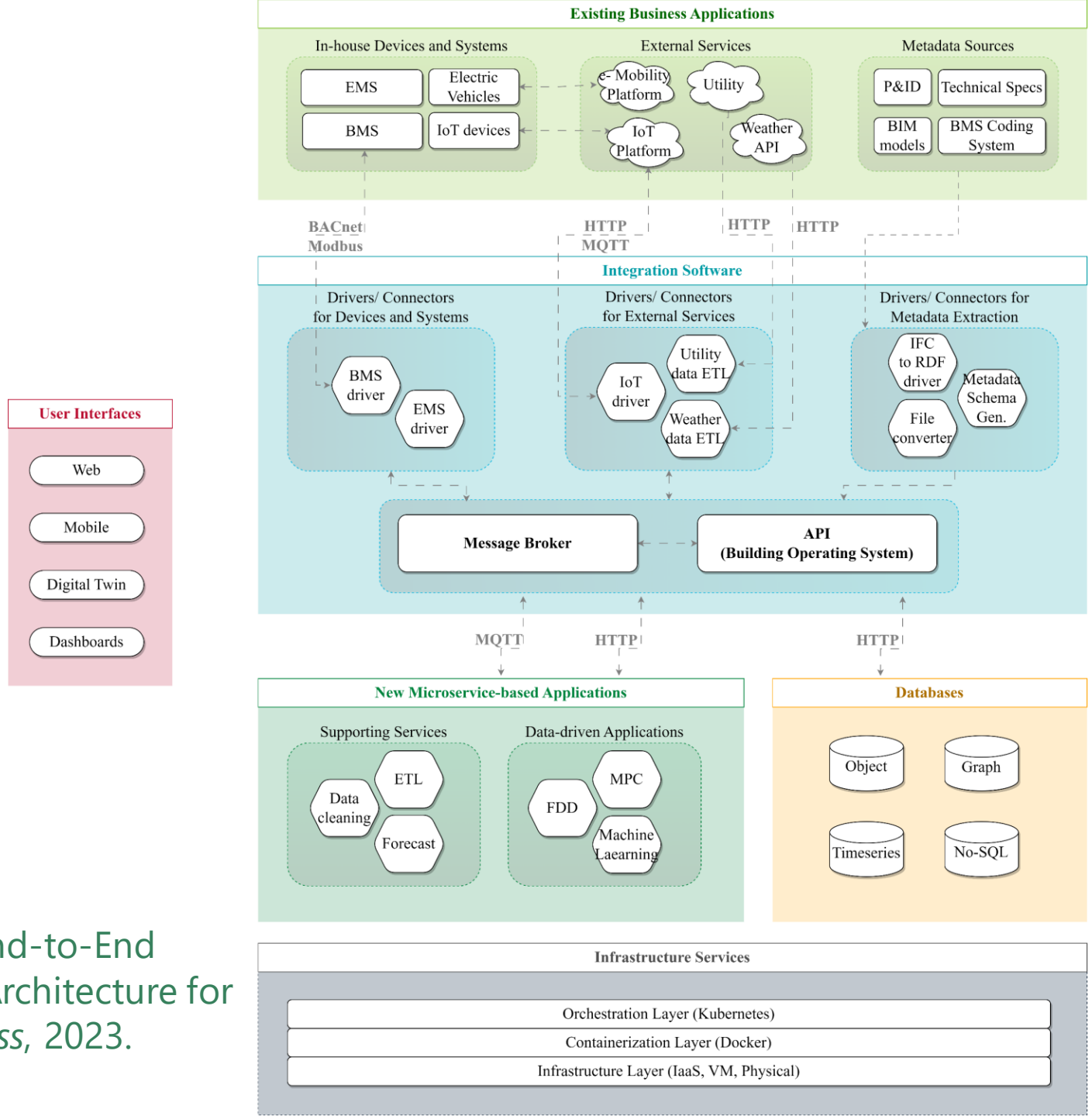
Architectural Components

What makes the architecture ?

Components of a Smart Building Architecture

1. Existing business applications
2. New service-oriented applications
3. Databases
4. Integration software
5. Infrastructure services
6. Shared services
7. User interfaces

Service-oriented representation



L. Chamari, E. Petrova, P. Pauwels, "An End-to-End Implementation of a Service-Oriented Architecture for Data-driven Smart Buildings," *IEEE Access*, 2023.

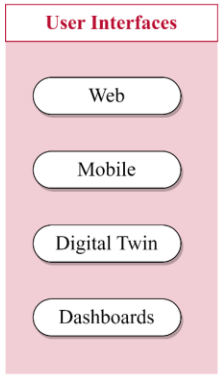
4. Architecture Implementation

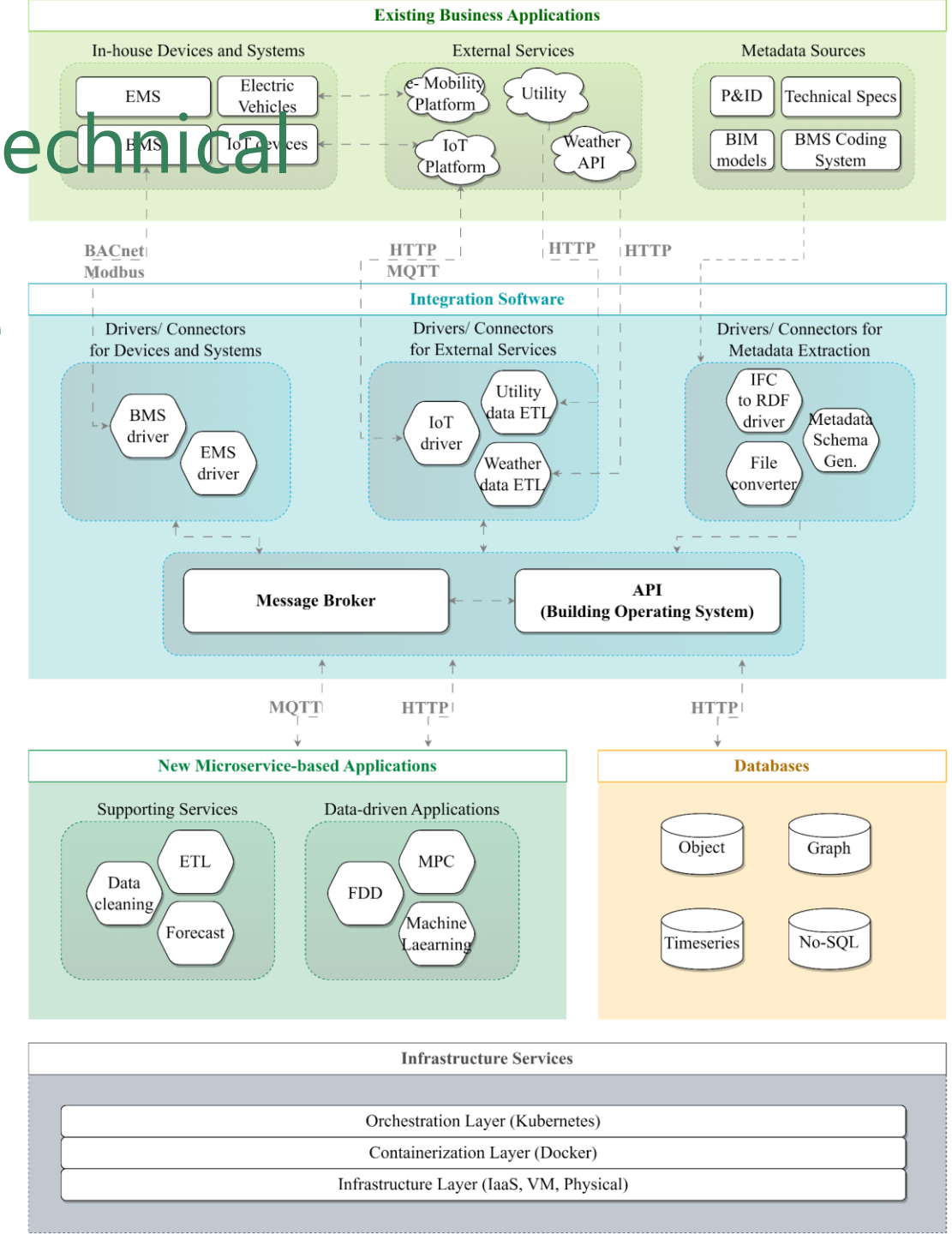
"A system's architecture ultimately resides in executable code"

- Software Architecture, Grady Booch

Solution architecture - technical

- Technology choices we made





API

Projects

POST	`/projects`	Create a project
GET	`/projects`	Get all projects
GET	`/projects/{id}`	Get project by id
PATCH	`/projects/{id}`	Update project properties by id
DELETE	`/projects/{id}`	Delete project by id

Project Files

POST	`/projects/{id}/xkt`	Upload a xkt file
GET	`/projects/{id}/xkt`	Download a xkt file of a project

RDF

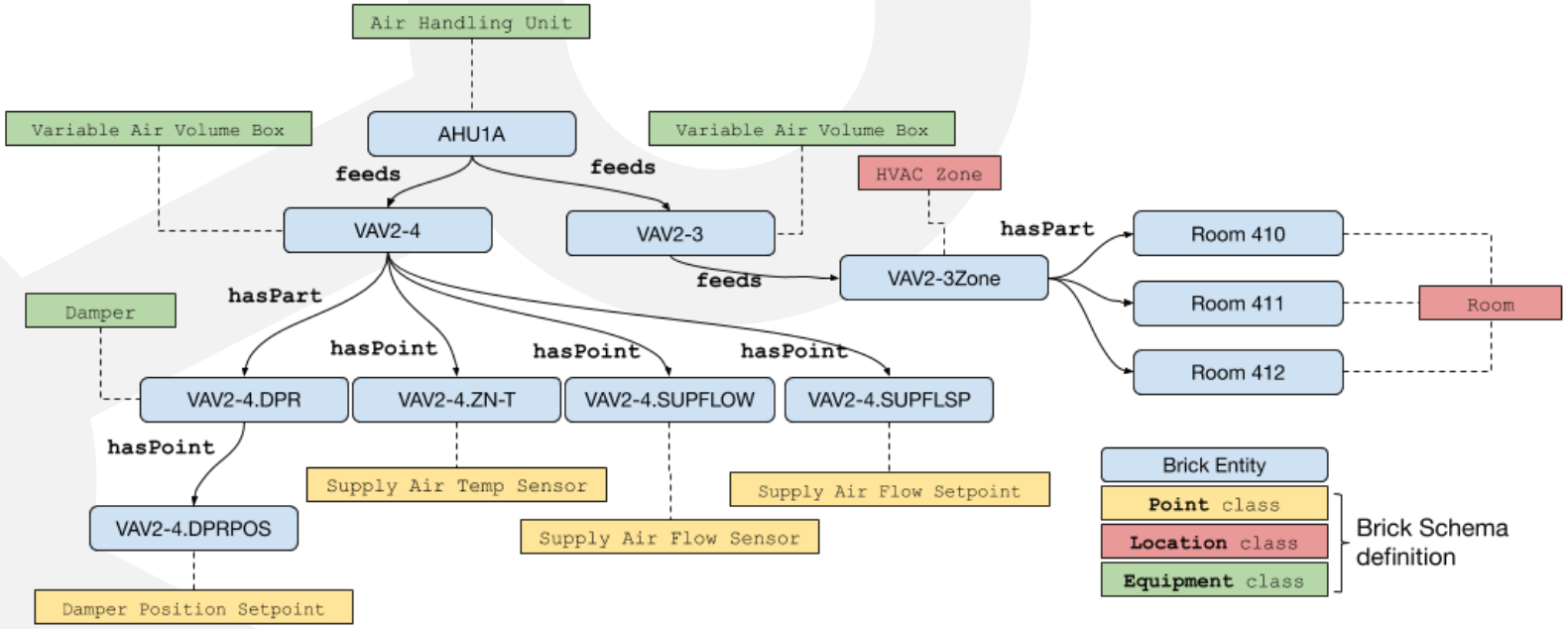
PUT	`/projects/{id}/rdf`	Upload a RDF graph document
POST	`/projects/{id}/sparql`	SPARQL endpoint for the graph database. Execute a sparql query againts a graph by the graph id
GET	`/projects/{id}/namespaces`	Get all the namespaces from the graph by the graph id
GET	`/projects/{id}/sensors`	Get Sensors by GUID of an IfcSpace from the graph by the graph id

Sensor data

GET	`/sensors/{sensor_id}/records`	Get sensor data by sensor id and time period

Linked Data, Metadata Models, Ontologies

- Two purposes –
  - Create links
  - Standardise semantics
- Efficient data collection
- Reusable applications
- Semantic graphs based on available ontologies
  - Brick, BOT, SSN
- Integrate with smart building API



Representing HVAC System using Brick Ontology (source: https://brickschema.org/)

Data storage

- Time-series
- Semantic (RDF graphs)
- Objects
- Documents

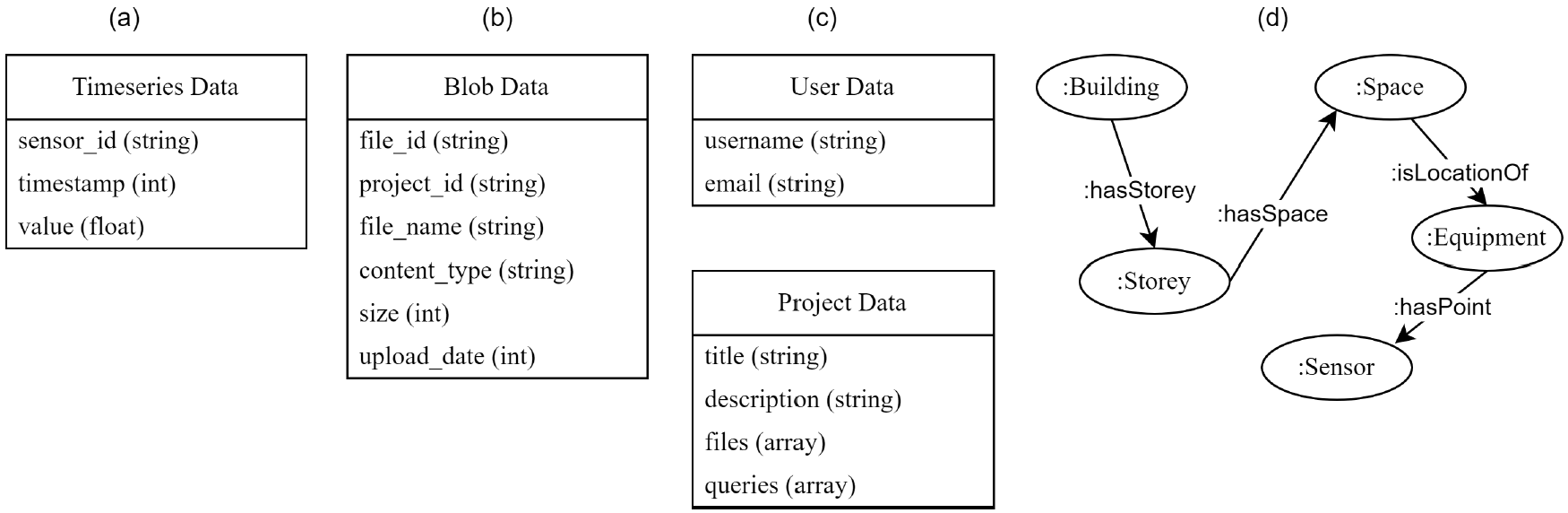
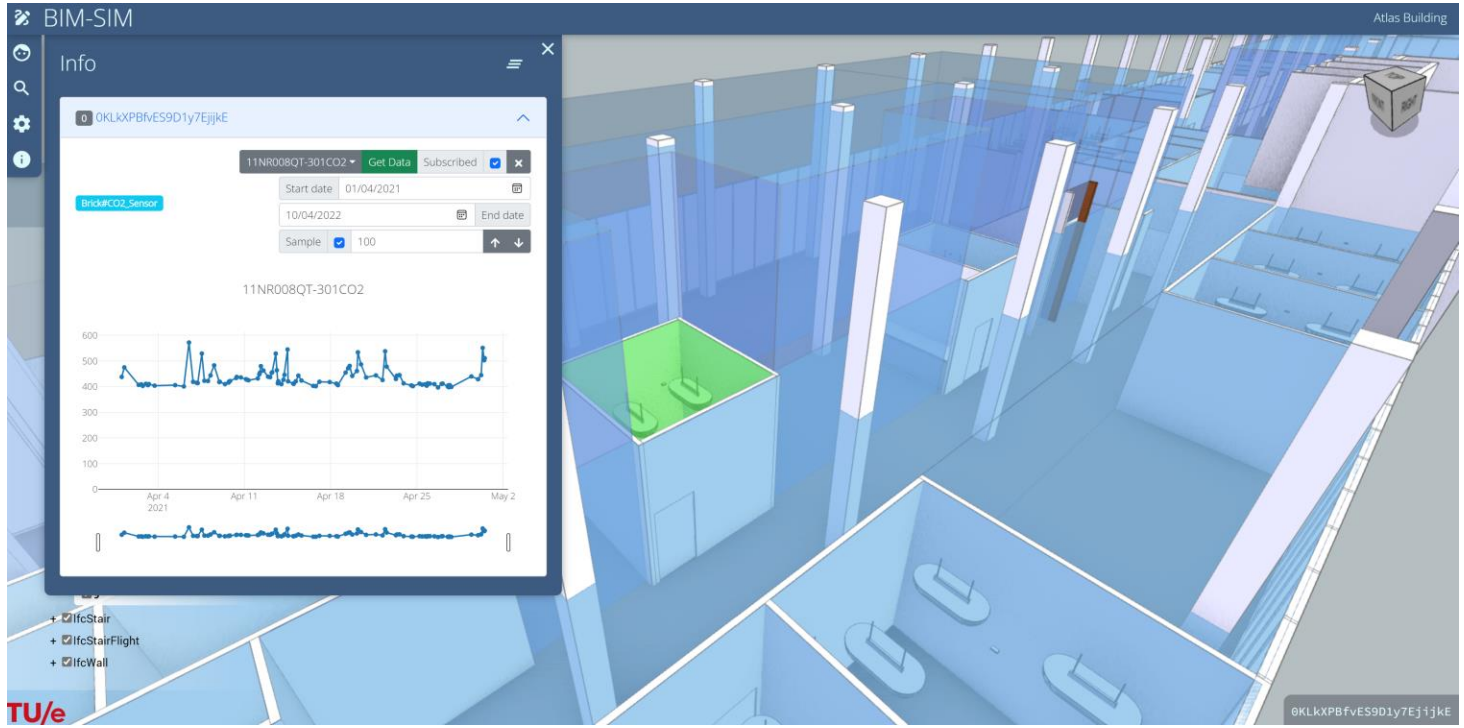


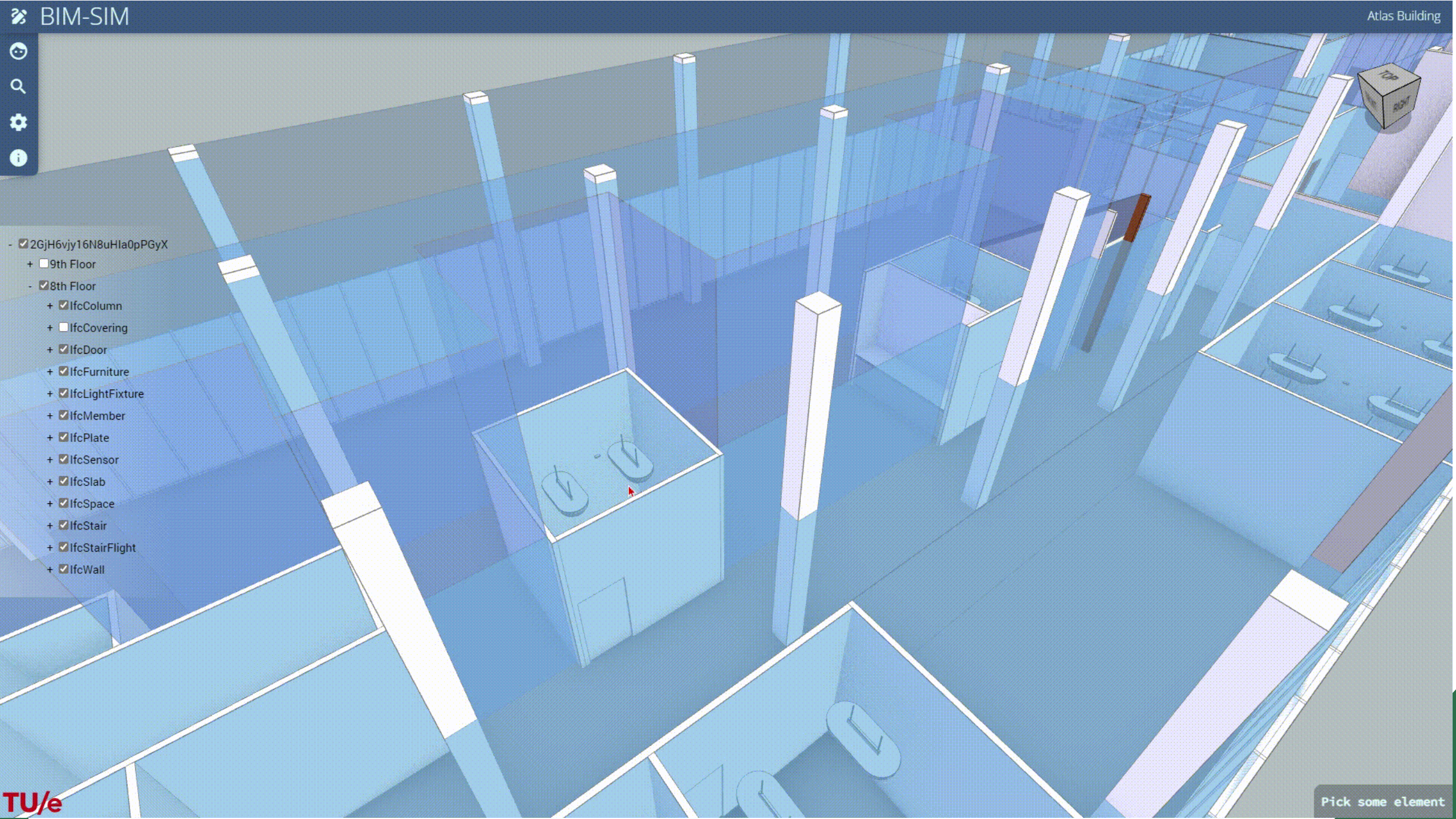
FIGURE 4. Logical data models of a) time series database b) Blob storage c) Document database and d) Graph database

Digital Twin

- Integrating sensor data at room level with BIM model Atlas Living Lab – TU Eindhoven



We based BIM-IoT Integration (L. Chamari et al, 2022)


BIM-SIM
Atlas Building
- 2GjH6vjy16N8uHIa0pPGyX
+ 9th Floor
- 8th Floor
+ IfcColumn
+ IfcCovering
+ IfcDoor
+ IfcFurniture
+ IfcLightFixture
+ IfcMember
+ IfcPlate
+ IfcSensor
+ IfcSlab
+ IfcSpace
+ IfcStair
+ IfcStairFlight
+ IfcWall
TU/e
Pick some element

#GenerateMyMetadataSchema

- One of the two living labs of TU Delft
- Integrate Brick model with BMS data

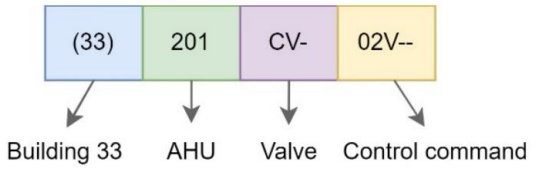


Figure 2: Point naming convention example

Metadata schema generation using BMS metadata (L. Chamari et. al, 2023)

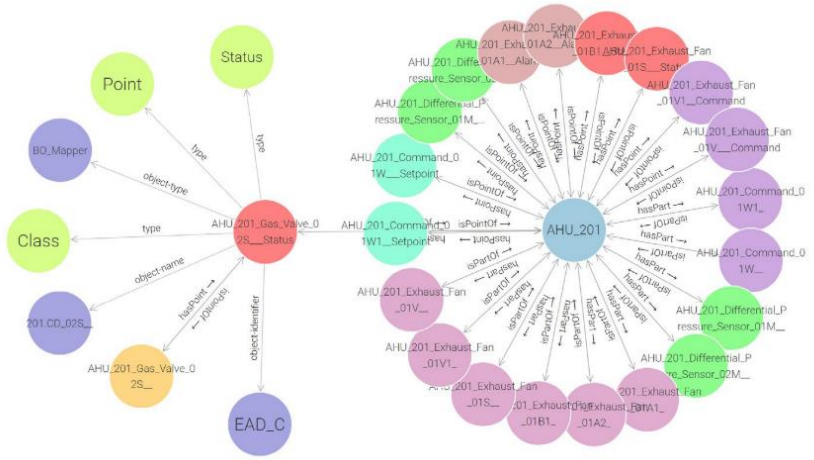


Figure 6: Part of the metadata schema containing the AHU and its Points represented graphically using GraphDB interface.

Model Predictive Controller for Energy Flexibility

- Ongoing
- Investigate how to implement MPC as a modular service

Further Information

- L. Chamari, E. Petrova, P. Pauwels, "An End-to-End Implementation of a Service-Oriented Architecture for Data-driven Smart Buildings," in IEEE Access, doi: 10.1109/ACCESS.2023.3325767.
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- IoT and semantic integration→ https://ec-3.org/publications/conferences/EC32023/papers/EC32023_300.pdf
- Metadata schema integration with BMS metadata→ https://linkedbuildingdata.net/ldac2023/files/papers/papers/LDAC2023_paper_8314.pdf
- Deliverable D4.3 Study of data needs and requirements in smart buildings
- Deliverable 4.06 Reference Architecture for Smart Buildings

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Collecting occupant feedback using smart watch Donkers, Alex, de Vries, Bauke, and Yang, Dujuan,

5. Questions, Thoughts, Feedback,…

Thanks for attending