W3C Linked Building Data Community Group

Enabling Portable, Interoperable and Scalable Demand Flexibility Controls with Semantic Modelling

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Outline

- **Introduction**
  - Context
  - Research gaps
- **Research scope**
  - The initial framework (portability)
  - The extended framework (interoperability)
  - The library (scalability)
- **Conclusion and future work**

California is leading the way towards renewables

APRIL 24, 2024 | 4 MIN READ

A Golden Age of Renewables Is Beginning, and California Is Leading the Way

California has hit record-breaking milestones in renewable electricity generation, showing that wind, water and solar are ready to cover our electricity needs

BY MARK Z. JACOBSON

California achieves 100% renewable energy for 100 days

On 100 out of 144 days since 8 March, California's electricity has been supplied fully by renewable energy for at least part of the day.

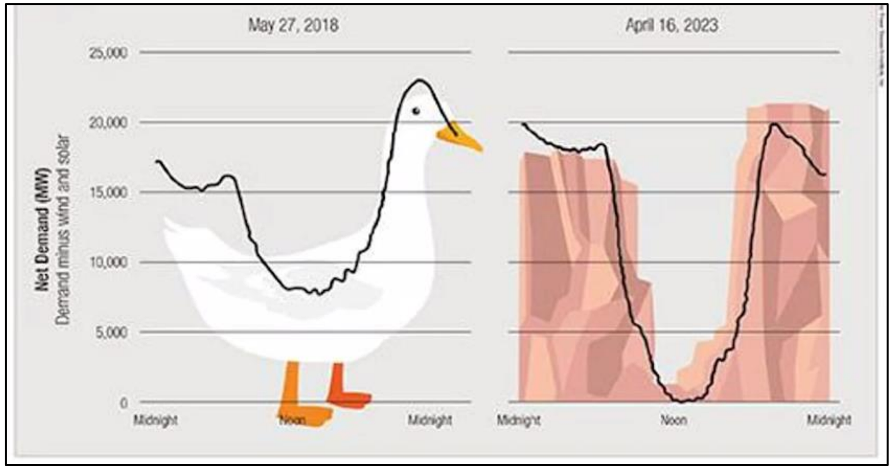
Alfie Shaw | July 30, 2024

California Hits 'Historical' Renewable Energy Milestone

Published Apr 15, 2024 at 11:50 AM EDT

The duck is turning into a canyon

- California net load



(EPRI, 2023)

- renewable overgeneration
- growing peak demand
- steep backup ramp

The duck is turning into a canyon

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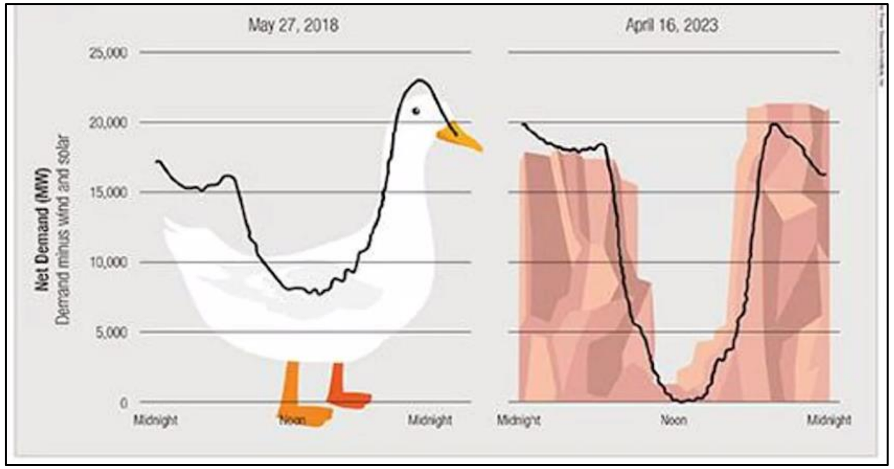
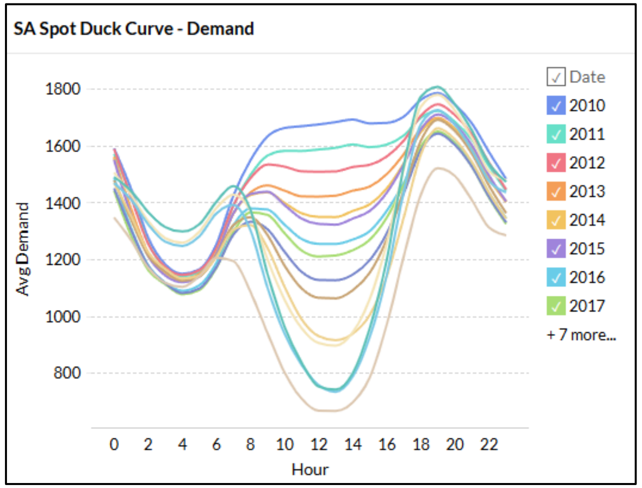


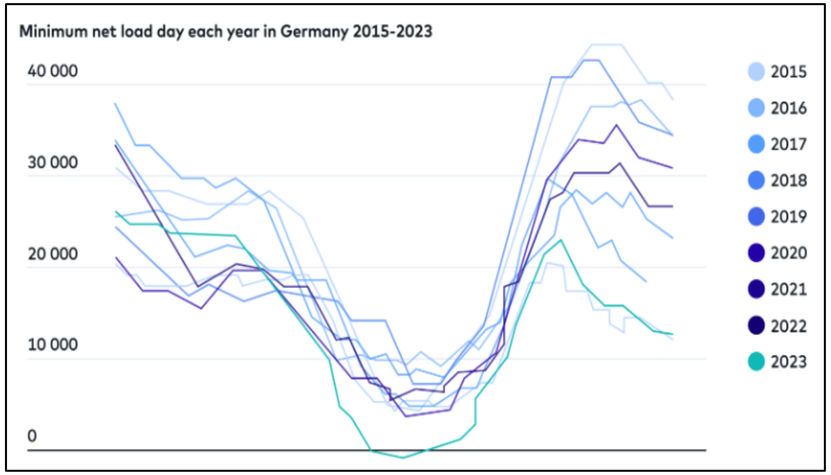
(EPRI, 2023)

- Australia net load



(Leading Edge Energy 2024)

- Germany net load



(Balasubramanian, 2023)

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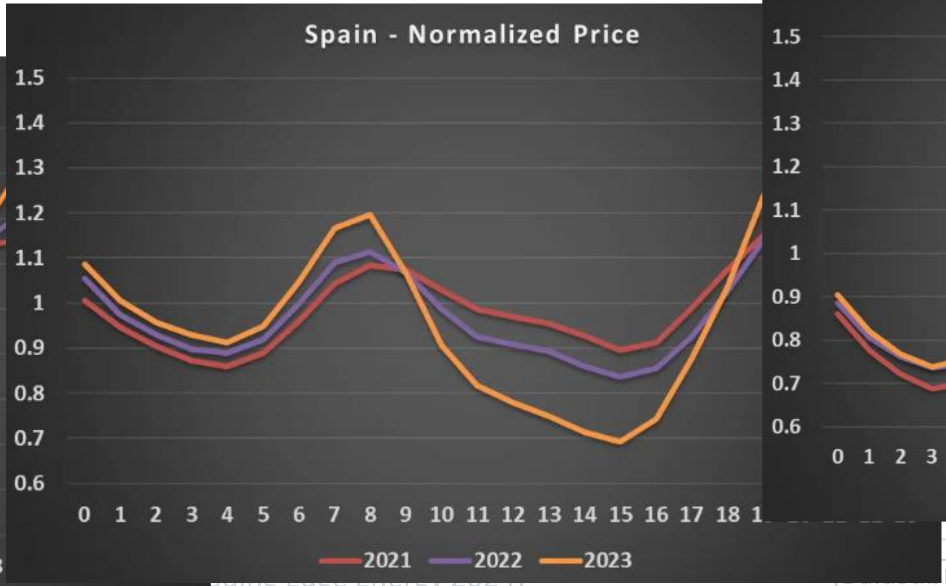

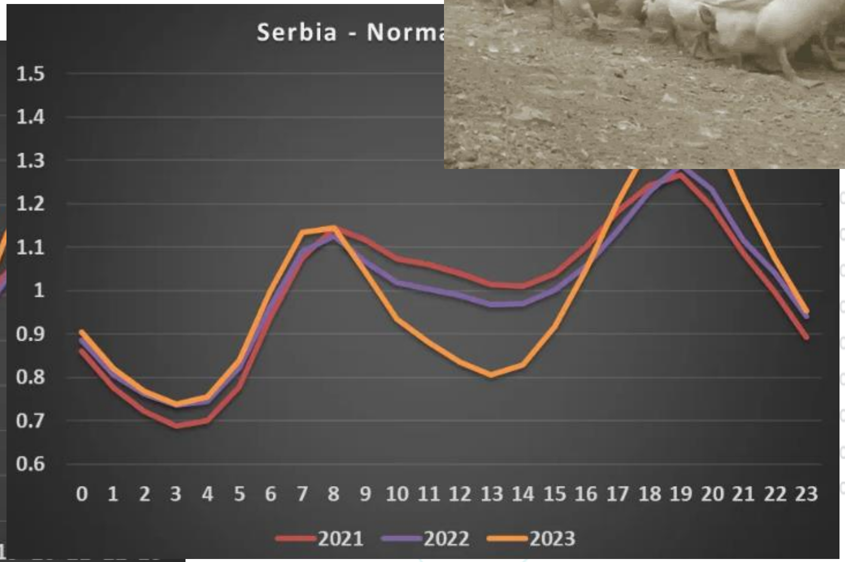

(Jomaux, 2024)

The duck is turning into a canyon

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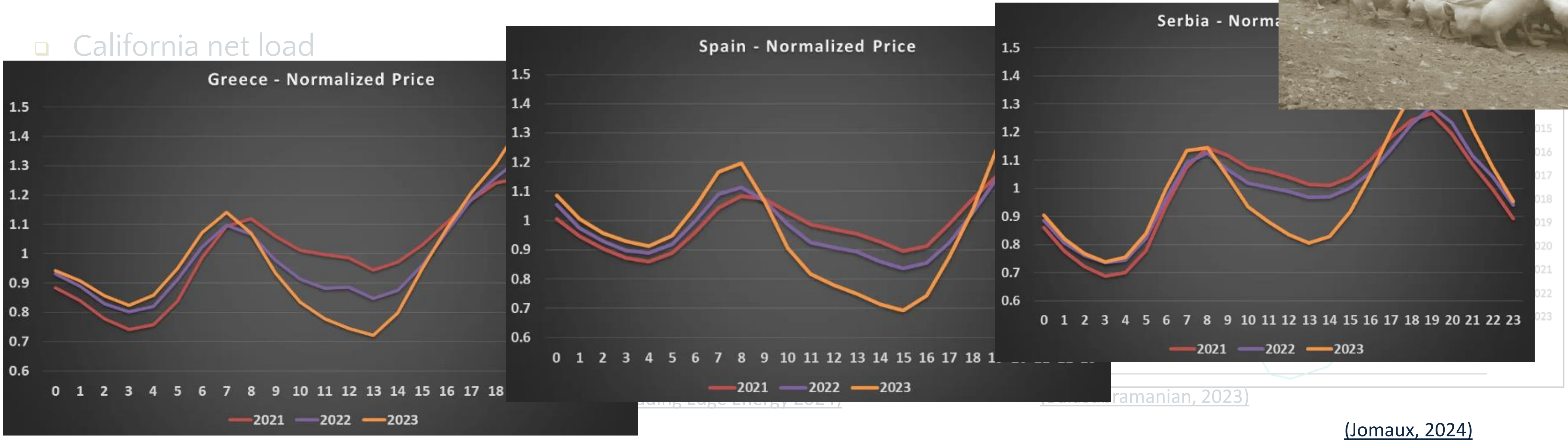
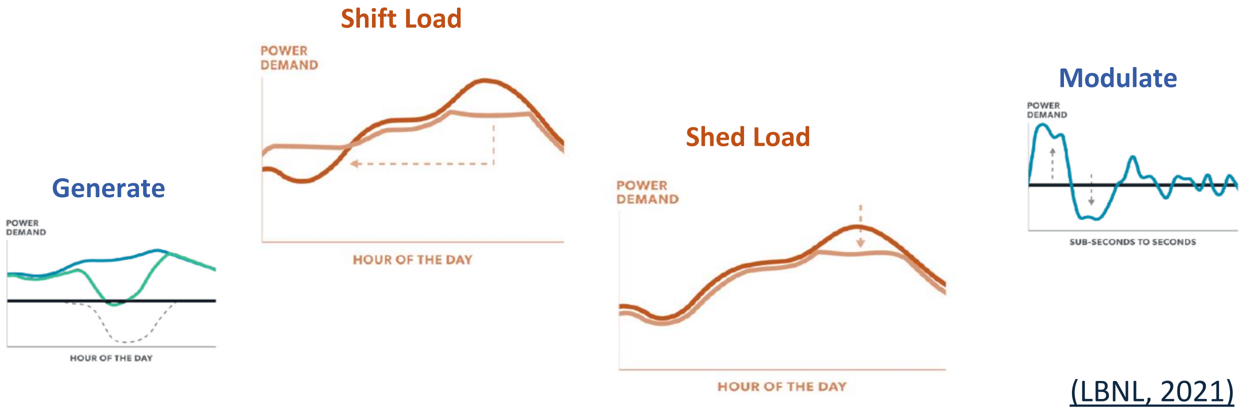


ramanian, 2023)

(Jomaux, 2024)

- **Demand flexibility** (DF) controls mitigate the mismatch between supply and demand



(LBNL, 2021)

Demand flexibility must increase 10 times

Clean energy flexibility takes centre stage in new EU electricity reforms

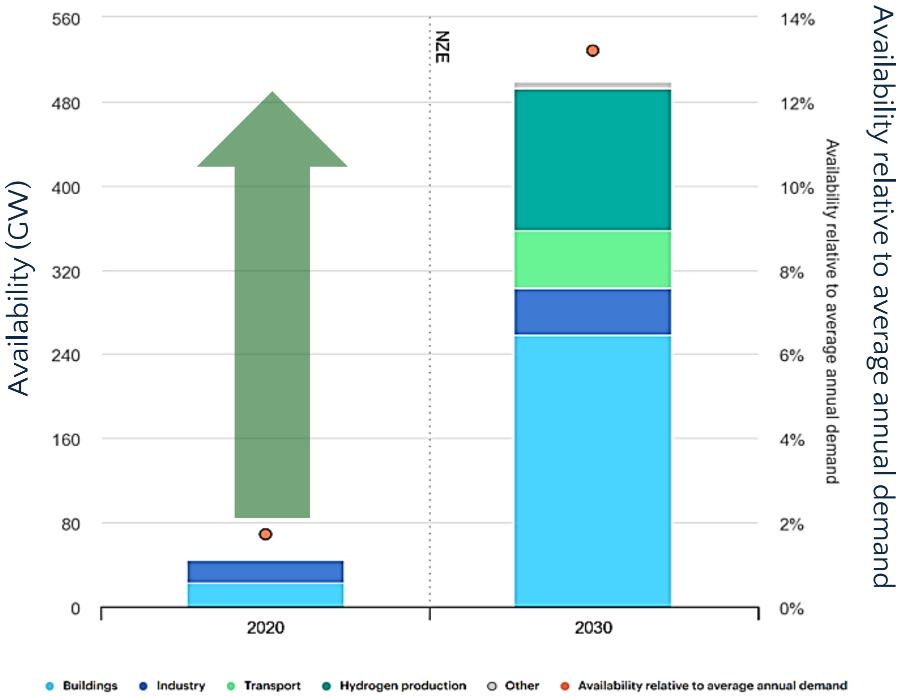
March 19, 2023

ACER
European Union Agency for the Cooperation of Energy Regulators

20.10.2023

Rapid growth in renewables calls for greater cooperation among Member States to double flexibility in the EU power system

- To achieve net zero energy **targets by 2030**, DF must increase **10 times** from 2020 levels
- The largest share (around 50%) is expected to come from **buildings**



Demand Flexibility Availability (IEA, 2022)

Demand flexibility must increase 10 times

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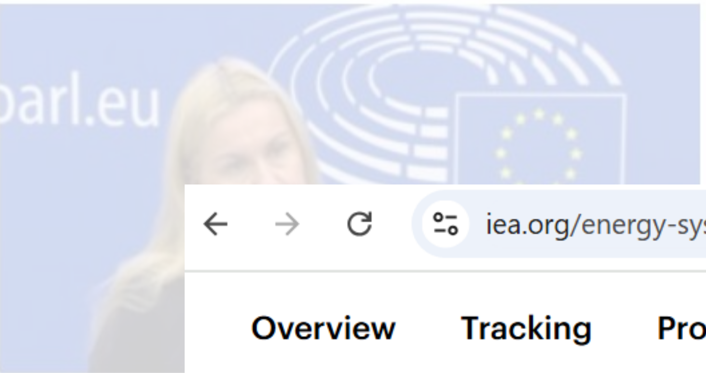

Clean ene
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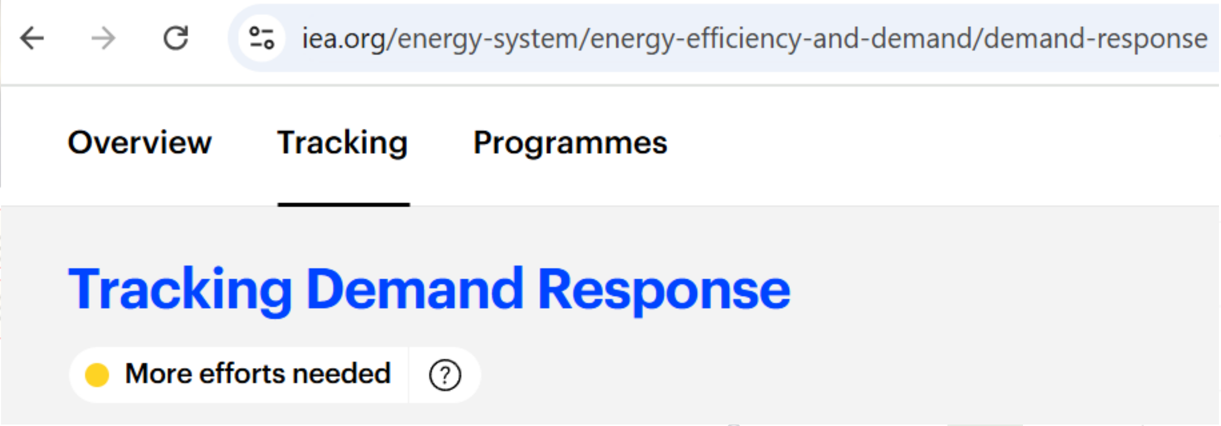
reforms
March 19, 2023



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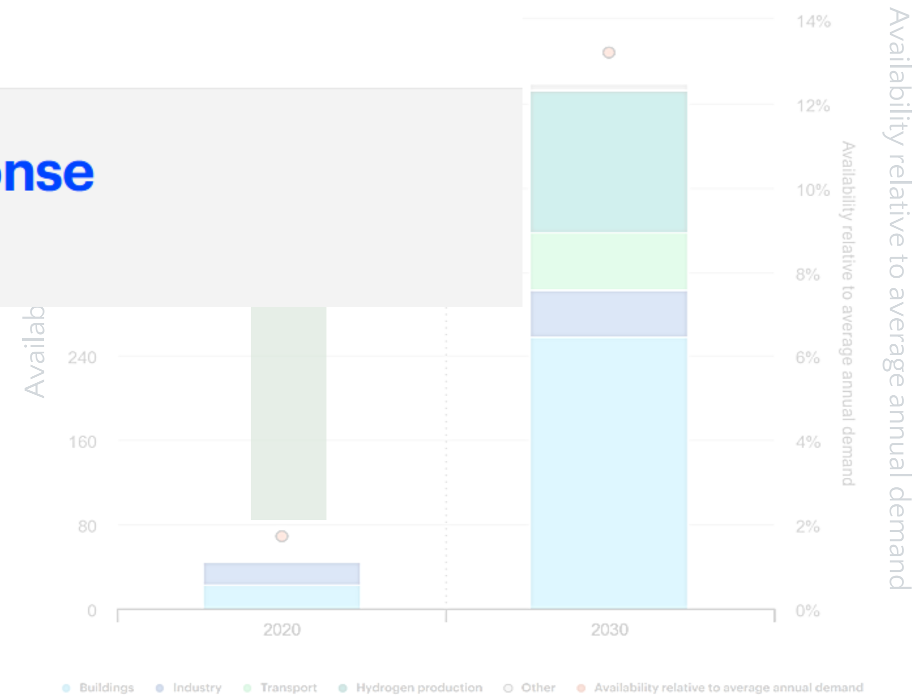
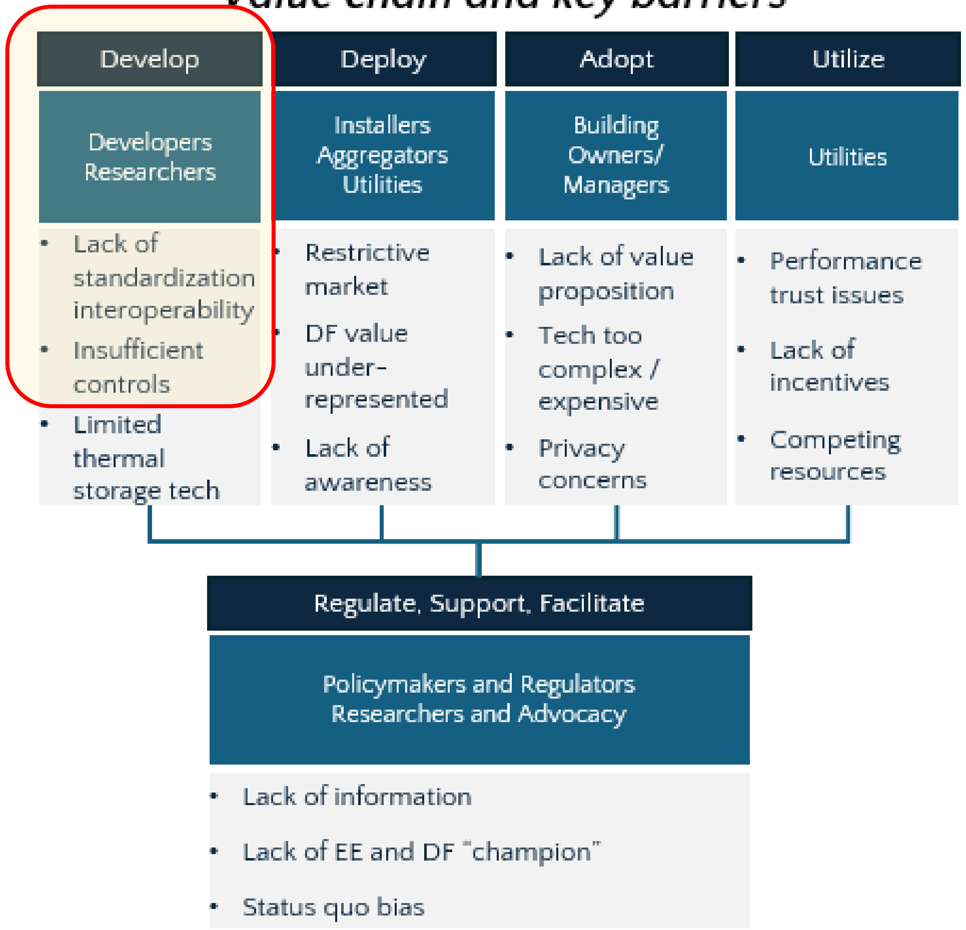


Demand Flexibility Availability (IEA, 2022)

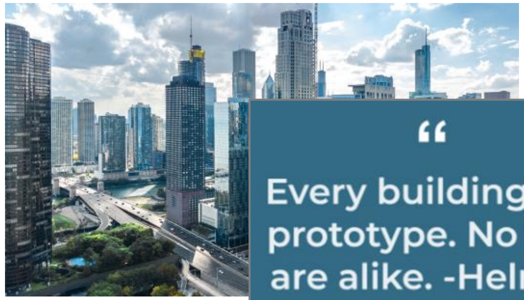
Why isn't demand flexibility widely adopted?

Value chain and key barriers



(LBNL, 2021)

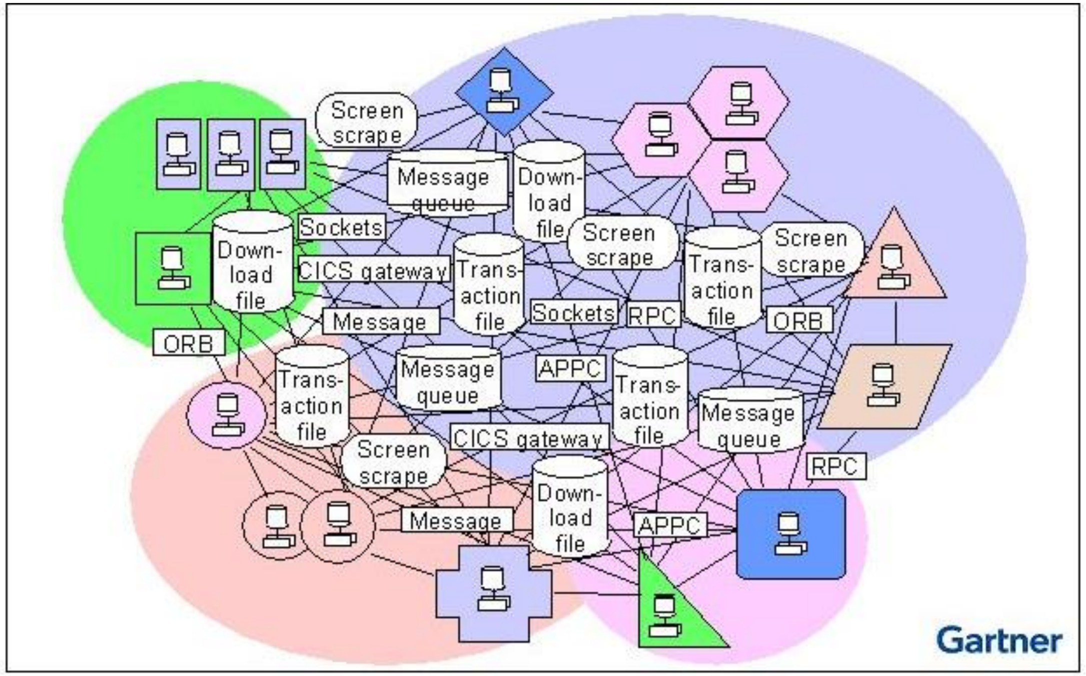
Why isn’t demand flexibility widely adopted?



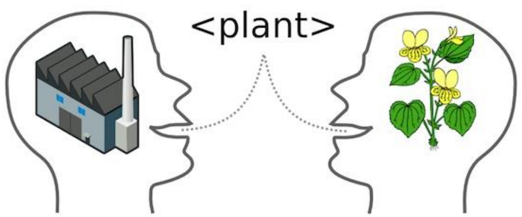
> “
> Every building is a prototype. No two are alike. -Helmut Jahn

- Lack of **interoperability** & **standardisation** led by buildings’ heterogeneity

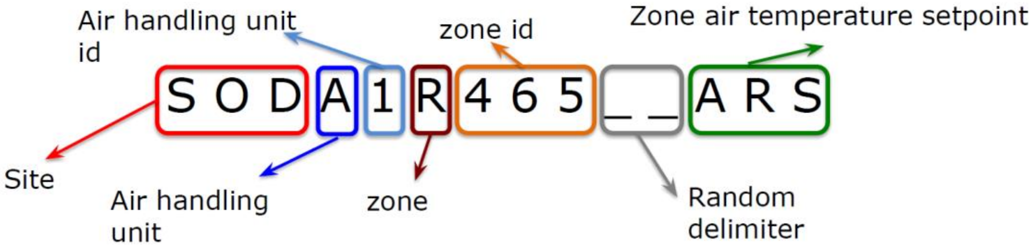
- Data silos & spaghetti arrangement



- Ambiguous & bespoke naming



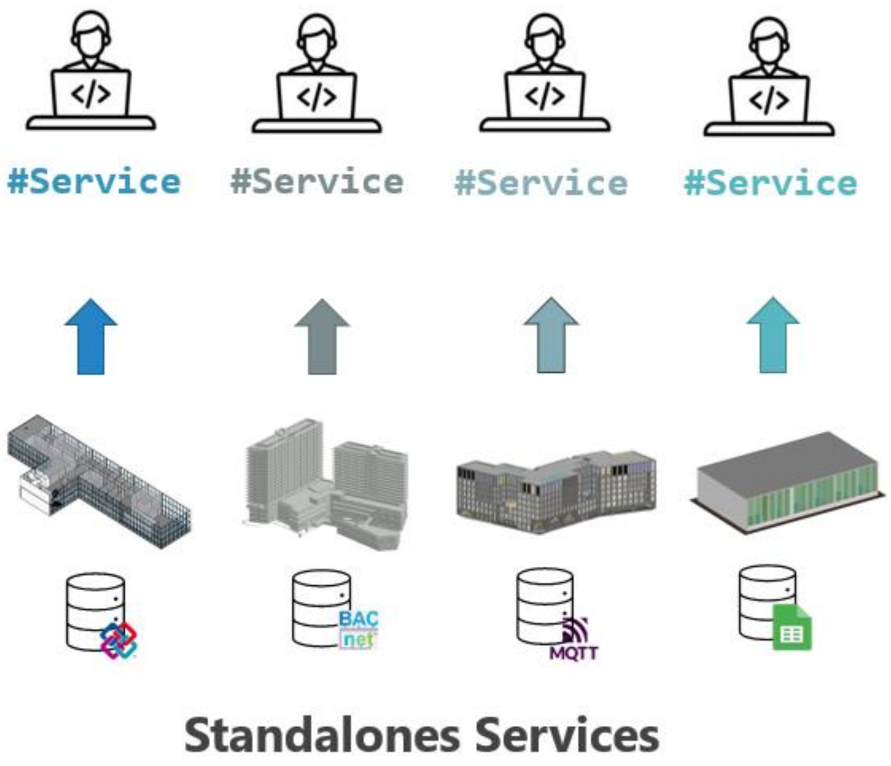
(Krantaz, 2010)



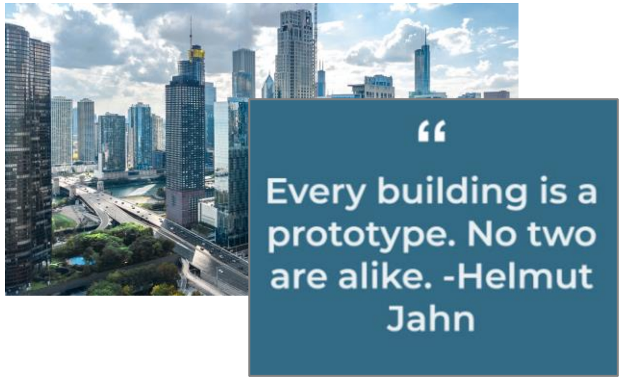
(Bhattacharya et al, 2015)

Why isn't demand flexibility widely adopted?

- Costly, manual configuration of applications & hardcoded **building-specific applications**



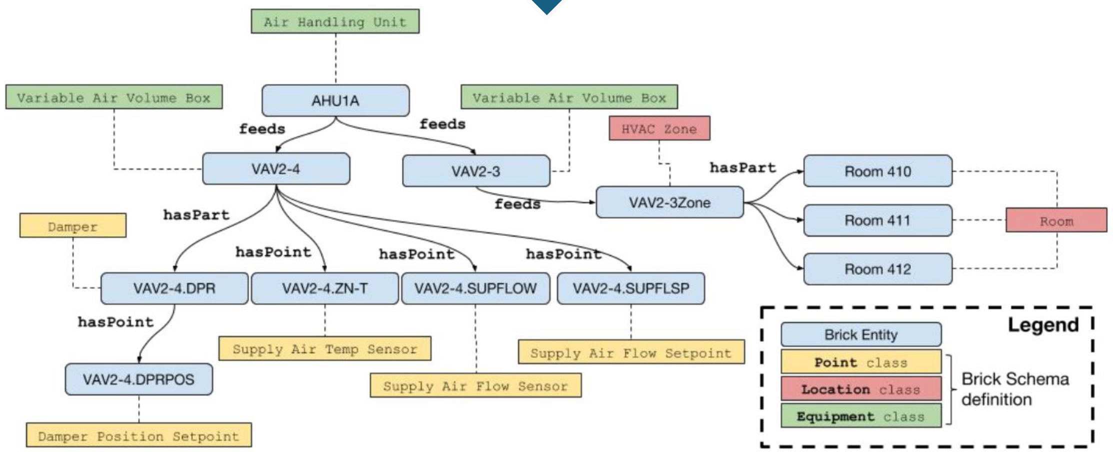
(Mavrokapnidis et al, 2023)



Ontologies as the necessary means for scalability

- Ontologies provide context and meaning of data
- Formally standardise knowledge domain

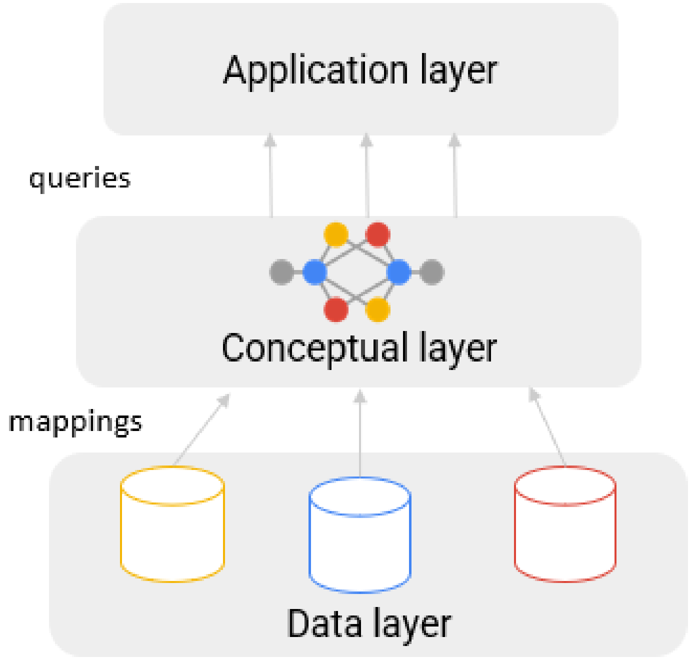
Building example



Building modelled with Brick

(Brick)

- When instantiated, as **semantic models**, they enable consistent and easily discoverable description of building data points

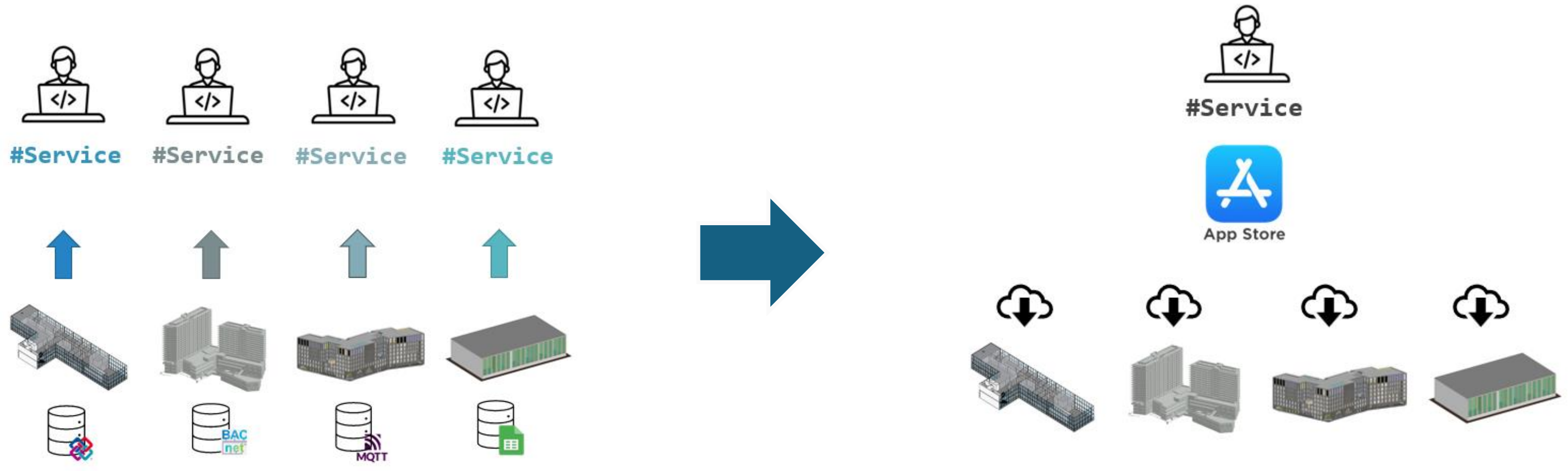


Ontology-based Data Access (OBDA)

(Calvanese et al, 2021)

Research gaps

- Use semantic models to automate the configuration of applications (plug-an-play behaviour)
  - Most focus on analytical apps (e.g., Mortar[1], Energon[2], SeeQ[3])



Standalones Services

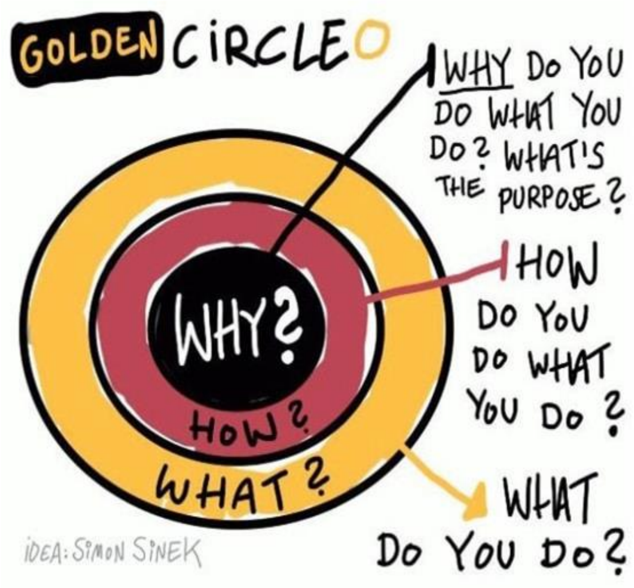
“Develop Once, Deploy Anywhere”

(Mavrokapnidis et al, 2023)

- Semantics-driven DF applications exist, but
  - custom-built ontologies (unmaintained, proprietary, lack alignment) [4,5,6,7]
  - control logic embedded in the ontology (store dynamic data) [8,9]

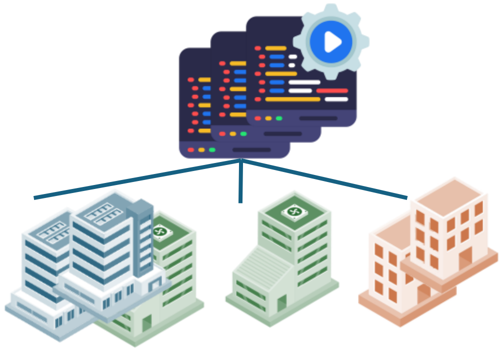
Key references: [1](Fierro et al, 2019), [2](He et al, 2021), [3](Mavrokapnidis et al, 2023), [4](Fernanndez-Izquierdo et al, 2020), [5](Santos et al, 2021), [6](Hviid et al, 2022), [7] (Li et al, 2022),, [8](Falcao et al, 2021), [9](Castro et al, 2023)

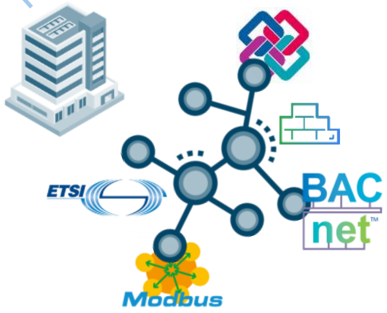
Research scope



Research scope

*Propose **semantics-driven frameworks** using semantic models built on well-established **ontologies** to assist the **portability**, **interoperability**, and **scalability** of DF control applications across heterogeneous buildings*





The initial framework

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Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Full length article

Enabling portable demand flexibility control applications in virtual and real buildings

Flavia de Andrade Pereira [a,b,c,*], Lazlo Paul [c], Marco Pritoni [c], Armando Casillas [c], Anand Prakash [c], Weiping Huang [c], Conor Shaw [a], Susana Martin-Toral [b], Donal Finn [a], James O' Donnell [a]

[a] School of Mechanical & Materials Engineering and UCD Energy Institute, University College Dublin, Dublin, Ireland
[b] CARTIF Technology Centre, Energy Division, Valladolid, Spain
[c] Lawrence Berkeley National Laboratory, Berkeley, United States of America

ARTICLE INFO

Dataset link: https://github.com/LBNL-ETA/DFLEXLIBS

Keywords:
Demand flexibility
Generalizable control
Semantic model
Portability
Simulation and field testing

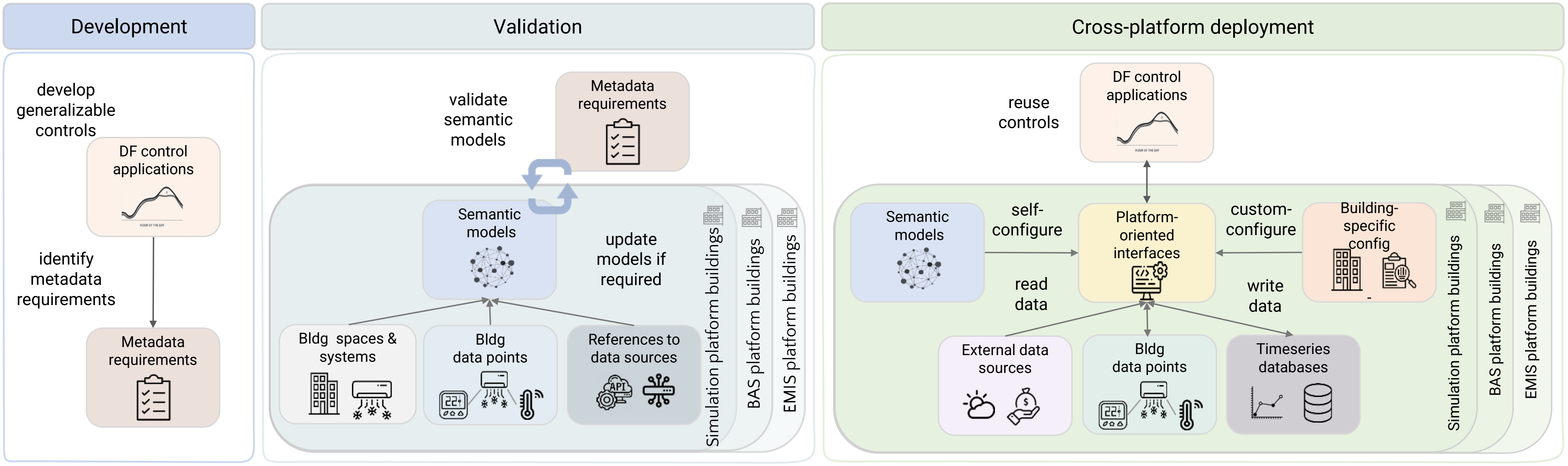
ABSTRACT

Control applications that facilitate Demand Flexibility (DF) are difficult to deploy at scale in existing buildings. The heterogeneity of systems and non-standard naming conventions for metadata describing data points in building automation systems often lead to ad-hoc and building-specific applications. In recent years, several researchers investigated semantic models to describe the meaning of building data. They suggest that these models can enhance the deployment of building applications, enabling data exchanges among heterogeneous sources and their portability across different buildings. However, the studies in question fail to explore these capabilities in the context of controls. This paper proposes a novel semantics-driven framework for developing and deploying portable DF control applications. The design of the framework leverages an iterative design science research methodology, evolving from evidence gathered through simulation and field demonstrations. The framework aims to decouple control applications from specific buildings and control platforms, enabling these control applications to be configured semi-automatically. This allows application developers and researchers to streamline the onboarding of new applications that could otherwise be time-consuming and resource-intensive. The framework has been validated for its capability to facilitate the deployment of control applications sharing the same codebase across diverse virtual and real buildings. The demonstration successfully tested two controls for load shifting and shedding in four virtual buildings using the Building Optimization Testing Framework (BOPTEST) and in one real building using the control platform VOLTTRON. Insights into the current limitations, benefits, and challenges of generalizable controls and semantic models are derived from the deployment efforts and outcomes to guide future research in this field.

https://doi.org/10.1016/j.jobe.2024.108645

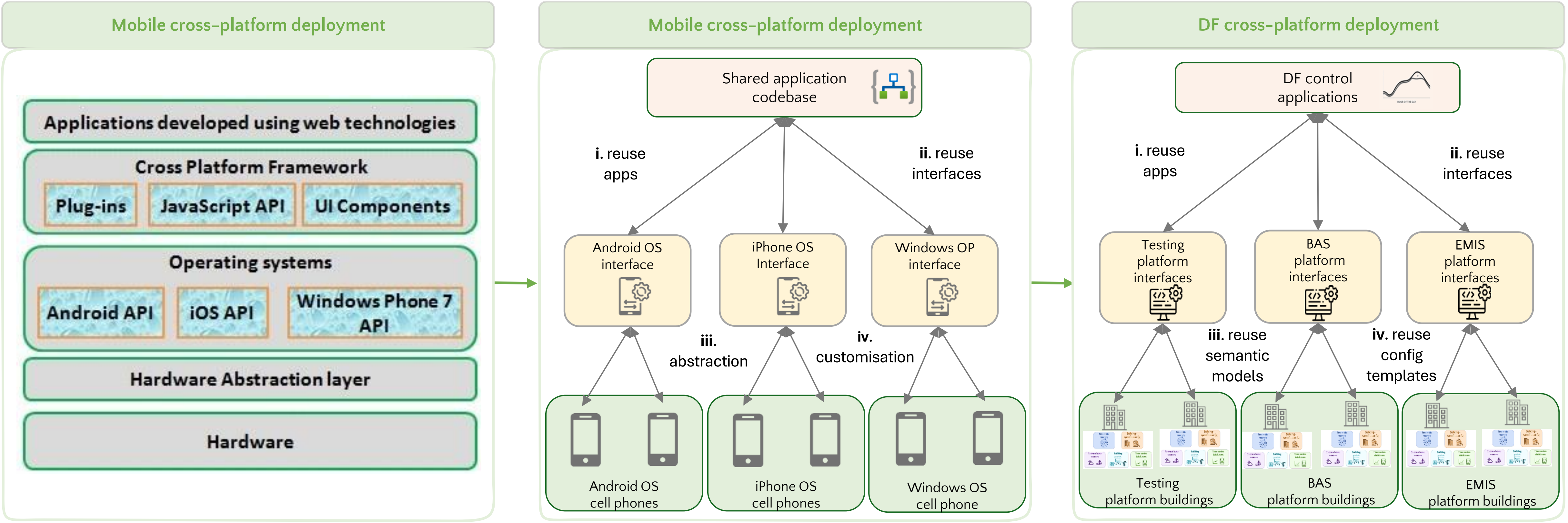
Semantics-driven framework for portable apps

- Framework based on **three main phases**: development, validation and deployment
- Propose **generalisable** applications' requirements
- Validate **Brick**-based semantic models
- **Self- and custom-configure** controls to deploy across different buildings

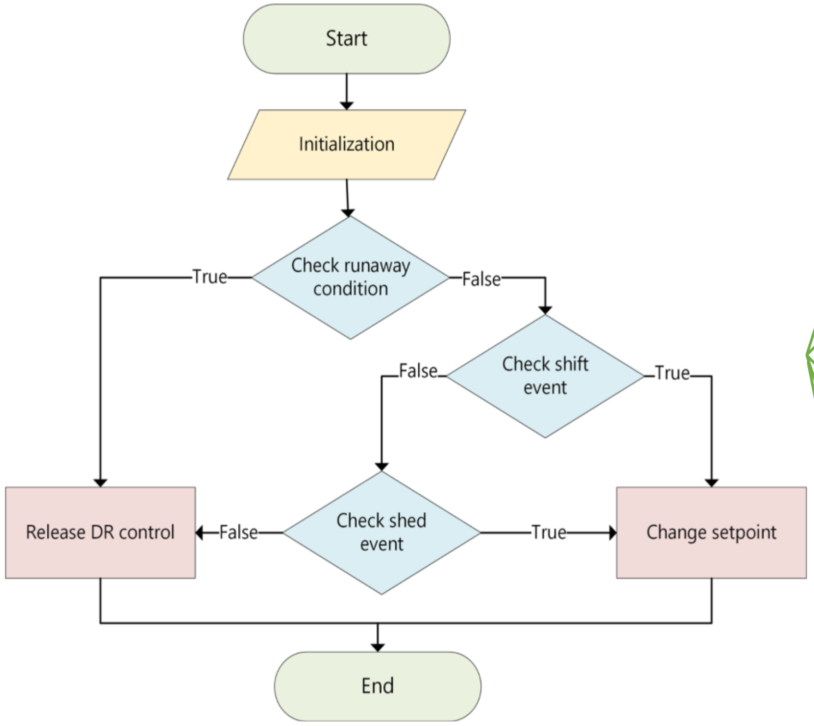


Cross-platform deployment

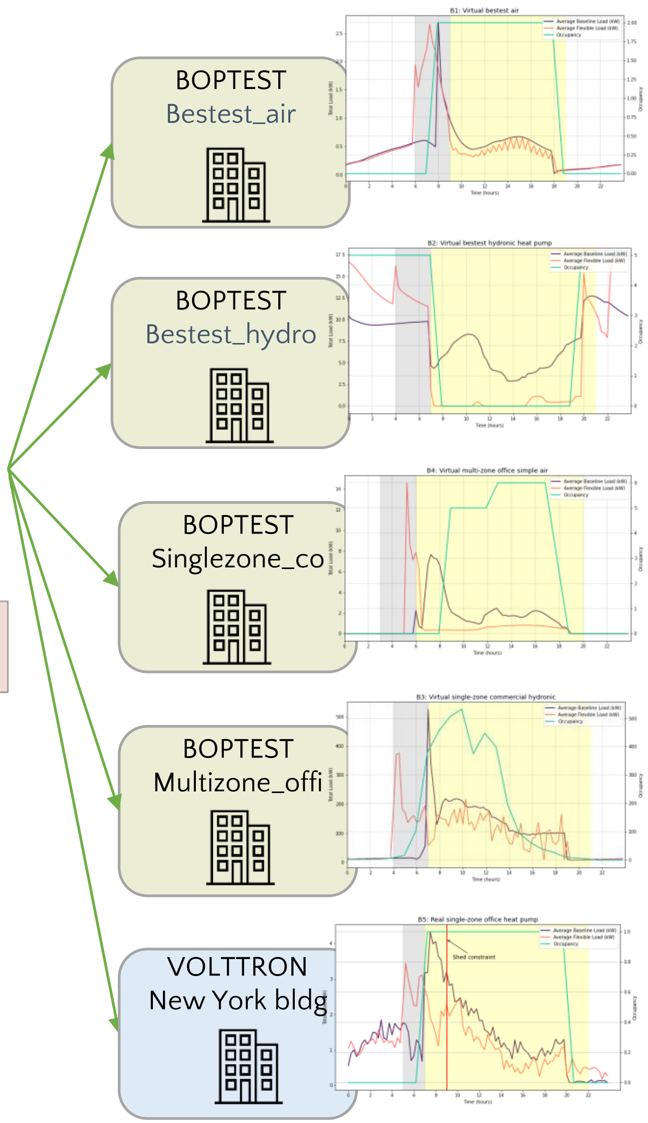
Mobile x Building Industry (plug-and-play paradigm)



Demonstration of DF portability



Rule-based DF control

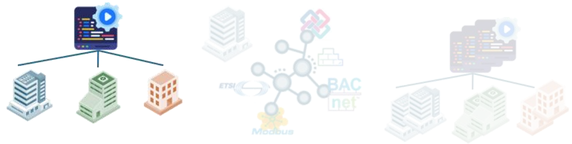


Simulation buildings

Real building

- **Streamlined** configuration process that **reduces labour efforts**
  - Among **BOPTEST** buildings (only a few lines of code)
  - **VOLTTRON** required a different interface

Key takeaways for DF portability



- Portability of controls relies on platform-specific dependencies, site-specific constraints
- Semantic models do not fully solve the data mapping challenge
- Generalisability of controls relies on lower-level logic and existing systems

❑ **Interfaces** that account for customisation beyond semantic models while decoupling apps

Addressed in this initial framework

❑ **Automated**, consistent semantic **model generation** based on well-established ontologies

Addressed in the extended framework

❑ **Comprehensive testing** across different scenarios

Addressed in the library

The extended framework

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ELSEVIER

Full length article

A semantics-driven framework to enable demand flexibility control applications in real buildings

Flavia de Andrade Pereira [a,b,c,*], Kyriakos Katsigarakis [b], Dimitrios Rovas [b], Marco Pritoni [c], Conor Shaw [a], Lazlo Paul [c], Anand Prakash [c], Susana Martin-Toral [d], Donal Finn [a], James O'Donnell [a]

[a] School of Mechanical & Materials Engineering and UCD Energy Institute, University College Dublin, Dublin, Ireland
[b] University College London, London, United Kingdom
[c] Lawrence Berkeley National Laboratory, Berkeley, United States of America
[d] CARTIF Technology Centre, Energy Division, Valladolid, Spain

ARTICLE INFO

Dataset link: https://github.com/ucl-sbde/semantics-driven_controls.git

Keywords:
Demand flexibility controls
Semantic models
Interoperability
Modularity
Brick
SAREF

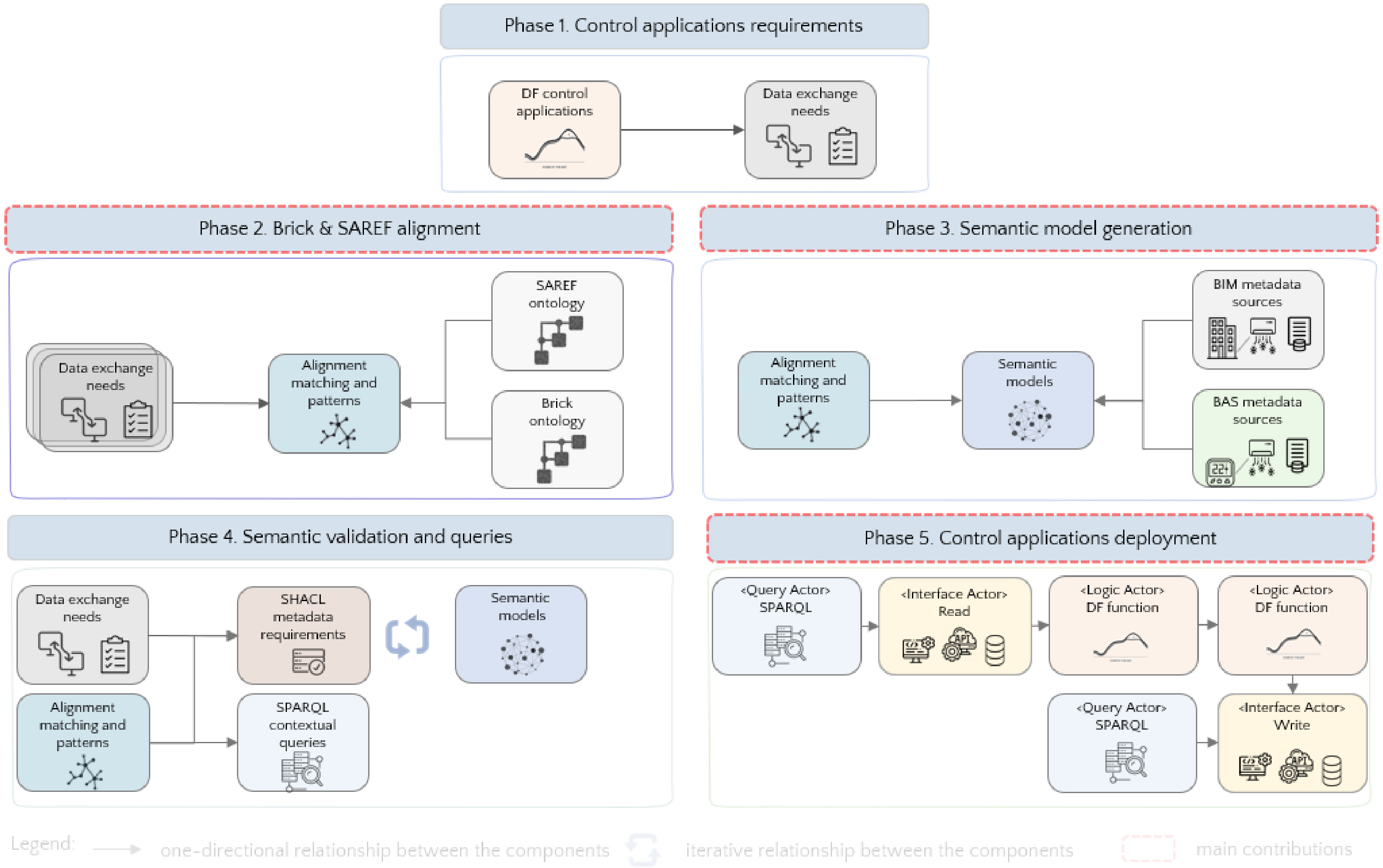
ABSTRACT

Decarbonising and digitalising the energy sector requires scalable and interoperable Demand Flexibility (DF) applications. Semantic models are promising technologies for achieving these goals, but existing studies focused on DF applications exhibit limitations. These include dependence on bespoke ontologies, lack of computational methods to generate semantic models, ineffective temporal data management and absence of platforms that use these models to easily develop, configure and deploy controls in real buildings. This paper introduces a semantics-driven framework to enable DF control applications in real buildings. The framework supports the generation of semantic models that adhere to Brick and SAREF while using metadata from Building Information Models (BIM) and Building Automation Systems (BAS). The work also introduces a web platform that leverages these models and an actor and microservices architecture to streamline the development, configuration and deployment of DF controls. The paper demonstrates the framework through a case study, illustrating its ability to integrate diverse data sources, execute DF actuation in a real building, and promote modularity for easy reuse, extension, and customisation of applications. The paper also discusses the alignment between Brick and SAREF, the value of leveraging BIM data sources, and the framework's benefits over existing approaches, demonstrating a 75% reduction in effort for developing, configuring, and deploying building controls.

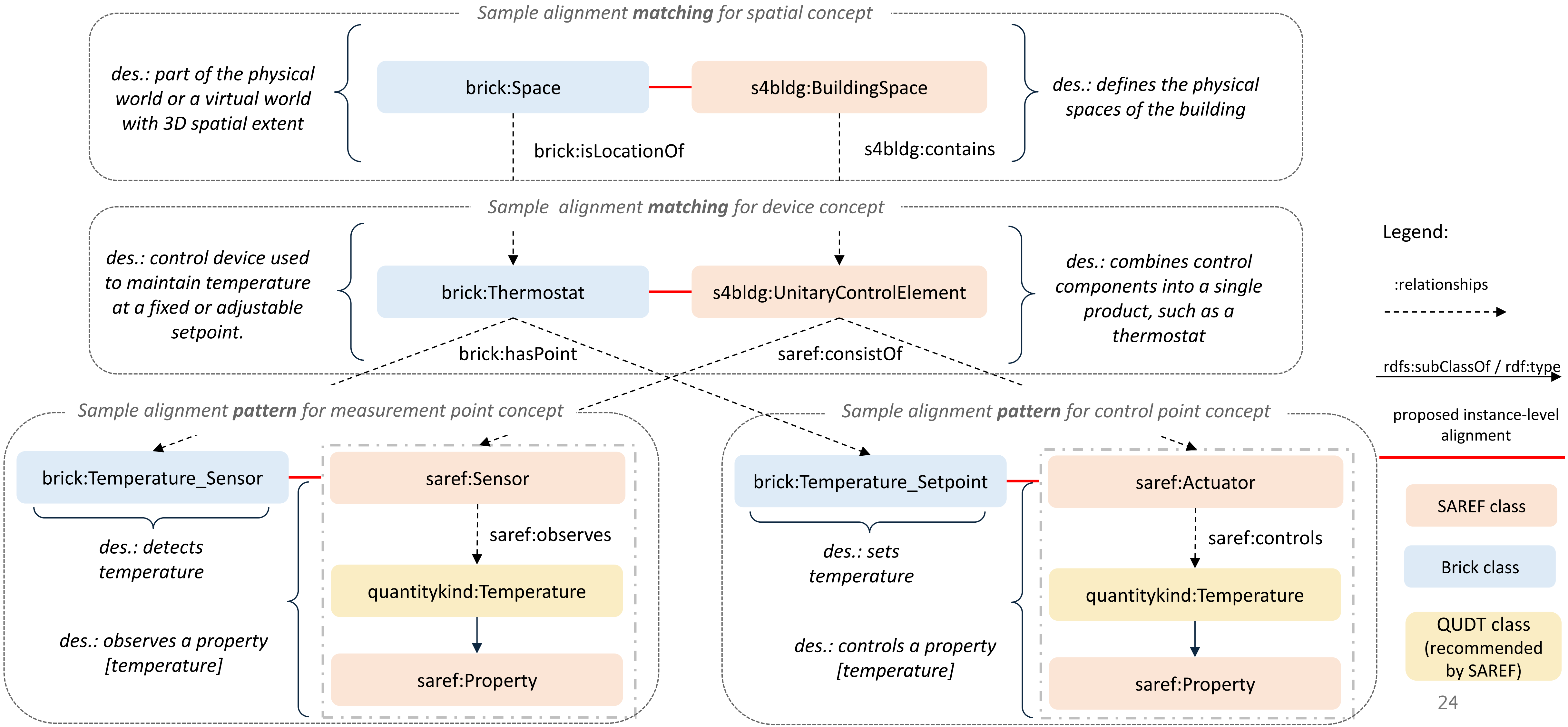
https://doi.org/10.1016/j.aei.2024.103049

Extended framework for interoperable apps

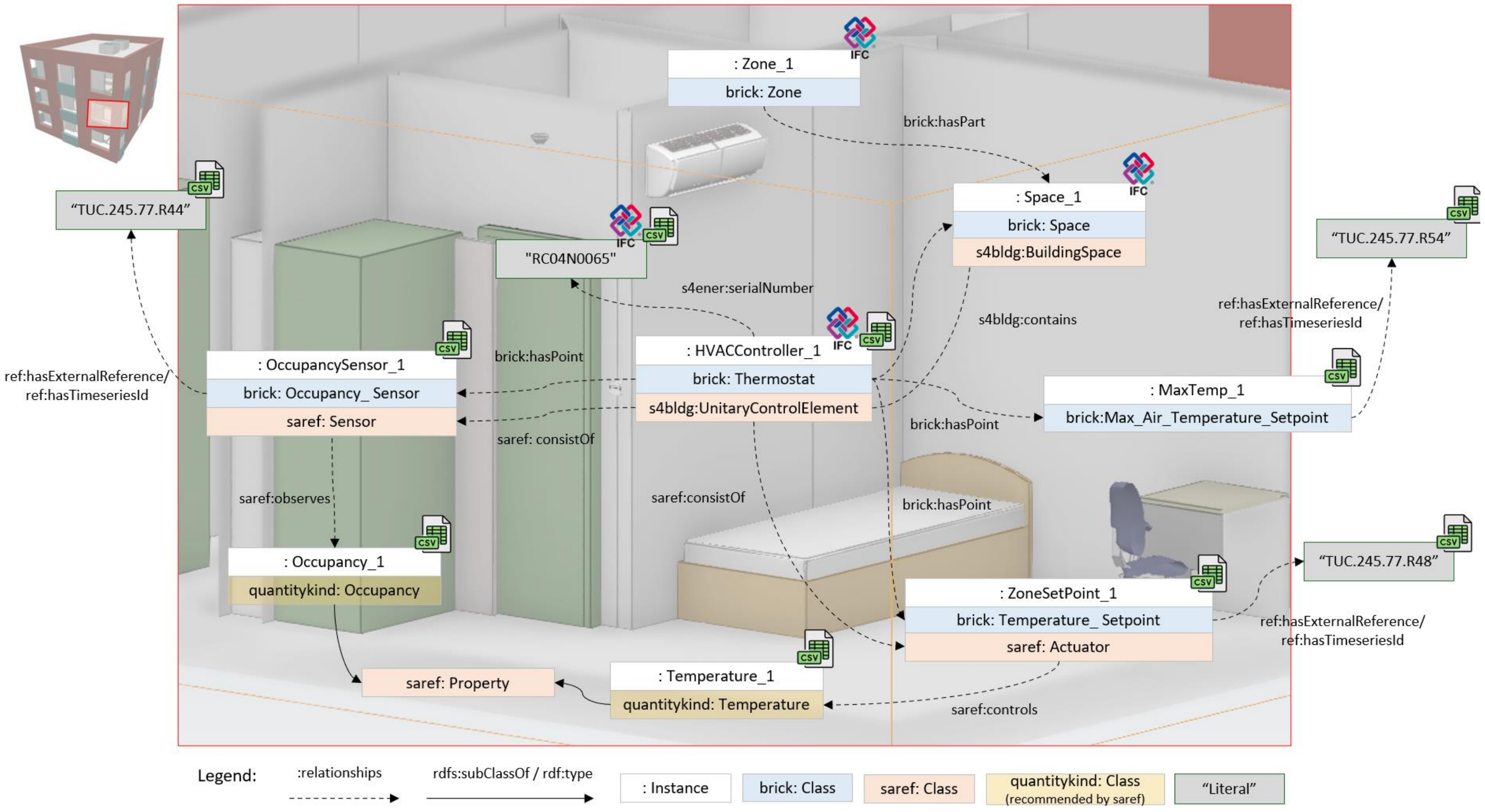
- Extended framework based on **five main phases** (three new)
- Proposes a **novel alignment** between the **Brick (US)** and **SAREF (Europe)**
- Introduces metadata **mapping methods** for **BIM and BAS**
- **Actor and microservices** middleware platform



Brick and SAREF proposed alignment



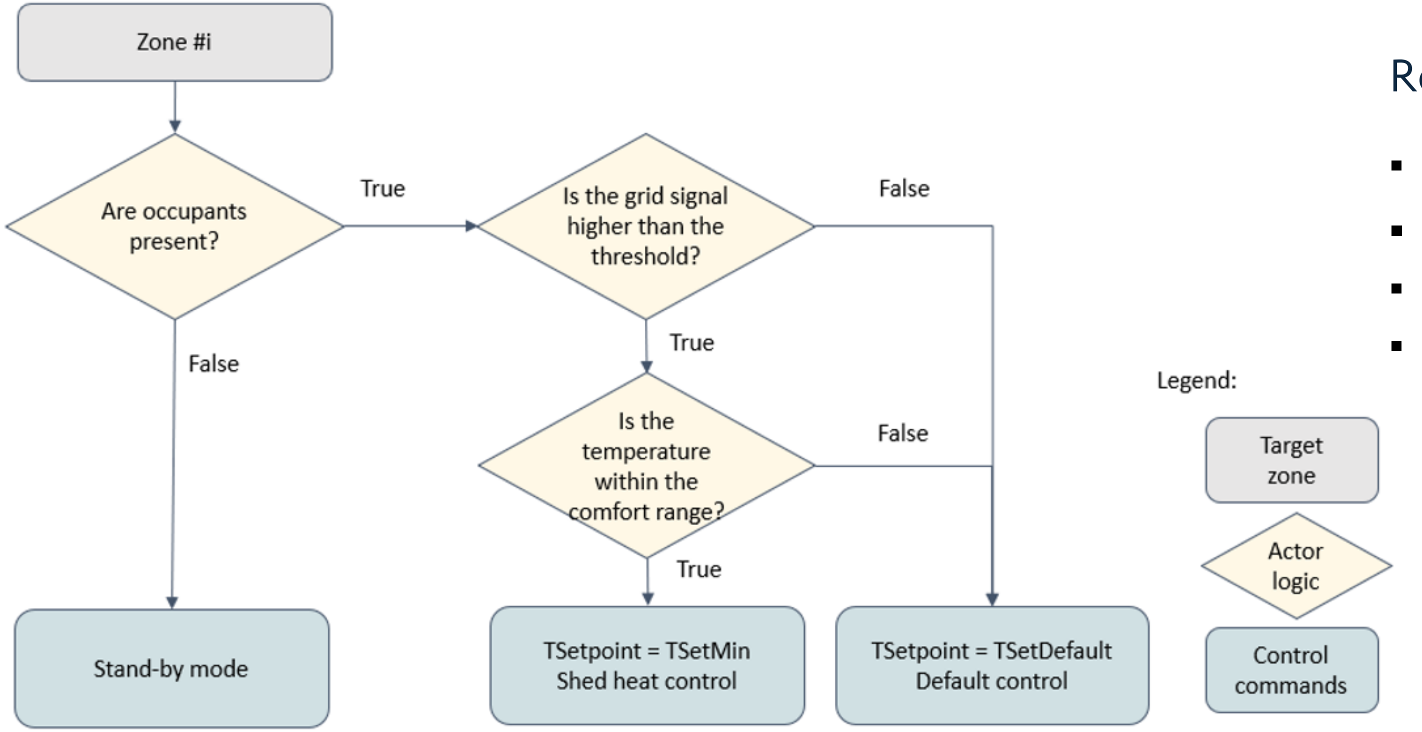
Demonstration of DF interoperability



Real building

- Greece
- 20 zones
- Independent AC units
- Potential: 15 similar buildings (> 6K points)

Demonstration of DF interoperability



Rule-based DF control

Real building

- Greece
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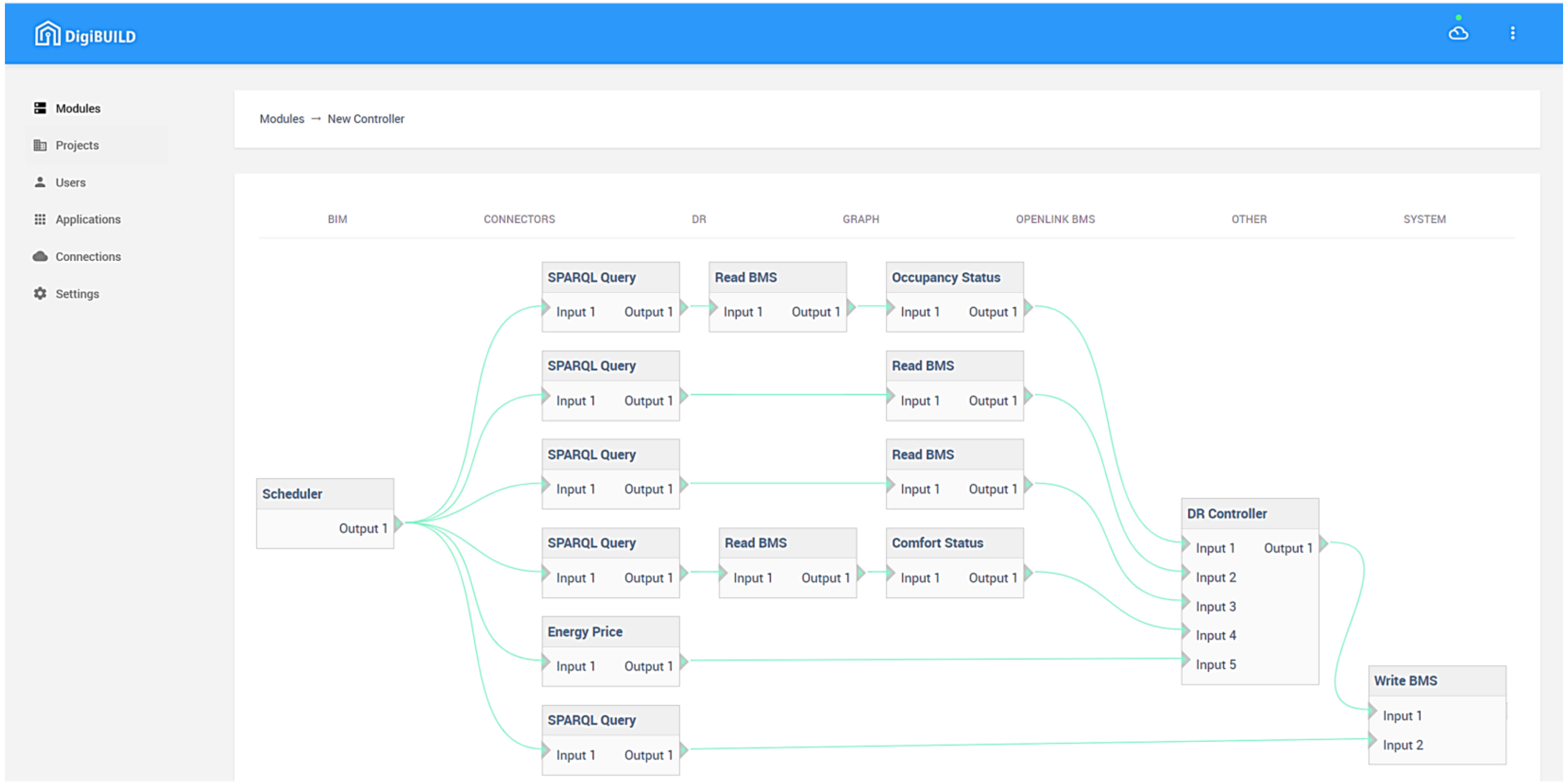
- Potential: 15 similar buildings (> 6K points)

Demonstration of DF interoperability

Actor and microservices-based platform decoupling data integration/access & application logic



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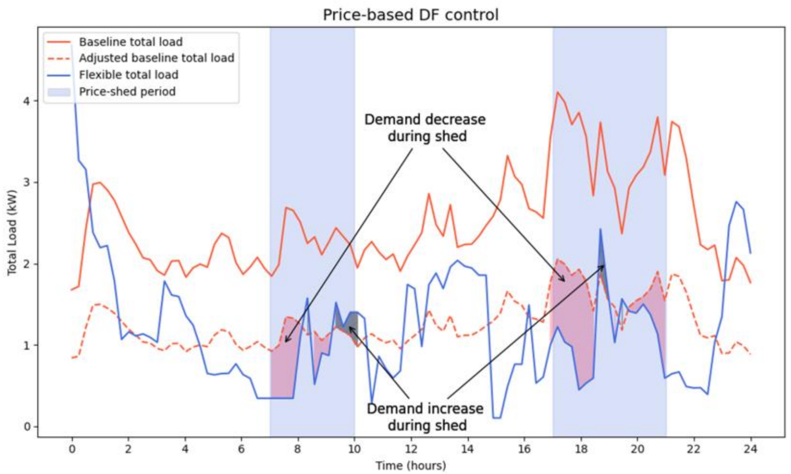
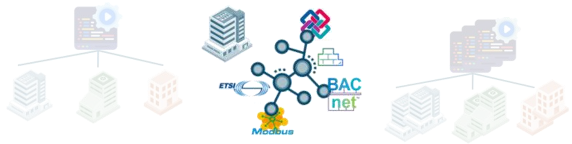


> 30 % of demand decrease

Key takeaways for DF interoperability



BIM & BAS

- BIM helps to add contextual information to BAS equipment and their data points
- Mapping relies on having a common instance presented in both
- Reliance on IFC proper modelling and completeness of CSV template

- No single data source needs capture everything; modularity is key

SAREF and Brick

- Both lack proper concepts for DF (e.g., grid signals, DF settings)
- SAREF provides abstraction but lacks expressiveness (e.g., zones, HVAC concepts)
- Brick can support simpler DF apps alone but lacks complex HVAC topology

- Existing ontologies need extension; or dedicated ontologies need ongoing support

The library

DFLEXLIBS: a Python-based Demand Flexibility Controls Library using Semantics

Flavia de Andrade Pereira[a,b,c,*], Marco Pritoni[c,*], Armando Casillas[c], Jessica Granderson[c], Lazlo Paul[c], Anand Prakash[c], Conor Shaw[a], Dimitrios Rovas[b], Susana Martin-Toral[d], Donal Finn[a] and James O'Donnell[a]

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[d] CARTIF Technology Centre, Energy Division, Valladolid, Spain

ARTICLE INFO

Keywords:
Demand flexibility
Controls Library
Portability
Semantic model
Scalability
Performance assessment

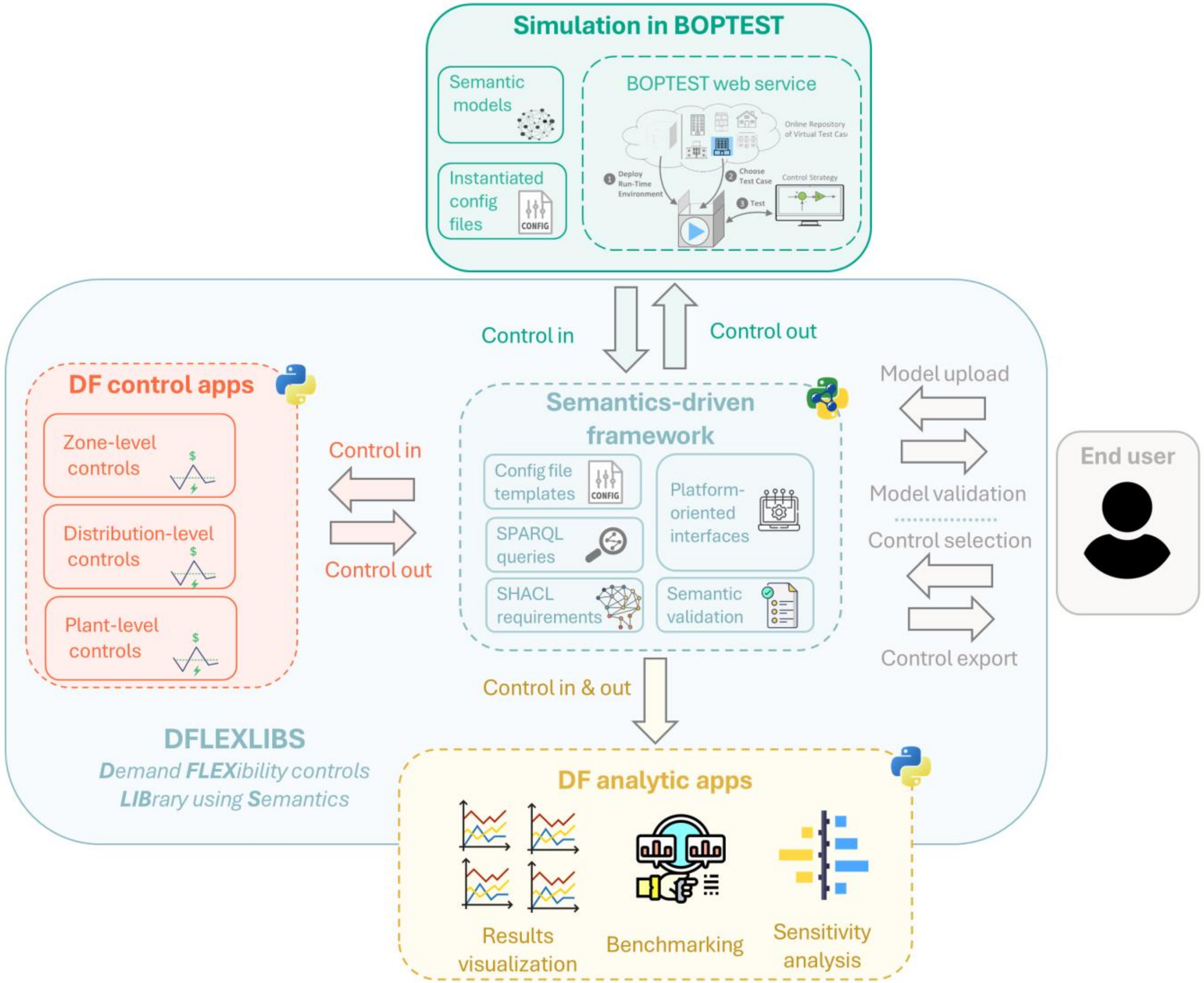
ABSTRACT

There is an increasing recognition that Demand Flexibility (DF) holds significant potential in decarbonizing the built environment. However, the traditional process of onboarding new control applications in buildings, including those for DF, remains largely manual, error-prone, and building-specific. Despite ongoing research aimed at streamlining DF control deployment, there is a lack of studies that integrate comprehensive specifications of DF controls, their open-source code implementations, and performance evaluations across diverse scenarios. This paper proposes a novel methodology to guide the design, implementation and evaluation of a library of reference and portable DF control applications. The work outlines the principles and requirements for creating such a library and introduces the Demand FLEXibility controls LIBrary using Semantics (DFLEXLIBS) as a prototype. DFLEXLIBS is a Python-based open-source library populated with recent DF control specifications. It has been implemented by leveraging our previously established semantics-driven framework to abstract building-specific data points, allowing a single code base to be reused across many buildings. The library has been successfully demonstrated through coding, testing, and evaluating several control applications across four virtual buildings with minimal effort required. The benchmarking of these controls focused on metrics such as demand, cost, and comfort, providing insights into their performance variability in different contexts and user-defined parameters. The results reveal that the same control can achieve a demand decrease intensity ranging from 2.6 to 8.8 W/m^2 across different buildings and from 1.6 to 2.9 W/m^2 within the same building by solely adjusting its user-defined parameters.

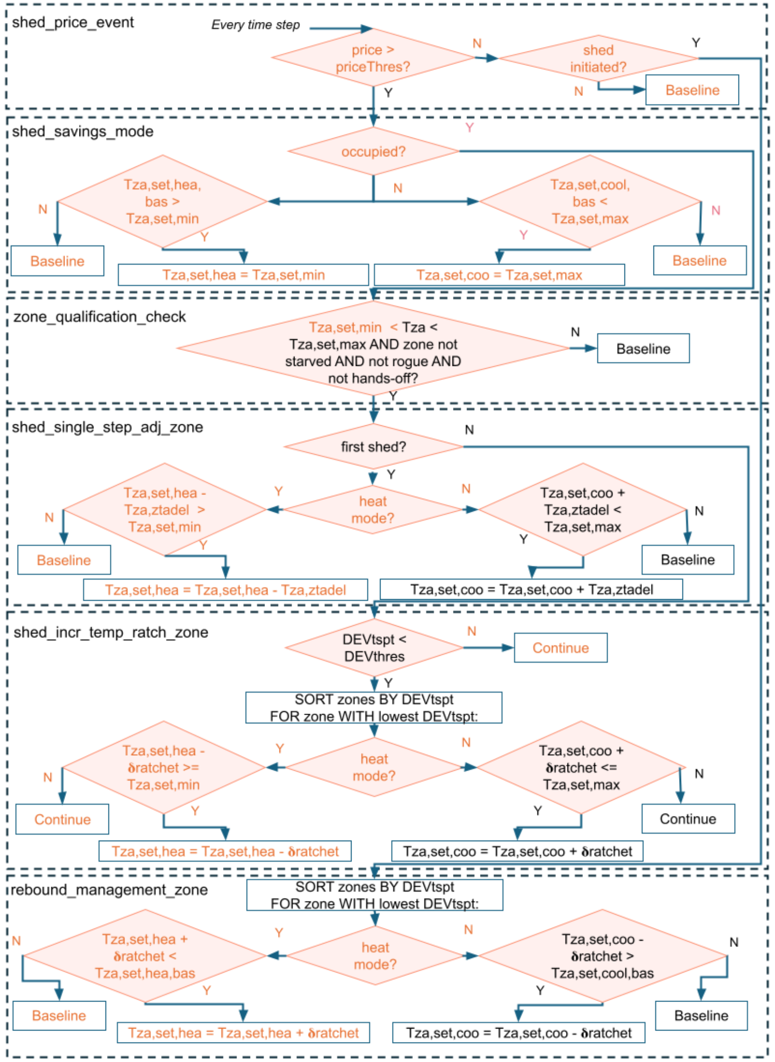
DFLEXLIBS: DF controls Library using Semantics

Portable DF **controls** and **analytic** apps:

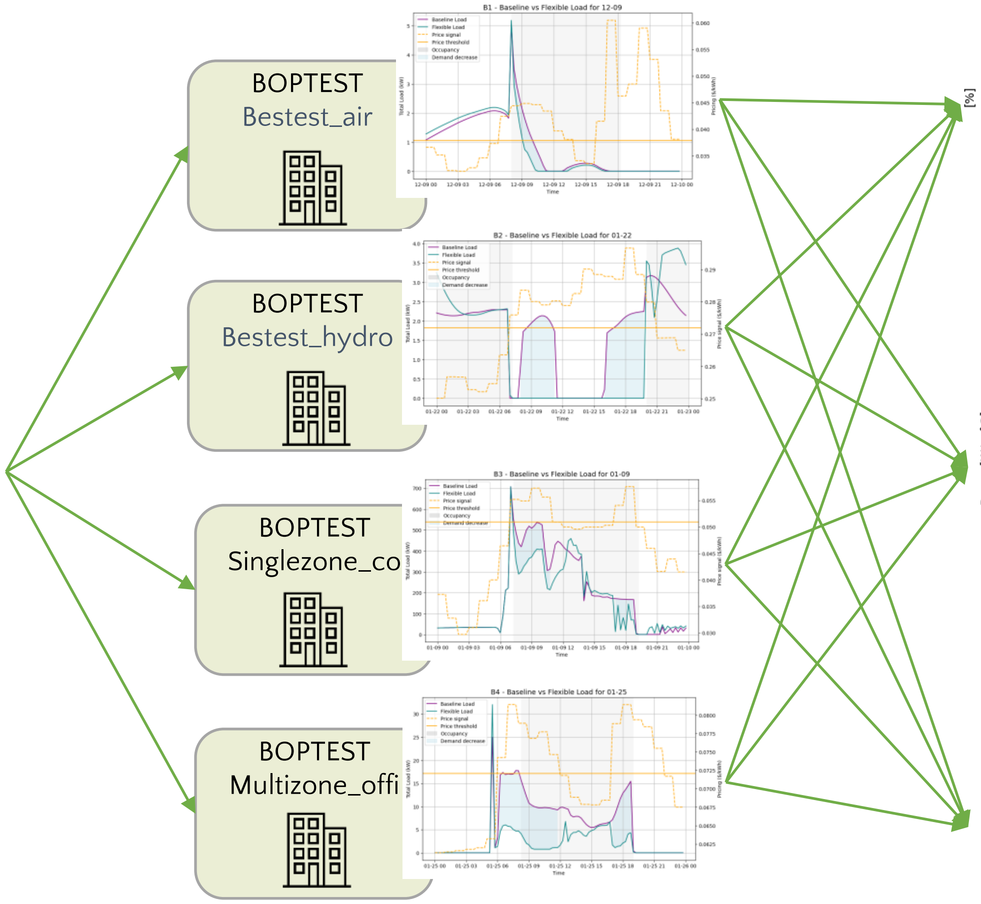
- DF controls based on LBNL Open Specification for best-practices
- DF analytics based on Annex 81 KPIs Python package
- Testing on BOPTEST virtual buildings



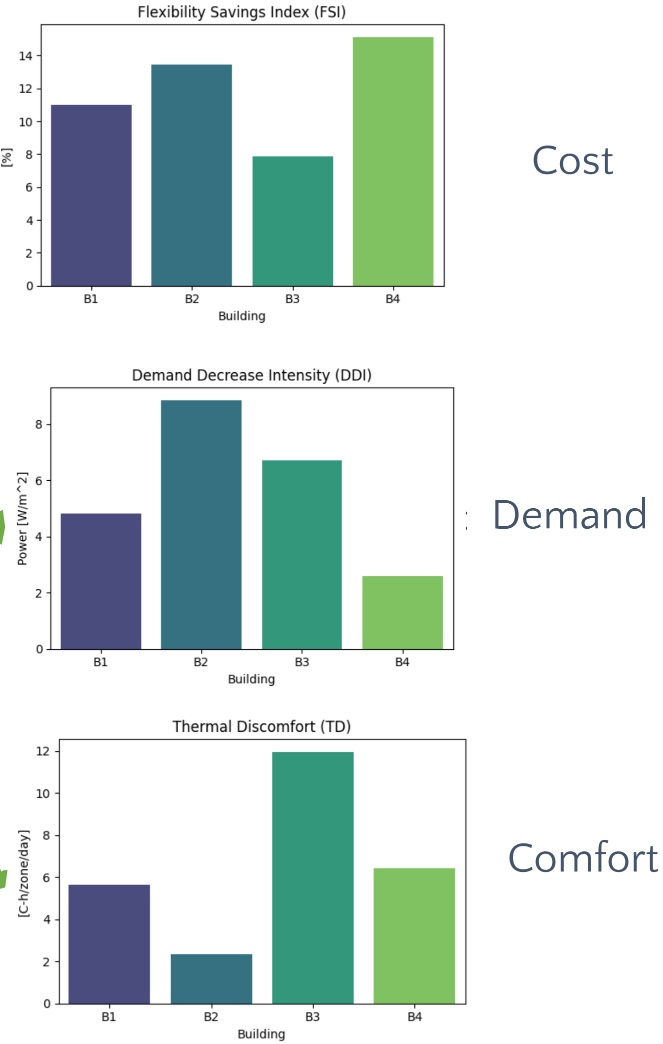
Demonstration of DF scalability



Advanced rule-based DF control



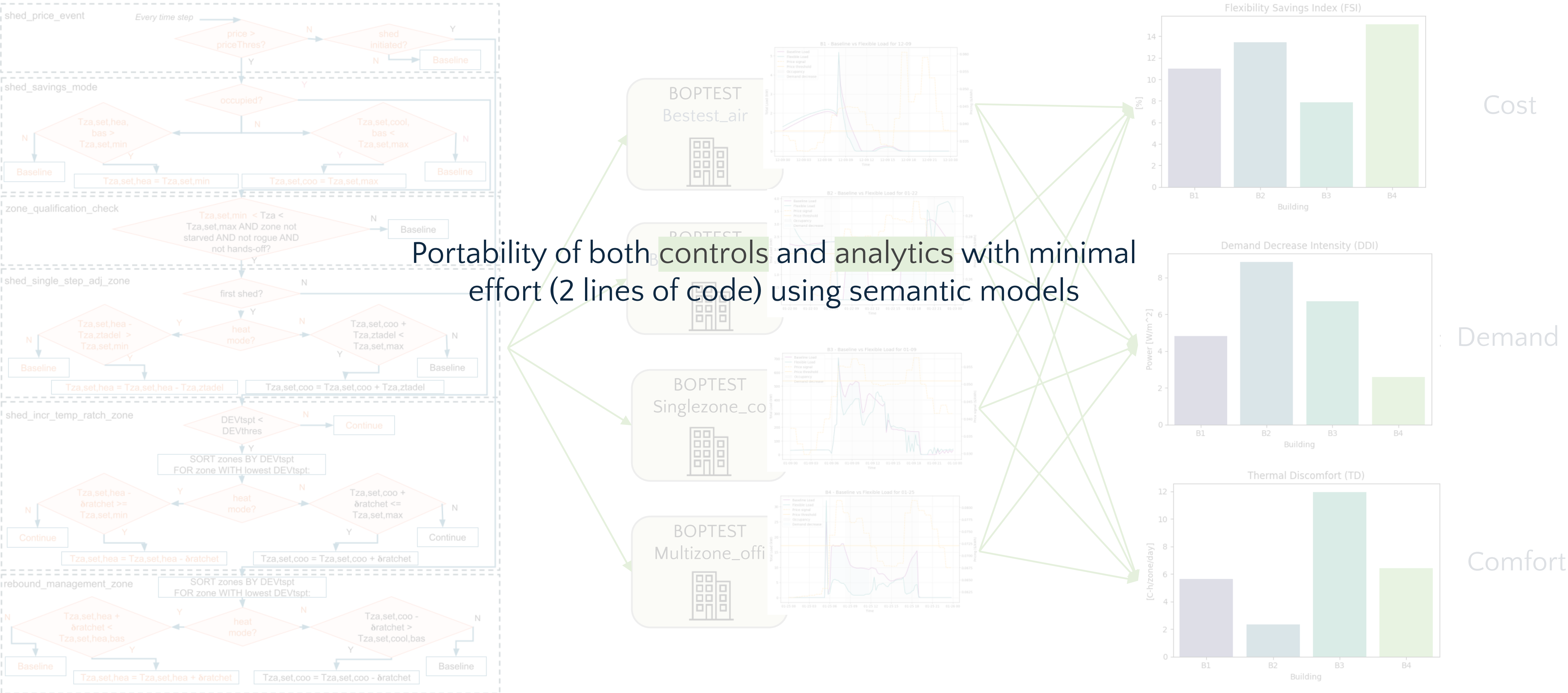
Simulation buildings



Performance variation

Demonstration of DF scalability

Portability of both controls and analytics with minimal effort (2 lines of code) using semantic models



Advanced rule-based DF control

Simulation buildings

Performance variation

DFLEXLIBS GUI

Search

DFLEXLIBS Home Search Navigate Validate

Search Sort Reset

Application	Menu
c_1a_zone_temp_adj_inc_ratch	≡
c_1b_zone_temp_adj_perform_ratch	≡
c_2a_zone_pre_heat_cool_sim	≡
c_2b_zone_pre_heat_cool_com	≡
c_1a2a_zone_temp_adj_inc_ratch_pre_...	≡
c_1a2b_zone_temp_adj_inc_ratch_pre_...	≡
c_1b2a_zone_temp_adj_perform_ratch_...	≡
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Navigate

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Archetype
Target level
Application

Select your application

- c_1a_zone_temp_adj_inc_ratch
- c_1b_zone_temp_adj_perform_ratch
- c_2a_zone_pre_heat_cool_sim
- c_2b_zone_pre_heat_cool_com
- c_1a2a_zone_temp_adj_inc_ratch_...
- c_1a2b_zone_temp_adj_inc_ratch_...

...

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Validate

DFLEXLIBS Home Search Navigate Validate

Upload your semantic model (brick)

bestest_air.ttl UPLOAD

Model Validation

Your model has been uploaded and validated.

CANCEL SEE RESULTS

DFLEXLIBS Home Search Navigate Validate

Model validation results Search

Validity Sort Reset

Application	Valid?	Menu
c_1a_zone_temp_adj_inc_ratch	True	≡
c_1b_zone_temp_adj_perform_ratch	False	≡

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See report

Key takeaways for DF scalability

- **Controls performance** do vary, due:
  - Efficiency rate, operating schedules, baseline and low-level controls, thermal mass, grid signals' dynamic, zoning configuration, HVAC type
  - User-defined parameters -> users need to **understand their priorities** to configure accordingly

Value-proposition

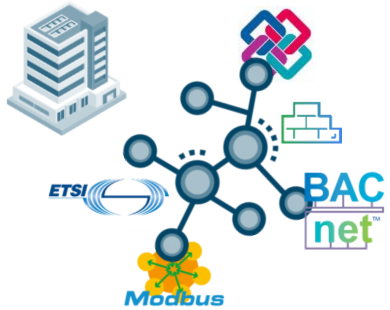
- Work integrates fragmented research fields, such as control specification, semantics-driven portability, and performance assessment, in an innovative way
- Pave the way for developing new products and markets

Conclusions, future work and research impact

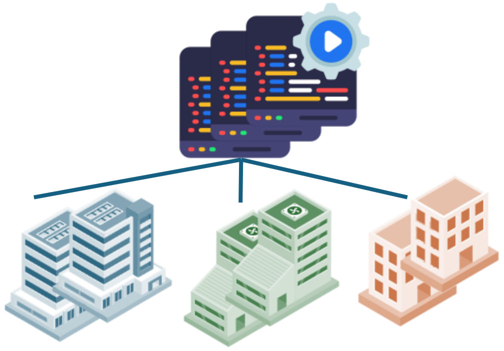
Conclusion

Novel semantics-driven frameworks enhancing DF control applications in terms of:

Portability => testing the same code-based controls in different buildings with minimal effort



Interoperability => integrating different data sources while leveraging diverse well-established ontologies



Scalability => multiple control and analytic applications evaluated across diverse buildings

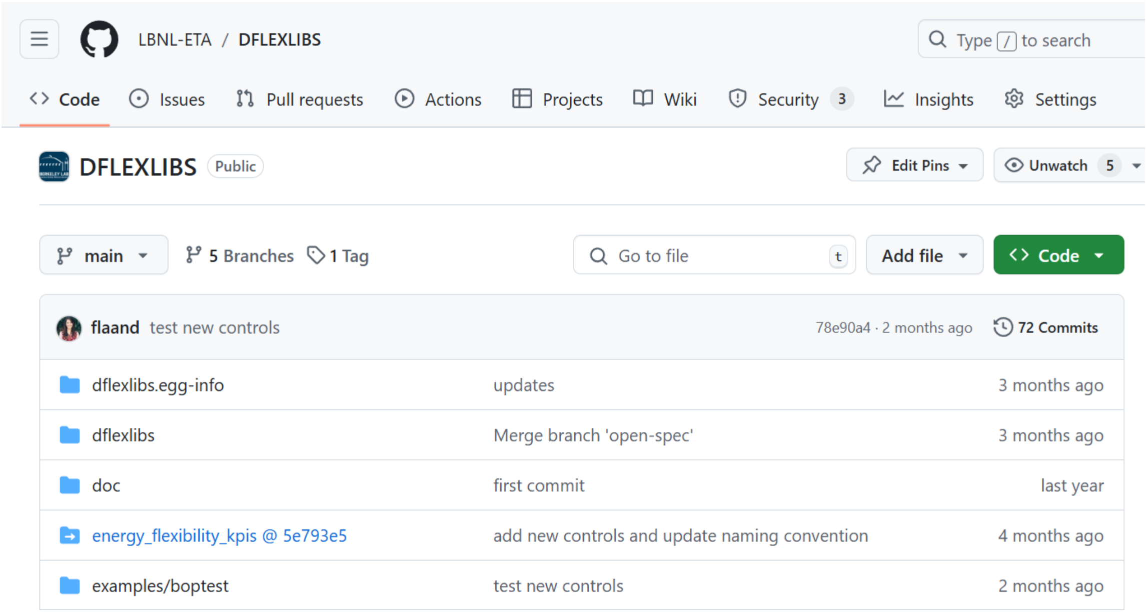
- **13** developed controls, **6** case studies (**2** real and **4** virtual buildings)
- Effort savings: reusable controls/mappings (**one-time cost**), minimal changes (**few lines of code**)
- Energy savings: demonstrated cost reduction (**15-27%)** and demand decrease (**35-60%**)

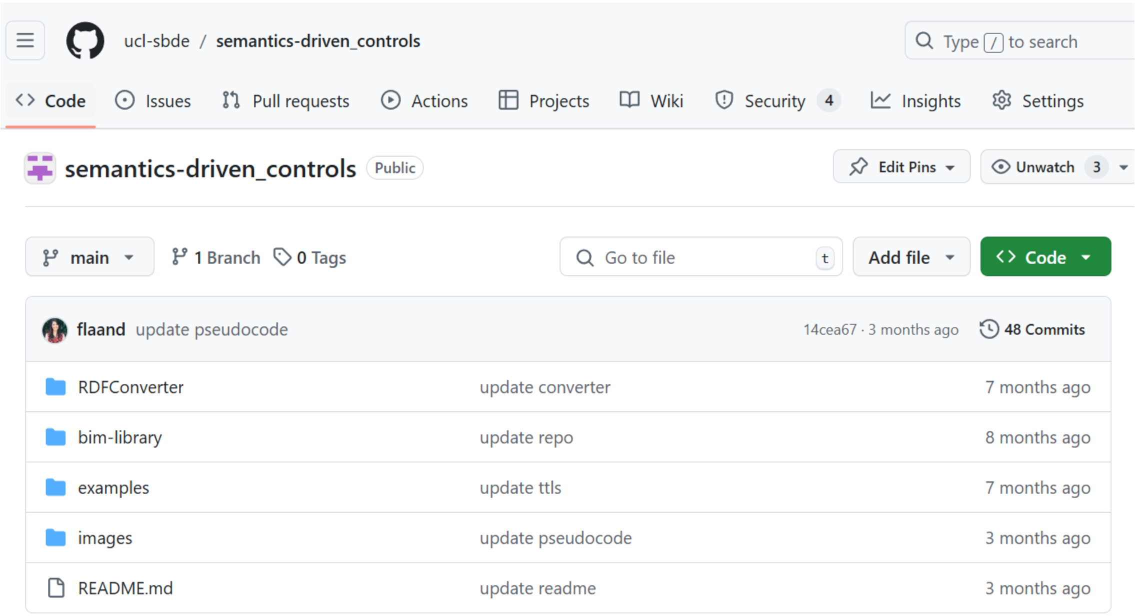
Future work

- Comprehensive **assessment of the framework** benefits (quantification of reduced efforts & interviews)
- **Extend existing ontologies** to support DF related concepts
- Addition of **new controls to the library** based on other algorithms and end uses
- Comprehensive **analytics** with available **controls results**
- Compliance with **new standards** (ASHRAE 231 for controls' design and 223 for semantic modelling, W3C WoT for interface specification)
- Deployment of a more robust web-based **user interface / platform** for the library
- Explore **large language models** to automate semantic models' generation and query definition
- Support a portable, scalable, and interoperable **EU flexibility needs assessment**

Research impact

- **First work** (as for the author's knowledge) proven semantics-driven portability of buildings controls
- **Open-source** solutions
  - DFLEXLIBS (DF controls, Annex 81 analytics & BOPTEST interfaces)
  - Mapping algorithms (BIM-to-RDF & BAS-to-RDF)





What to do with all of this?

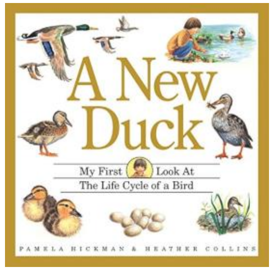
- **Benefits** to multiple stakeholders

Researchers can test the portability and performance variation of state-of-art controls

Developers can test new controls, reuse available controls and create new products and markets *‘DF marketplace’*

Integrators can generate new semantic models and extend well-established ontologies

- **DF open specification & semantics** in practice
  - *Berkeley lab team’s new funding from **California Energy Commission** “Enabling Interoperable Demand Flexibility in Commercial Buildings” using ASHRAE new standards*



CBIM - European Training Network

Cloud-based Building Information Modelling

Thank you!

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