EKATERINA PETROVA

TOWARDS HOLISTIC BIM-BASED BUILDING DESIGN

APPLYING COMPUTATIONAL APPROACHES TO ENHANCE SUSTAINABLE DESIGN PRACTICES

ABOUT ME

Feb 2014 - Feb 2016: MSc in Technology in Management in the Building Industry, Department of Civil Engineering, AAU

Information Exchange between BIM, Building Performance Assessment and Sustainability Certification in Conceptual Building Design

June 2016 - June 2019: PhD Student, Department of Civil Engineering, AAU

Holistic Sustainable BIM-Based Building Design and Performance Assessment

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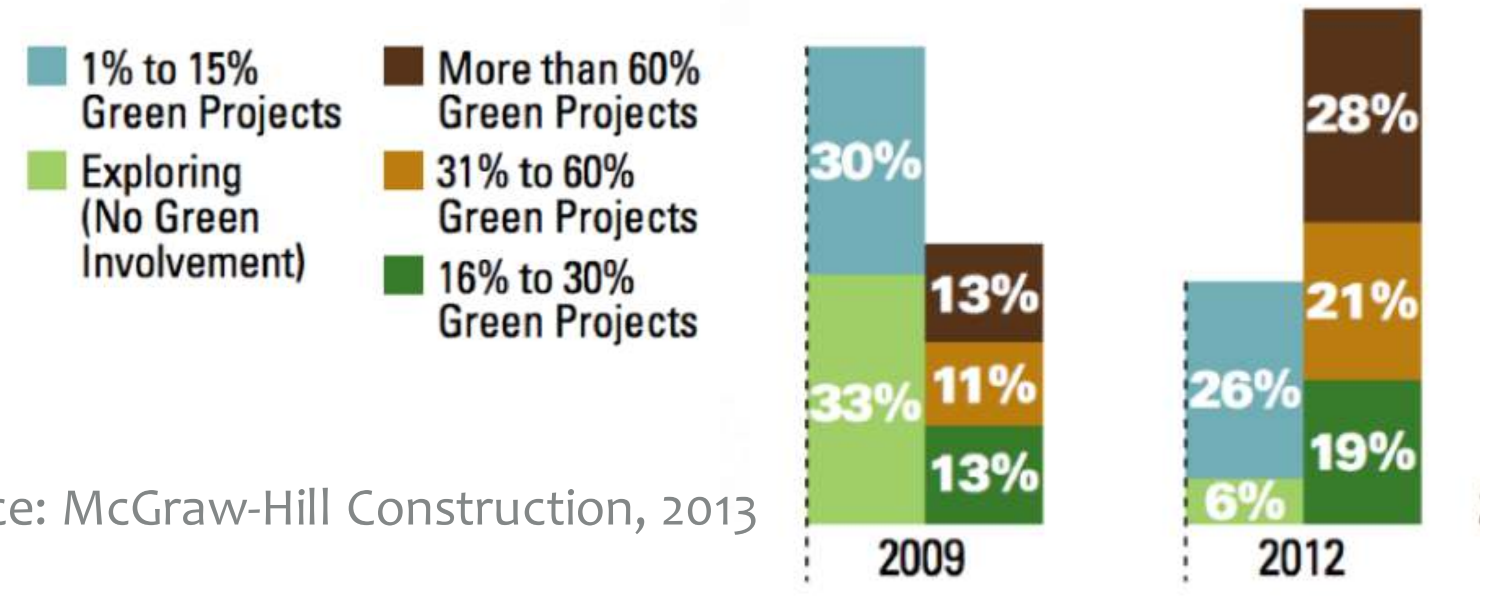
OUTLINE

- **Building performance and data in buildings**
- What data is available and how can it be leveraged
- Knowledge Discovery in Databases
- Handling the data: semantics, geometry matching, data mining
- Towards evidence-based decision support in high-performance design

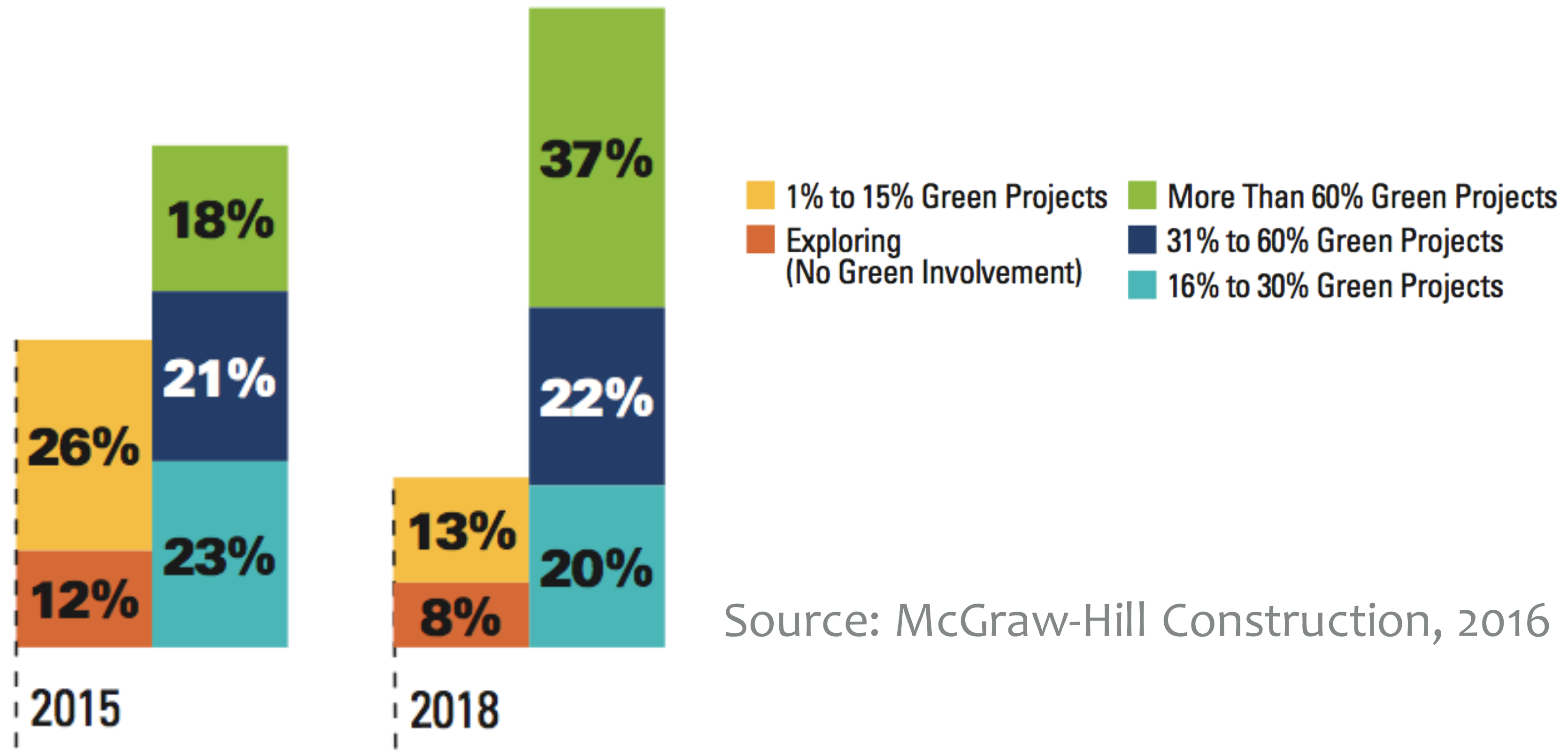
A SHORT STORY ABOUT BUILDING PERFORMANCE

Source: www.datadrivenbuilding.org

Levels of green building activity globally (2009-2018 expected)



Source: McGraw-Hill Construction, 2013



Source: McGraw-Hill Construction, 2016

- Increase in client demands concerning building performance
- Tightened regulations
- Stronger focus on high-performance, energy efficiency, comfort, health, and productivity
- Rapid technological and methodological developments allowing performance analyses and prediction

A SHORT STORY ABOUT BUILDING NON-PERFORMANCE

Source: www.datadrivenbuilding.org

- Inaccurately predicted building performance and energy consumption
- Difference between predicted and measured performance
- Inaccurate assumptions about input parameters (e.g. occupancy rate and after hour plug load use)
- Models are rarely reused or revisited during operation
- No modification of design assumptions based on actual performance
- Inconsistencies due to external conditions, operational issues and occupant behavior
- Oversized or underperforming HVAC systems
- **Operational data is available, but decisions are still largely based on experience and rules of thumb**

A SHORT STORY ABOUT DATA AND DECISION-MAKING IN AEC

- A lot of **guesswork**- would the completed building accommodate all current needs? What about the severely underestimated future needs?
- Project-specific **expertise** is hardly transferrable
- Previous **experiences** tend to drive decision-making in industry, but **decisions should be evidence-based.**

OBJECTIVES

- Bridge the gap between the intuitive/experience-driven and the analytic/**data-informed decision-making**.
- Identify useful patterns from past projects and buildings in operation, transform information, **discover new knowledge and better predict outcomes**.
- **Sustainable design process**, which is **performance and data-informed**, rather than just data dependent.

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WHAT KINDS OF DATA ARE AVAILABLE?

Design brief data graph databases, design requirements, traceability, natural language processing

3D geometric data point clouds, 3D mesh geometry, 2D shapes, fully semantic geometry

Semantic BIM data aspect models and coordination models, clash detection, product characteristics

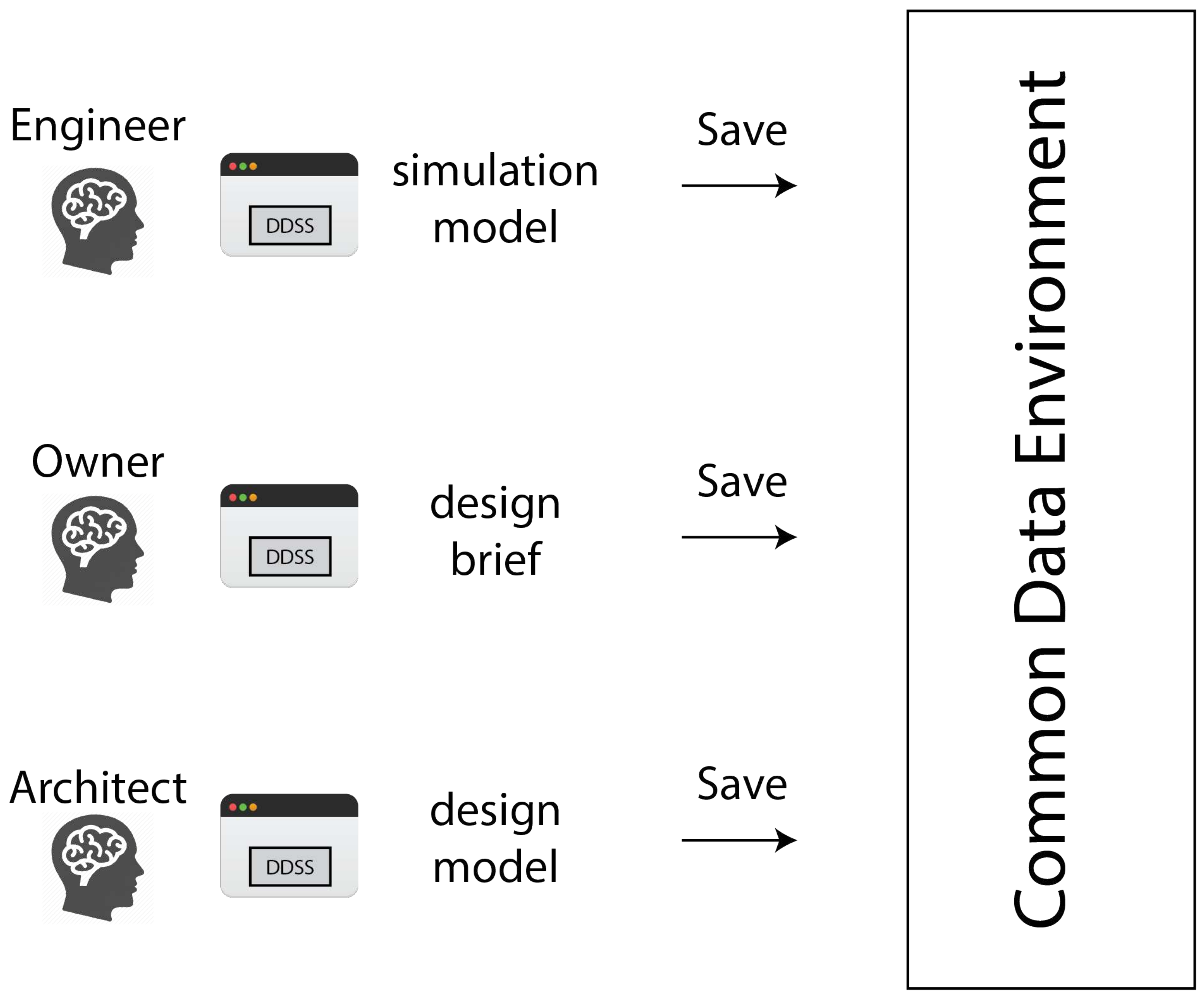
Simulation data default parameters, product characteristics, static and dynamic parameters, measured data

Monitored operational data data lakes, sensor data, data streams

Source: Schneider Electric

THE COMMON DATA ENVIRONMENT

"The **common data environment** (CDE) is a central repository where construction project information is housed. The contents of the CDE are not limited to assets created in a 'BIM environment' and it will therefore include documentation, graphical model and non-graphical assets." (BSI, 2013)



Documentation documents

Graphical data data conveyed using shape and arrangement in space

Non-graphical data data conveyed using alphanumeric characters

Semantic BIM data

Design brief data

3D geometric data

Simulation data

Operational data

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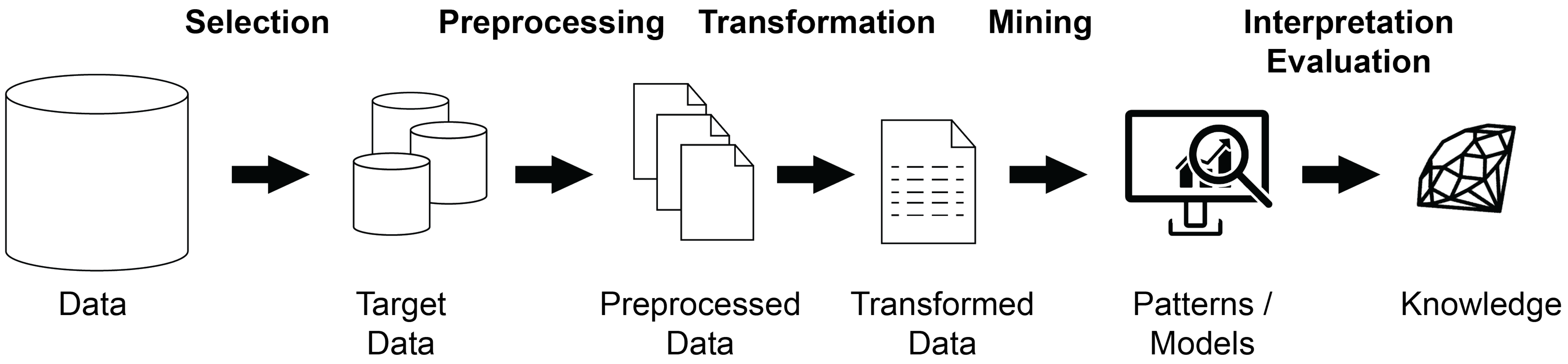
KNOWLEDGE DISCOVERY IN DATABASES (KDD)

- Evidence is in hidden knowledge
- Knowledge can be captured by using knowledge discovery in databases (KDD) approaches
- Yet, KDD needs to be tailored to the different kinds of available data



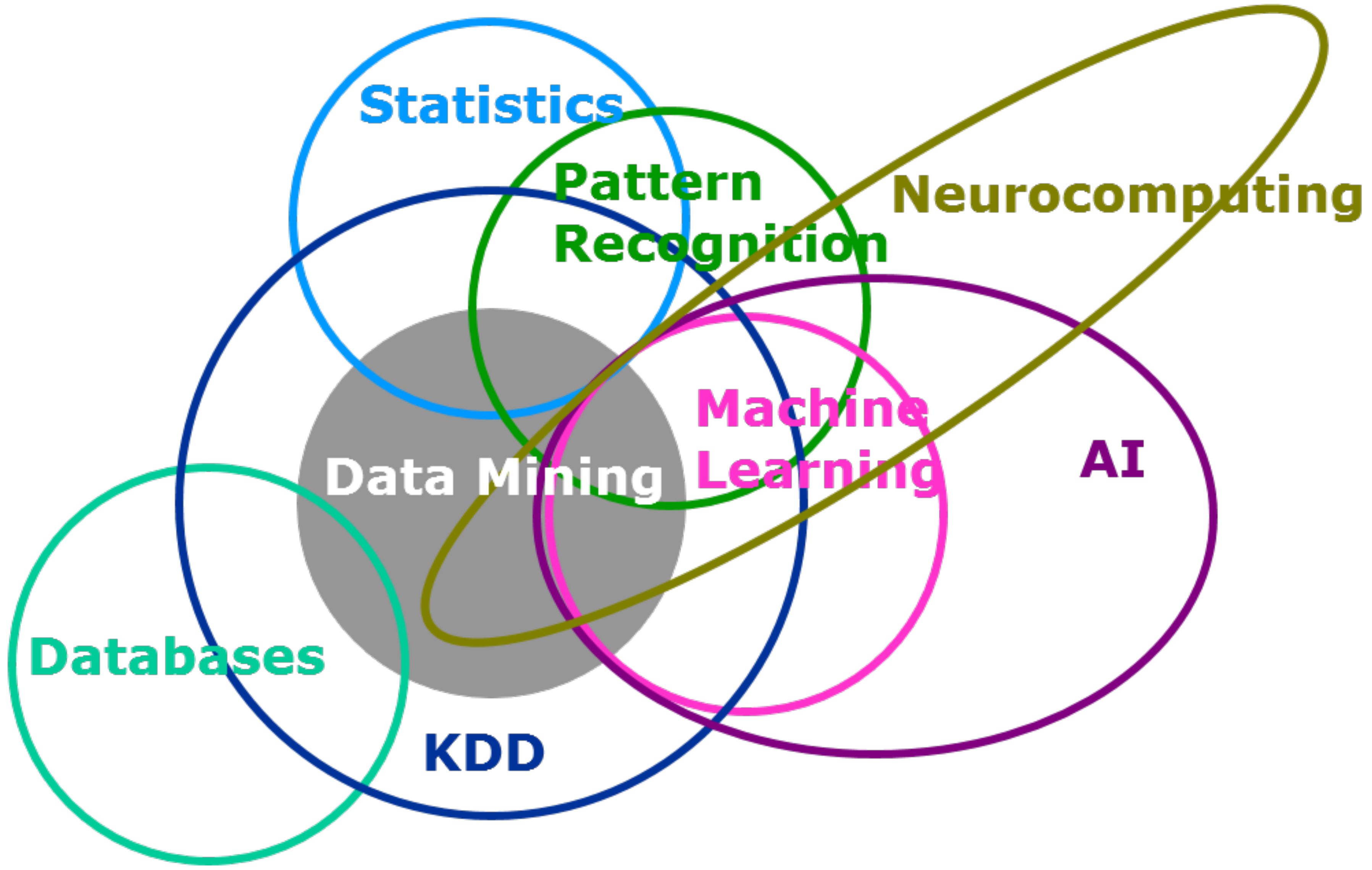
Knowledge discovery in databases (KDD), Fayyad et al. (1996)

DATA MINING

"The analysis of large observational datasets to find unsuspected relationships and to summarize the data in novel ways so that data owners can fully understand and make use of the data." (Hand et al., 2001)

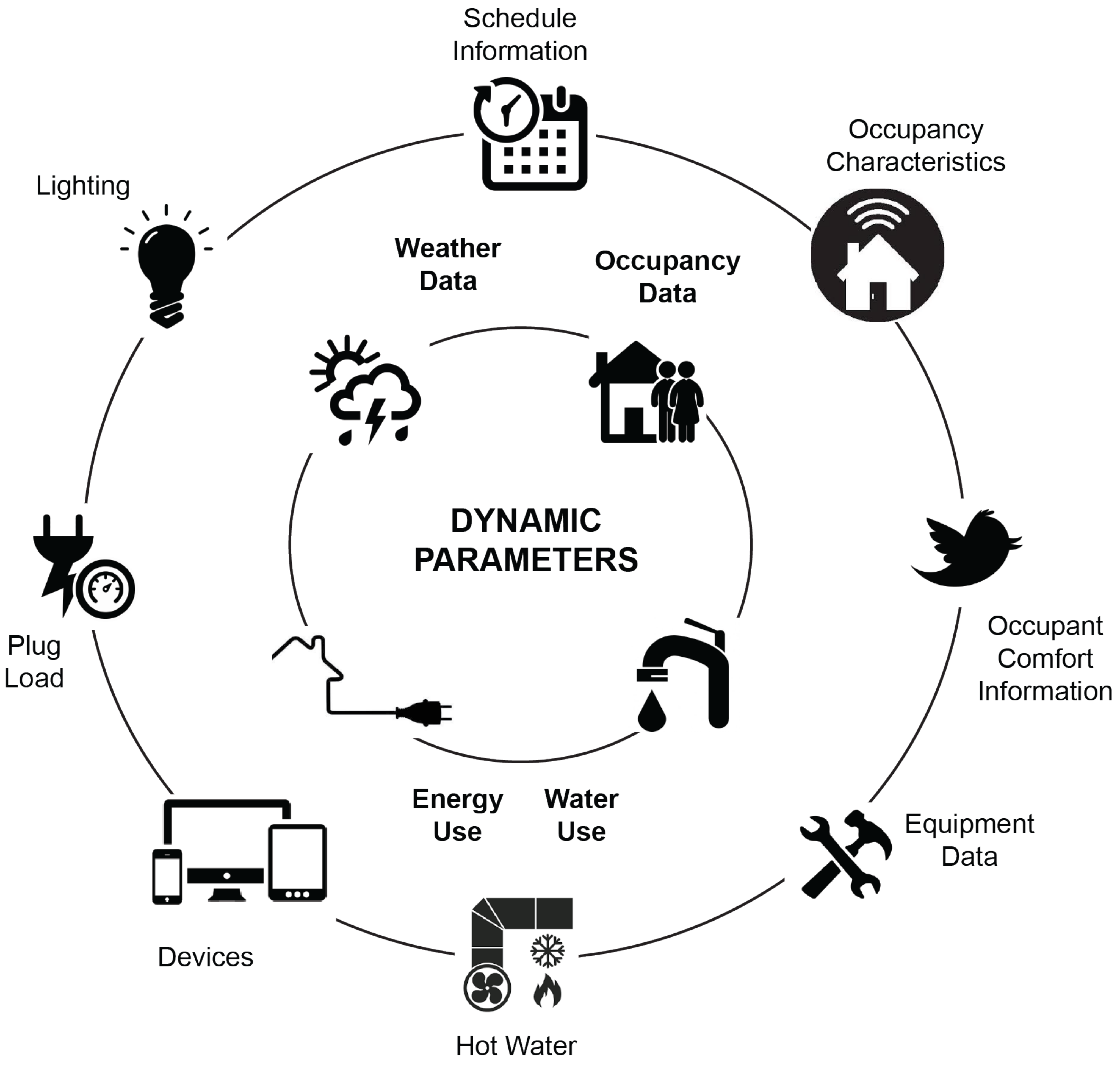
PATTERN RECOGNITION

'Pattern recognition is concerned with the automatic discovery of regularities in data through the use of computer algorithms and with the use of these regularities to take actions such as classifying the data into different categories'. (Bishop, 2006)



Source: SAS workshop,1998

DATA AND KNOWLEDGE AT OPERATIONAL STAGE



Source: Based on Mantha et al. (2015)

Time data

Energy consumption data

HVAC system operation data

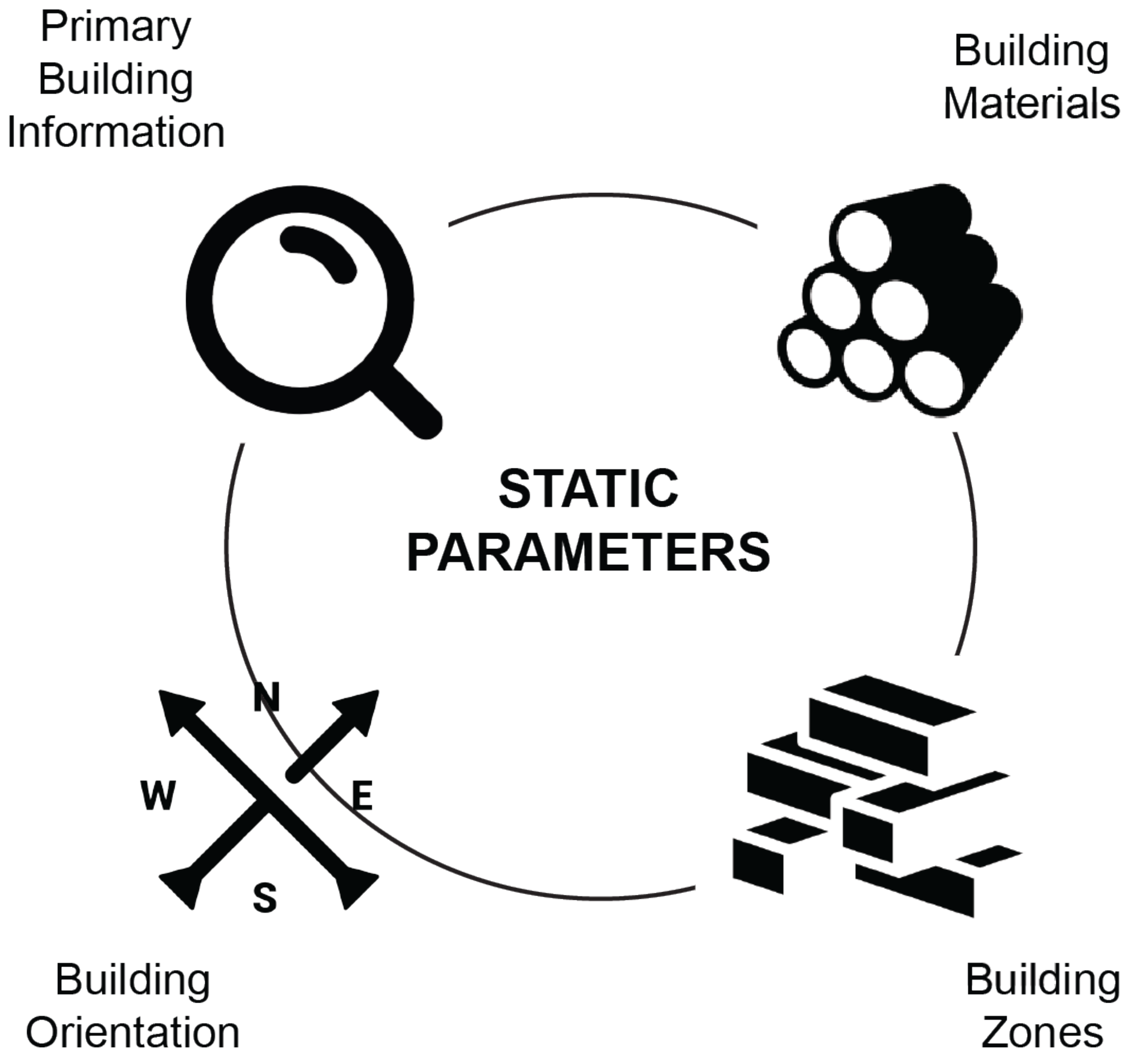
Environmental data

Numeric data

2D tabular data

- **Data mining** for operational performance analysis
- **Cross-sectional hidden knowledge discovery-** each row is treated as an independent observation, temporal dependencies between rows are neglected (e.g. interaction between system components)
- **Temporal knowledge discovery-mining** data along both axises of the two-dimensional data table (e.g. characterizing dynamics in building operations)

DATA AND KNOWLEDGE AT DESIGN STAGE



Source: Based on Mantha et al. (2015)

Design brief requirements

Preliminary space layout 3D block model, 2D topological model

Object type data walls, windows, flow terminal, pumps, etc.

Building materials thermal conductivity, fire rating, material

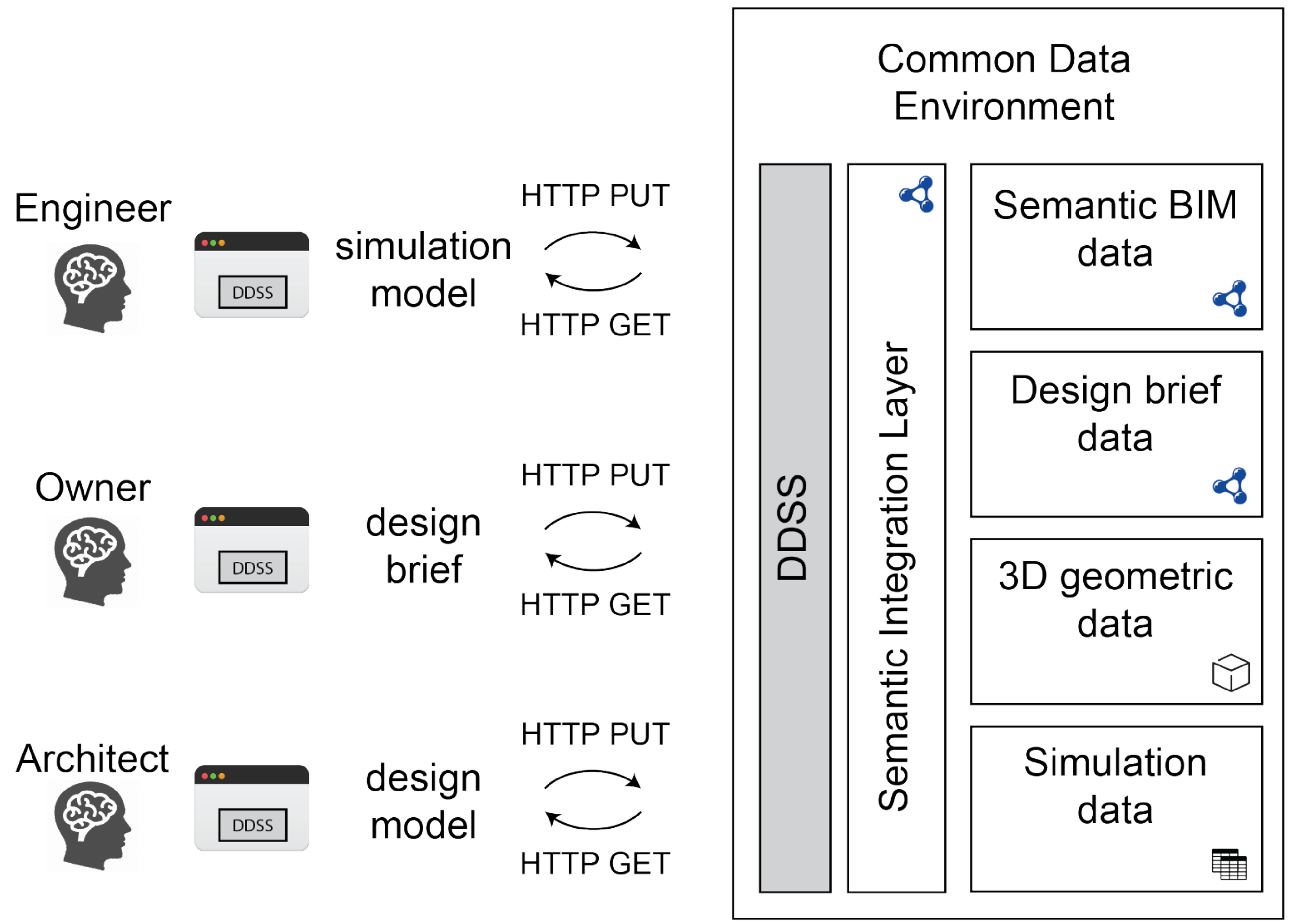
Semantic data

Full 3D geometry CSG, BREP, 2D geospatial, point cloud models

Geometric data

⇨ Viewing and editing of BIM models over versions in time

HOW CAN DATA BE HANDLED?



Semantic BIM data

Design brief data

→ **Direct semantic queries**

3D geometric data → **Geometric feature matching**

Simulation data

Operational data

→ **Data mining**

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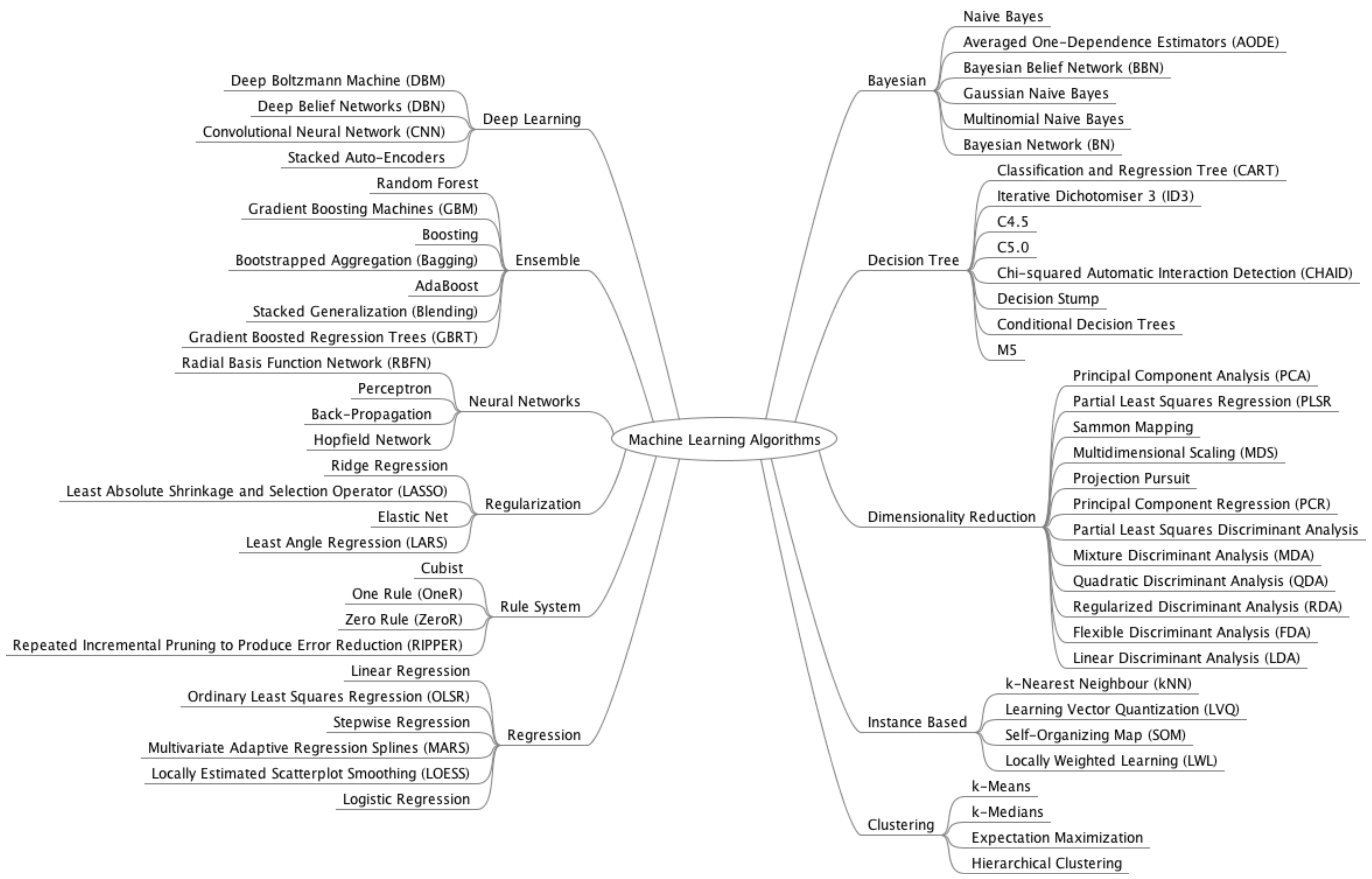
DATA MINING APPROACHES



Supervised / Predictive

- Predictive models and their knowledge representations
- Relationships between input and output variables
- Training data and domain expertise
- Novel knowledge discovery unlikely- input and output are predefined

Unsupervised / Descriptive

- Intrinsic structure, correlations and associations in data
- Input and output not predefined
- Ability to discover previously unknown hidden knowledge
- No explicit target- ability to discover interesting patterns

GEOMETRIC FEATURE MATCHING

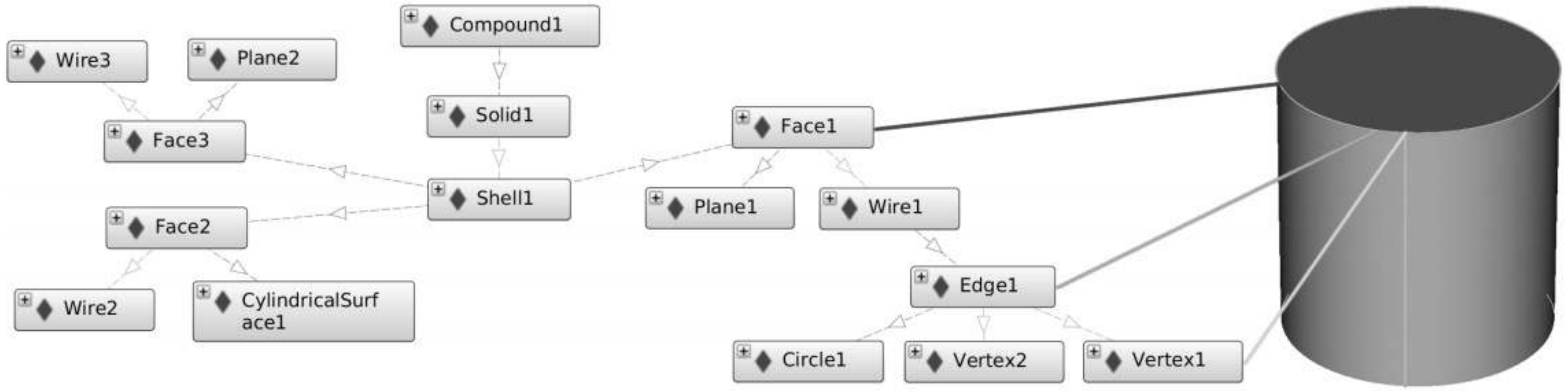
Well-Known Text (markup language for representing vector geometry objects on a map)

IFC-SPFF

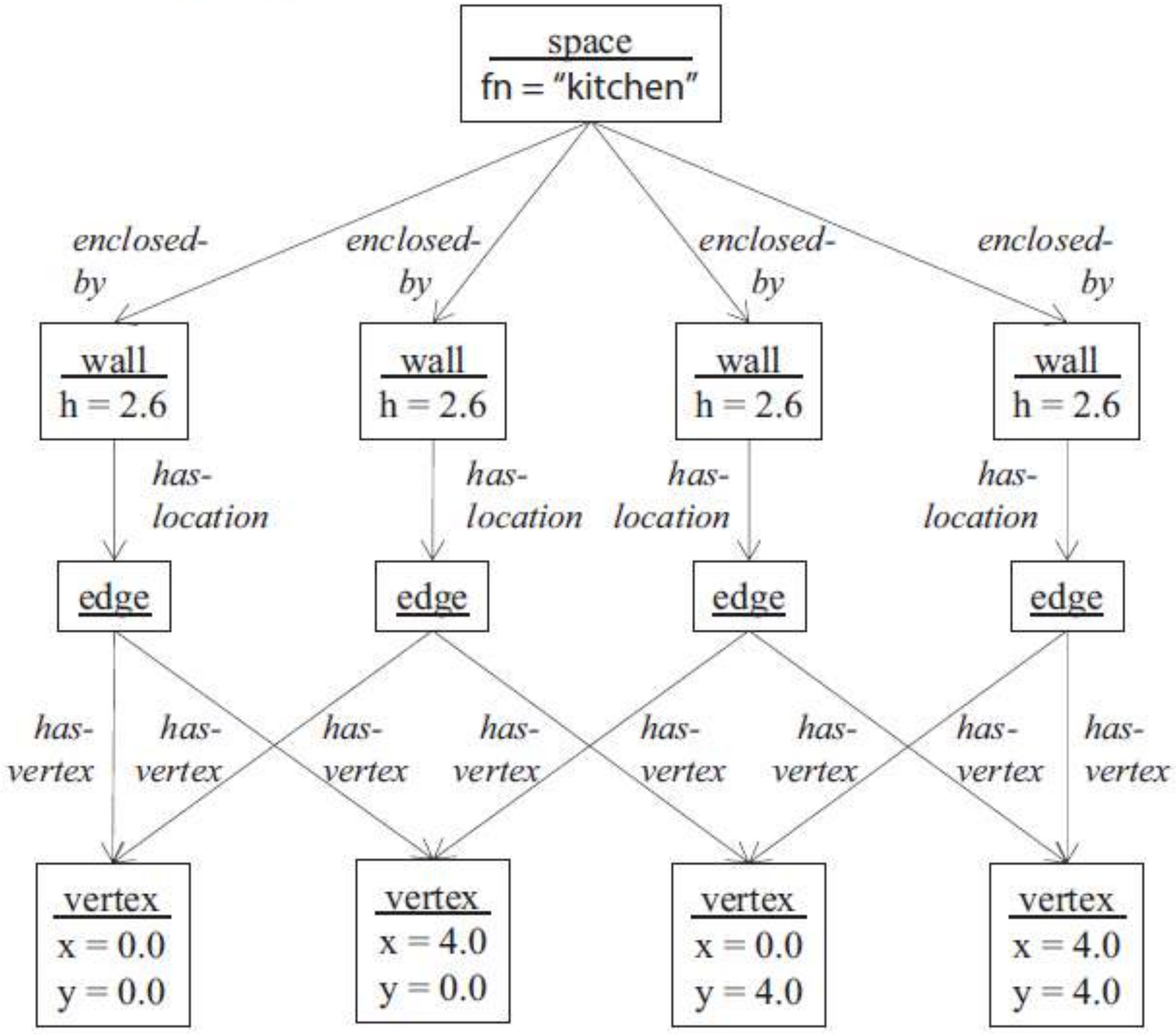
3D Mesh

Point cloud

Fully semantic geometry



Source: *Perzylo et al. (2015)*



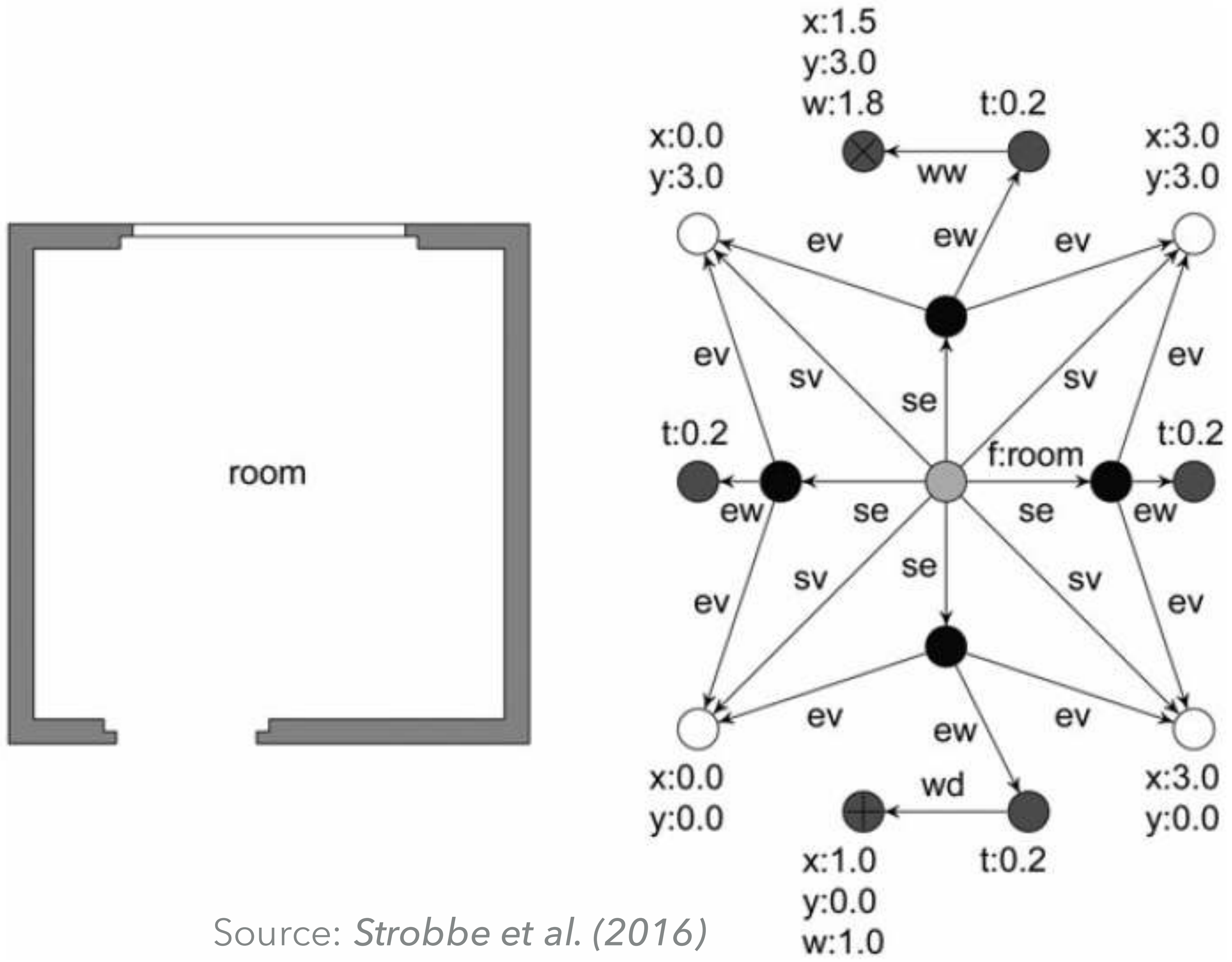
Source: *Pauwels et al. (2015)*

GEOMETRIC FEATURE MATCHING (2)

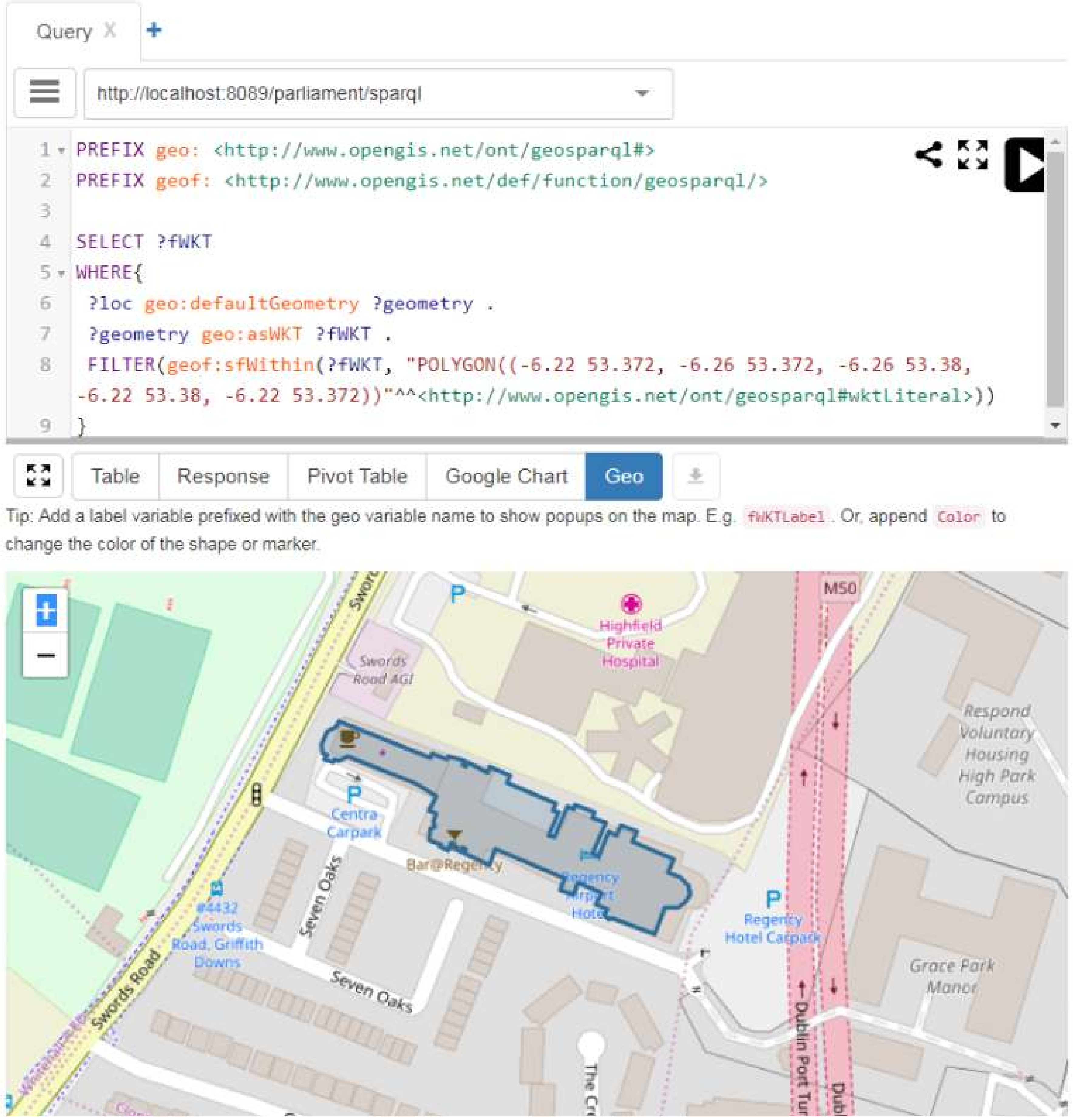
Image-based feature matching

Graph matching

Geometric analysis algorithms



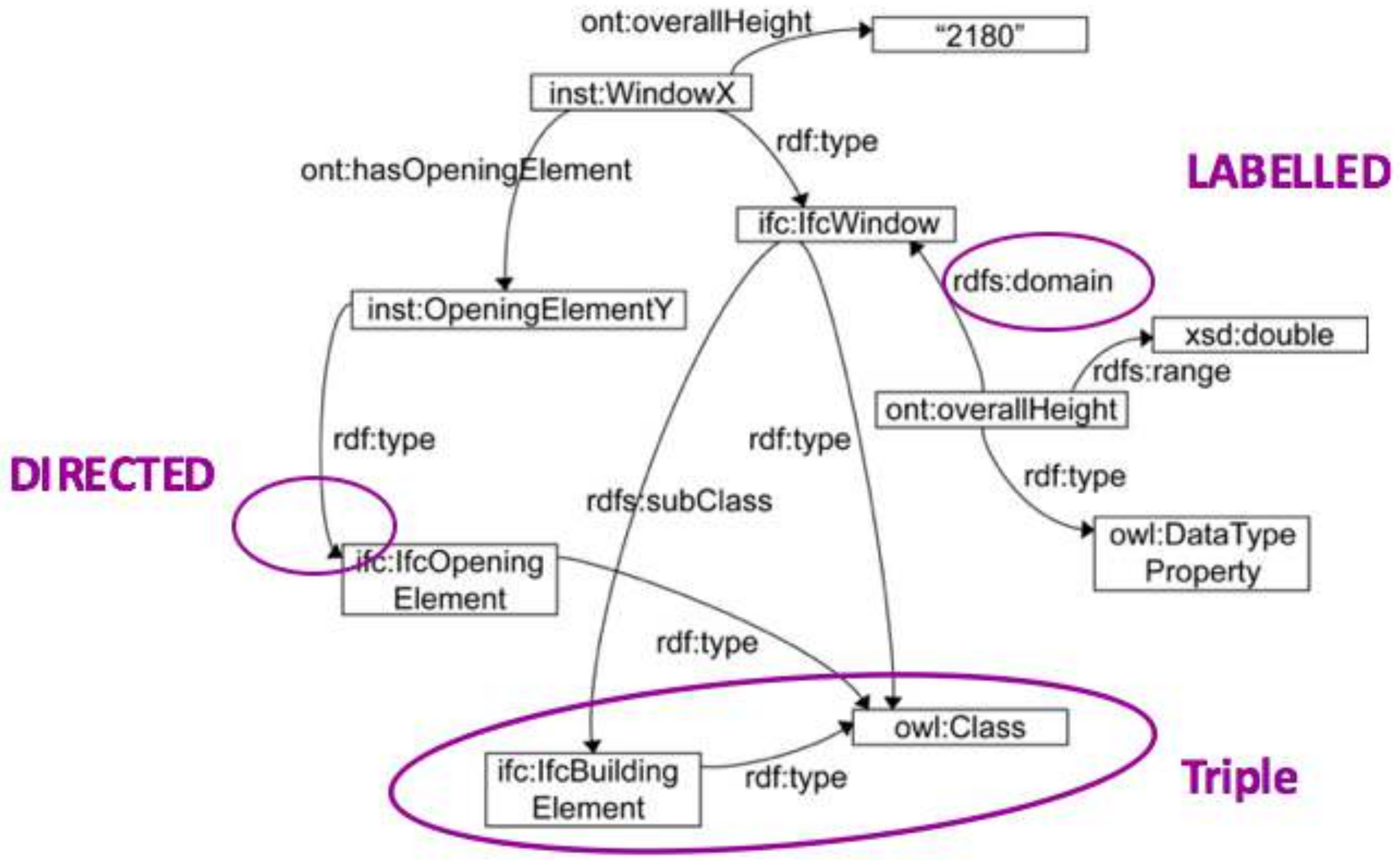
Source: *Strobbe et al. (2016)*



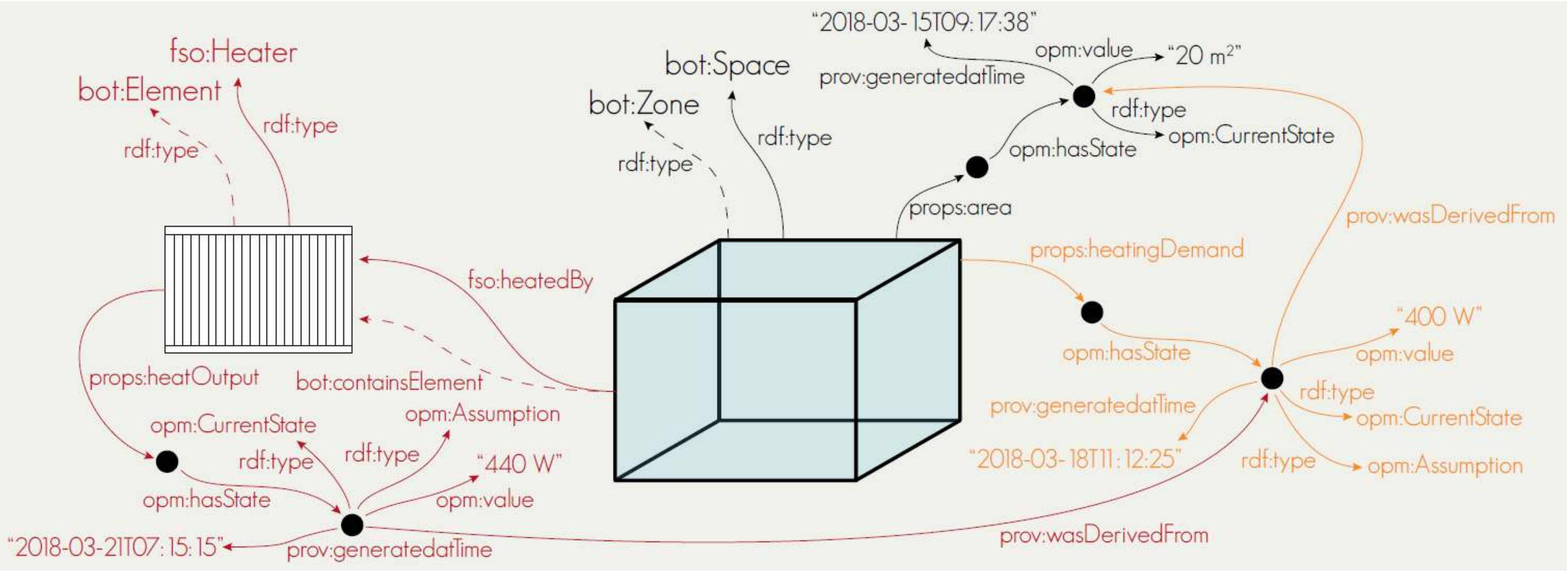
Source: http://phaedrus.scss.tcd.ie/buildviz/images/osi_dublin_building_yasgui.png

DIRECT SEMANTIC QUERIES

- **Semantic queries** allow for queries and analytics of associations and context
- **Derive information** based on syntactic, semantic and structural information contained in data.
- Deliver precise results/answer more fuzzy and wide open questions through **pattern matching** and **digital reasoning**.
- Semantic queries work on **named graphs**, **linked data or triples** (subject, predicate, object). Knowledge always comes in three.
- **Recourse Description Framework (RDF)-** data model to describe things and their interrelations
- **Querying RDF: SPARQL-** graph matching query language



Source: Pauwels et al. (2011)



Source: Rasmussen (2018)

USER-DRIVEN KNOWLEDGE DISCOVERY

- The outcome of geometric similarity matching and data mining can be captured in graphs
- A decision support system can then be built using direct graph semantic queries (CYPHER, SPARQL)
- Yet, this results in a highly supervised and biased DDSS, because everything goes through user-defined semantic queries

- **Alternative:** keep also the original data (geometry; numeric data), so that alternative data mining or geometry matching techniques can be applied, **based on user input**
- Towards both **user-centric and evidence-based** holistic sustainable design

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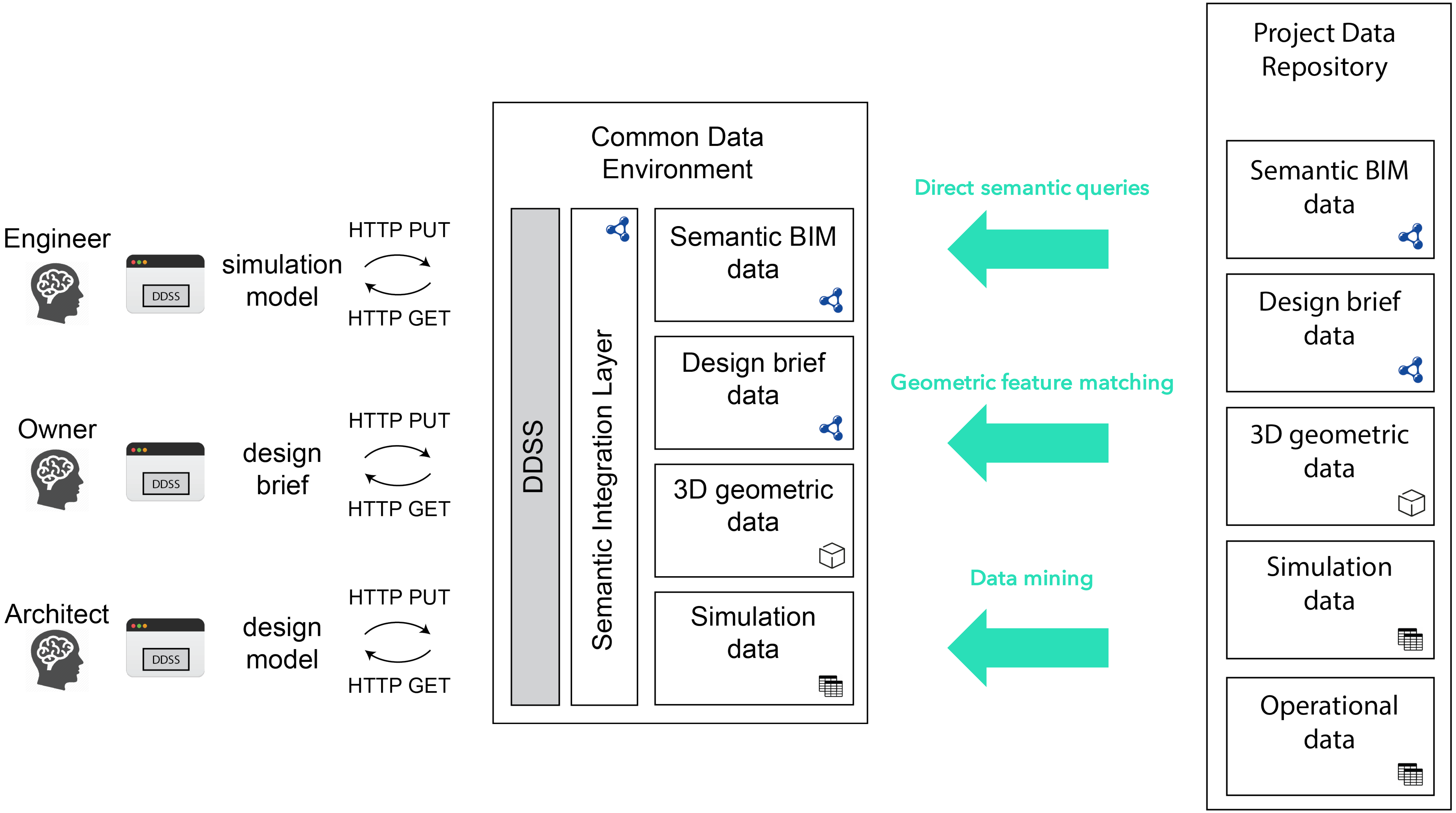
KEY CONSIDERATIONS IN THE STUDY

(1) the **full use of BIM software** as a means to connect to previous project data (e.g. through a CDE),

(2) the reliance on **web-based semantic representation methods** as a means to build a semantically rich and global graph of data, and

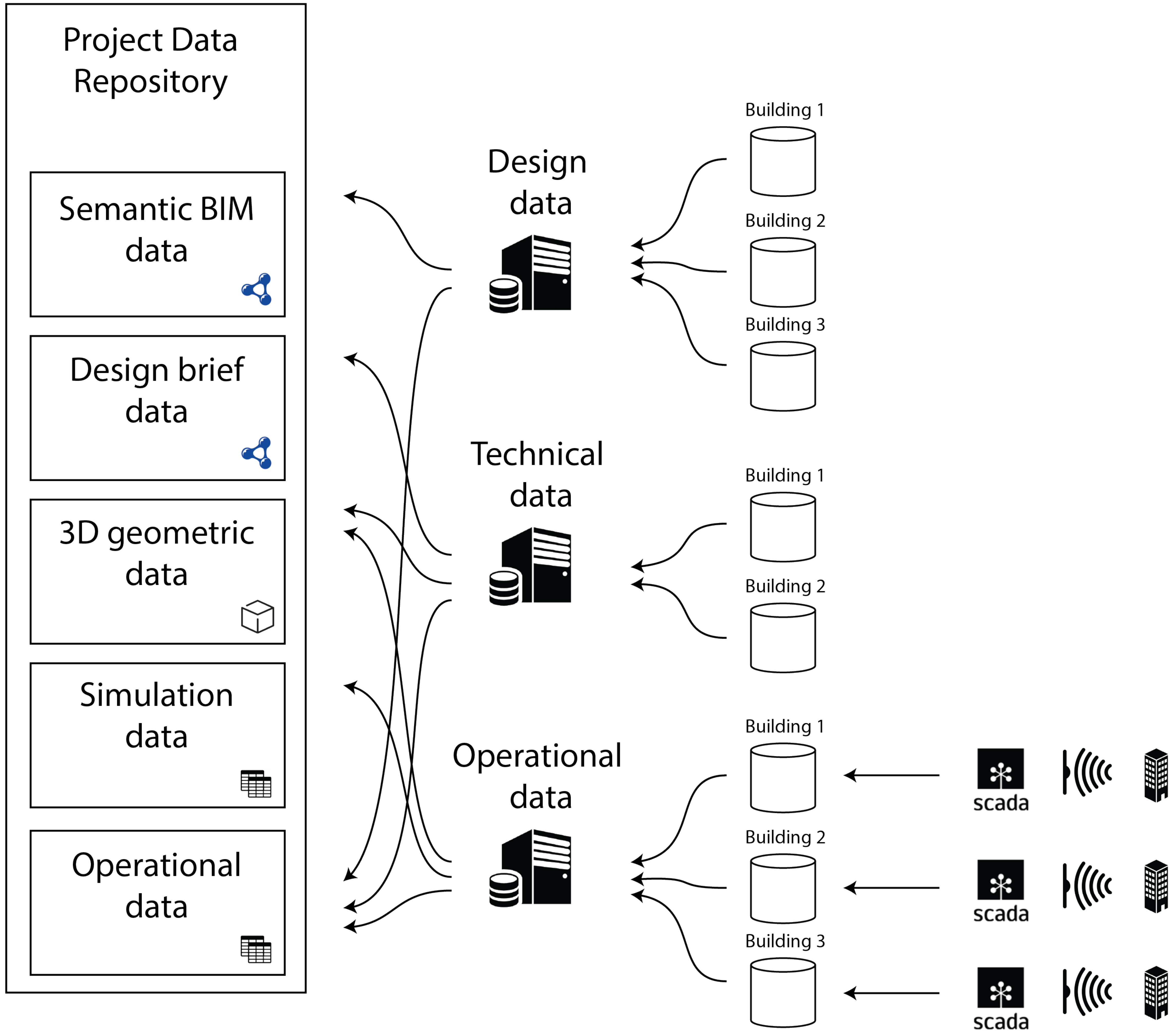
(3) the deployment of **Knowledge Discovery in Databases (KDD)** to discover hidden knowledge on an unprecedented scale.

CONNECTING TO EVIDENCE!



USE CASES: GIGANTIUM AALBORG AND IGENT TOWER

COLLECTING DATA FROM EXISTING BUILDINGS

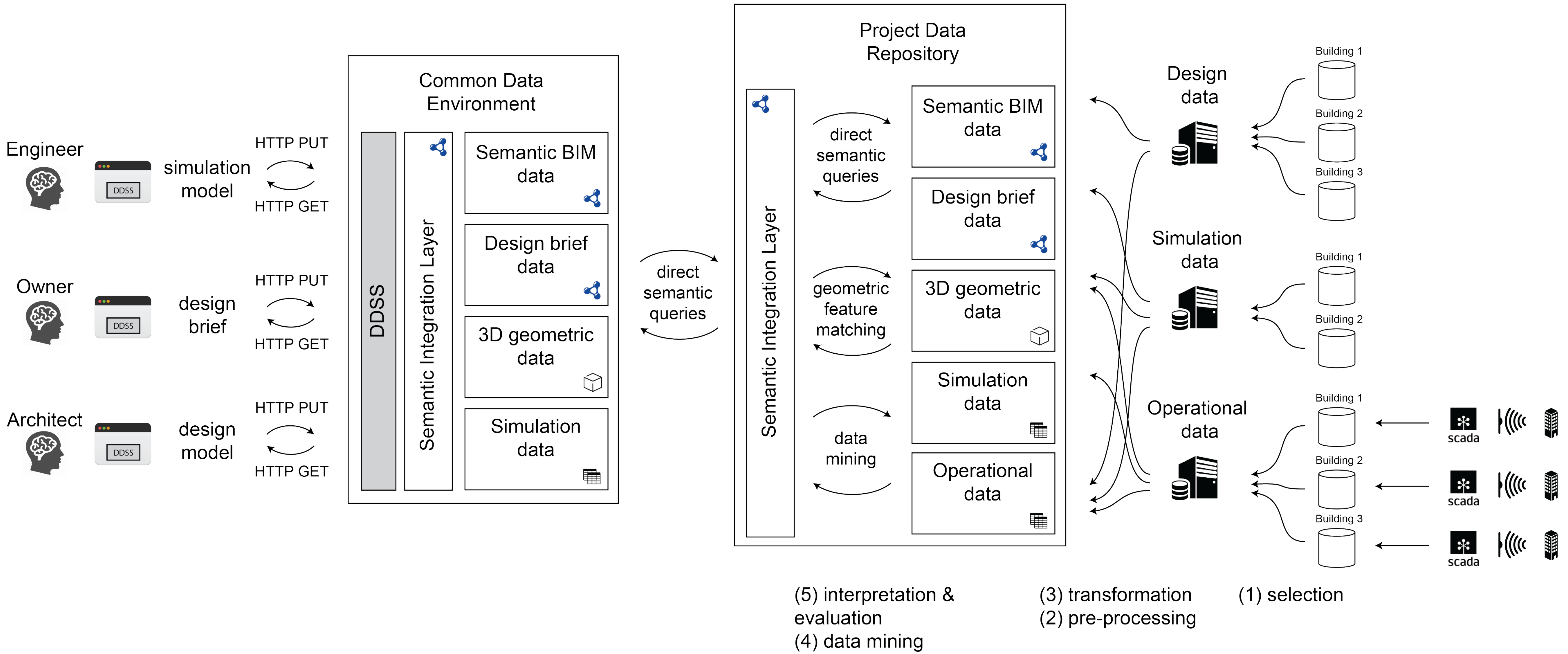


Design Brief and BIM Model

Detailed / Technical Design

Operational Data

KDD-DRIVEN DESIGN DECISION SUPPORT



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KEY RESEARCH AIMS AND CHALLENGES

1. Connecting to evidence using high-performing pattern matching
   - direct semantic queries
   - geometric feature matching
   - data mining

Smart selection of diverse pattern-matching techniques (user-driven!!)

2. Building a project data repository
   - data selection
   - data cleansing
   - data transformation

Manual methods prevail and need to be replaced with semi-automatic methods

3. Make data mining results machine-processable and bring the knowledge back to the end-user in a DDSS

REFERENCES

British Standards Institute, 2013. PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling.

Fayyad, U., Piatetsky-Shapiro, G. & Smyth, P., 1996. From Data Mining to Knowledge Discovery in Databases. AI Magazine, 17:3.

Mantha, B.R.K., Menassa, C.C., Kamat, V.R., 2015. A taxonomy of data types and data collection methods for building energy monitoring and performance simulation. Advances in Building Energy Research,10:2.

Pauwels, P., Strobbe, T., Eloy, S. & De Meyer, R., 2015. Shape Grammars for Architectural Design: The Need for Reframing. CAAD Futures.

Pauwels, P., Van Deursen, D., Verstraeten, R., De Roo, J., De Meyer, R., Van de Walle, R., and Van Campenhout, J., 2011. A semantic rule checking environment for building performance checking Automation in Construction Volume 20, Issue 5.

Perzylo, A. & Rickert, M., 2017. OntoBREP: An Ontology for CAD Data and Geometric Constraints. W3C LBD Community Group Meeting.

Rasmussen, M.H., 2018. Linked Building Data. Presentation in the 2018 BuildingSMART Standards Summit.

Strobbe, T., Eloy, S., Pauwels,P., Ruben Verstraeten, De Meyer, R. & Van Campenhout, J., 2016. A graph-theoretic implementation of the Rabo-de-Bacalhau transformation grammar. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 30.

THANK YOU FOR YOUR ATTENTION!

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