

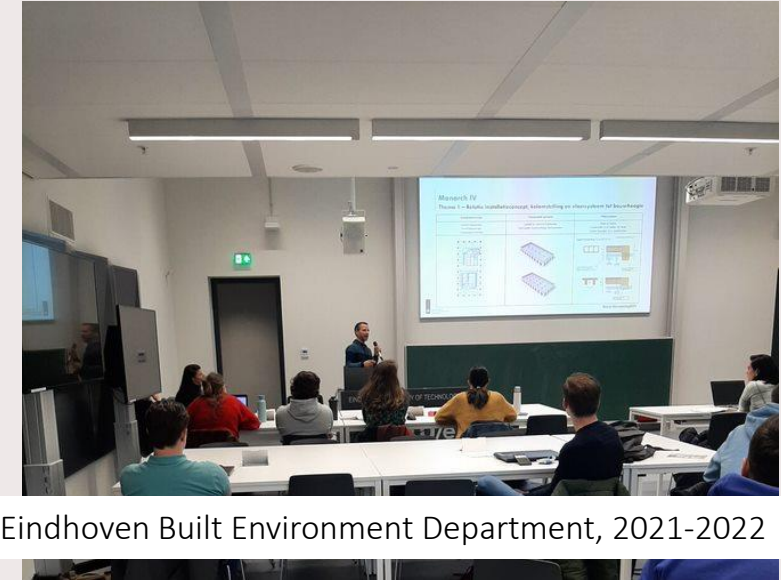
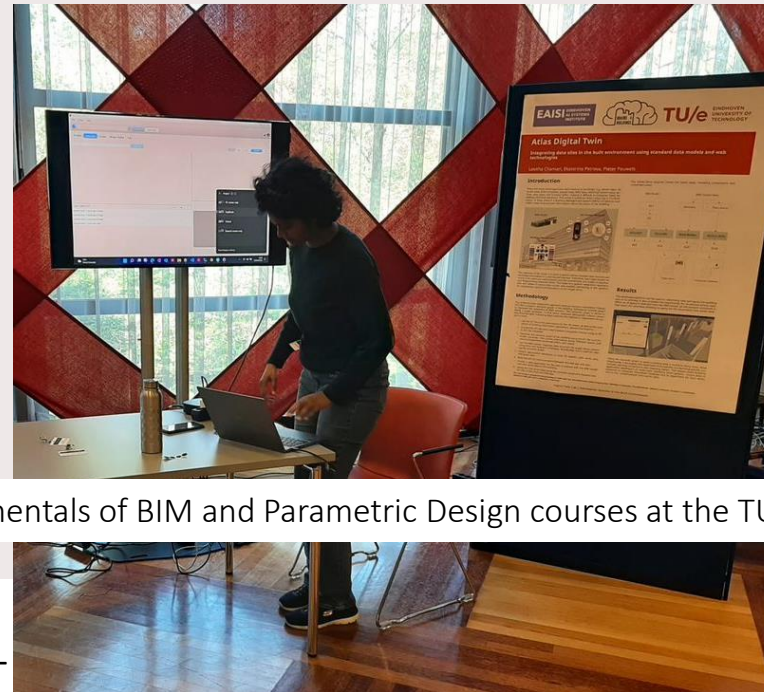
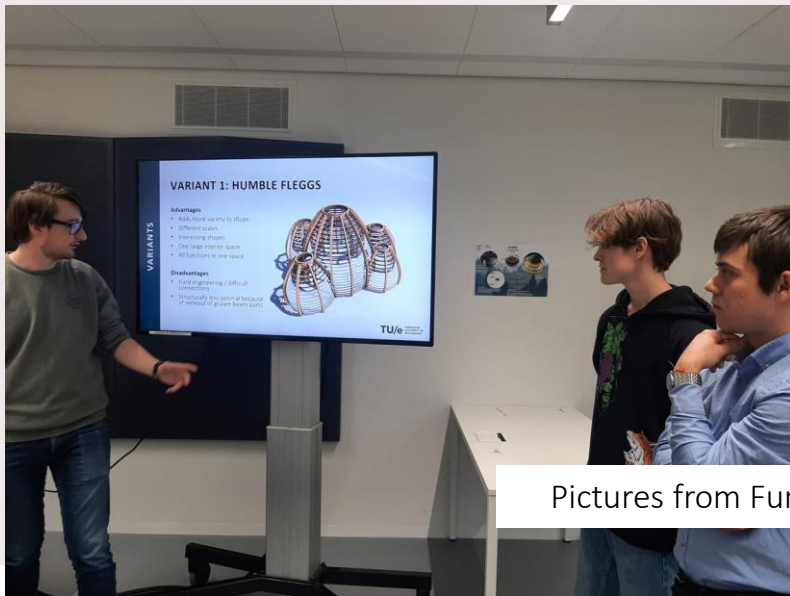


# AI, ROBOTISERING EN AUTOMATISATIE IN DE GEBOUWDE OMGEVING

KIVI LUSTRUM 175 JAAR, 10 SEPTEMBER 2022, DELFT

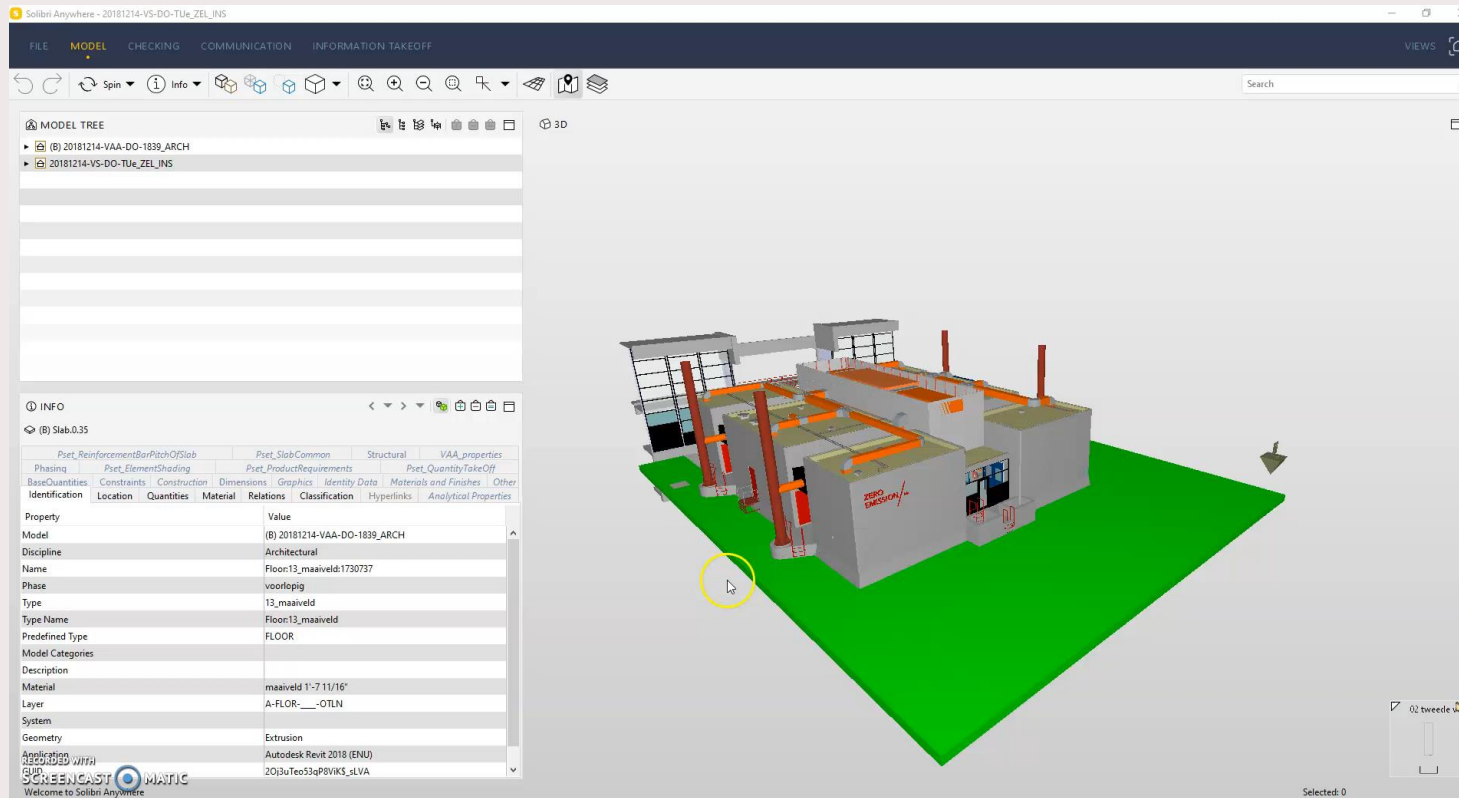
Pieter Pauwels, Associate Professor

Department of the Built Environment, Information Systems in the Built Environment



Pictures from Fundamentals of BIM and Parametric Design courses at the TU Eindhoven Built Environment Department, 2021-2022

# Building data, building data, and then more building data

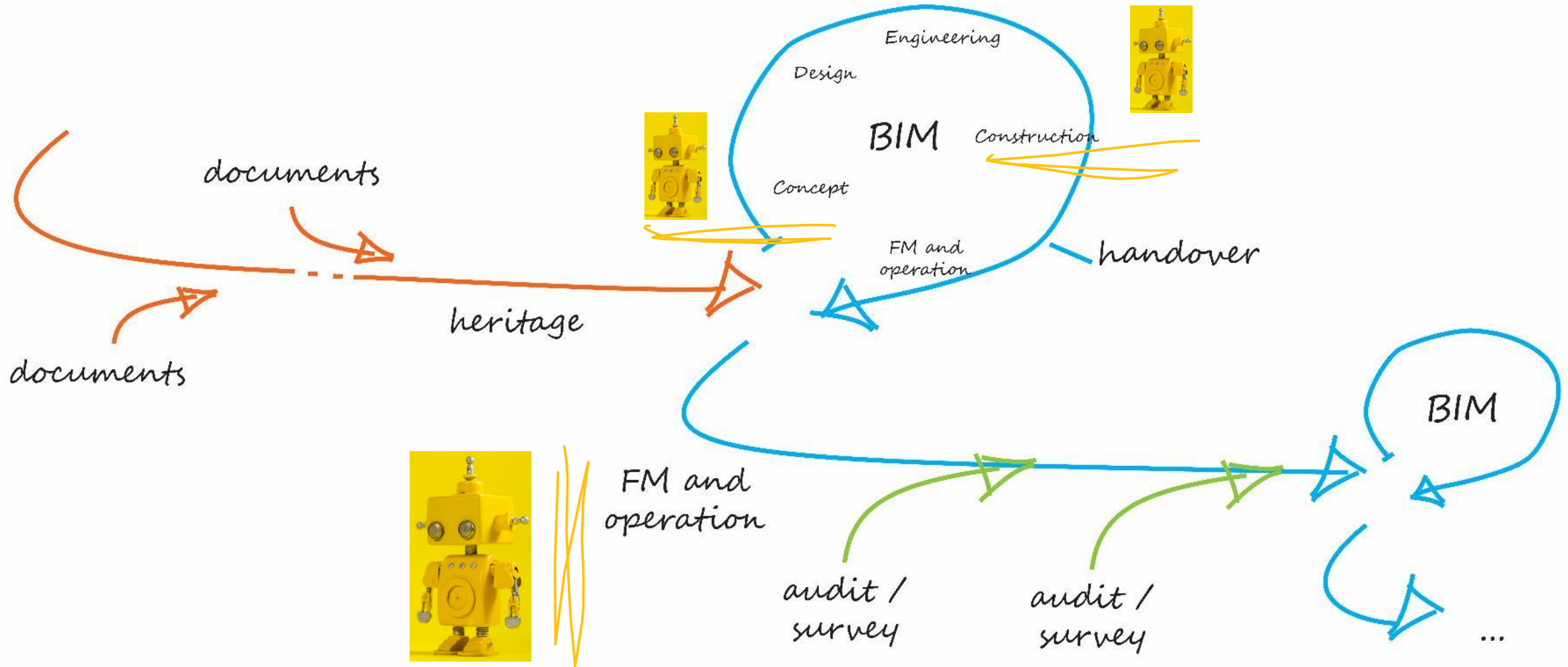


**Building Information Model (BIM)**  
3D representation enriched with semantic information

**Digital Twin (DT)**  
Digital counterpart for a physically existing object

**Linked Building Data (LBD)**  
Set of interlinked web-based data about the built environment

Gemini Digital Twin: combining building data with sensor data



Pieter Pauwels. Supporting decision-making in the building life-cycle using linked building data. Buildings 4 (3): 549–579. 2014.

Part 1:  
Robotics in the Operational Phase



## ATLAS LIVING LAB

The Atlas Living Lab is our newest and most sophisticated living lab, in which 10 years of experience with living labs accumulated in a flexible infrastructure and accompanying processes to conduct ground breaking research while respecting the privacy and comfort of the residents.

# B4B: Brains for Building's Energy Systems

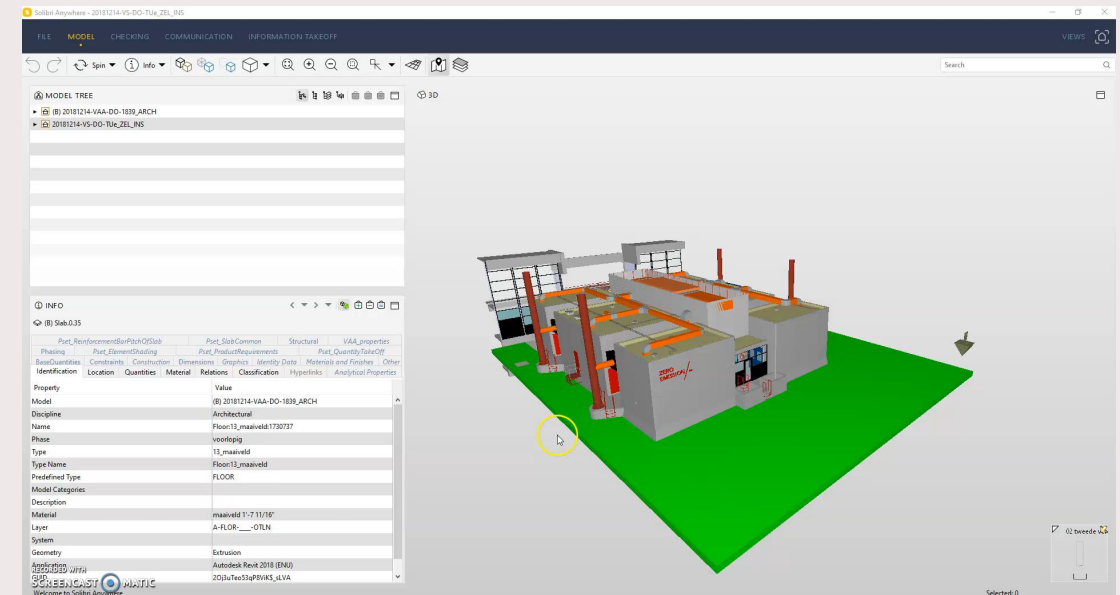


Content from [tue-lighthouse.nl](https://tue-lighthouse.nl)

# Object-Oriented Modelling of Buildings

An **information system** represents information about **objects** (entities) that occur in the **UoD (Universe of Discourse)** associated with its application domain.

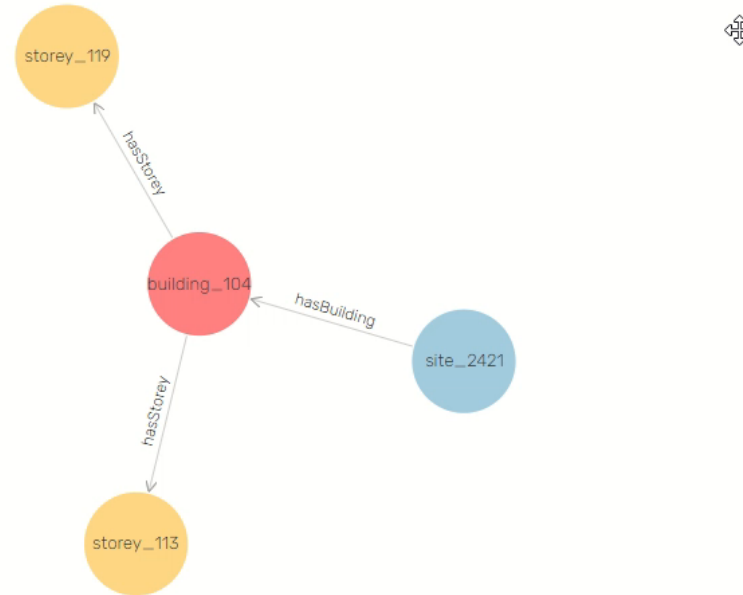
- **Objects** are **physical (tangible) or conceptual (intangible) things** in the real world.
- Objects have **properties** (attribute and value)
- **Links** define the connections between objects
- Objects are identified by **a unique identity**



# Visual graph ?



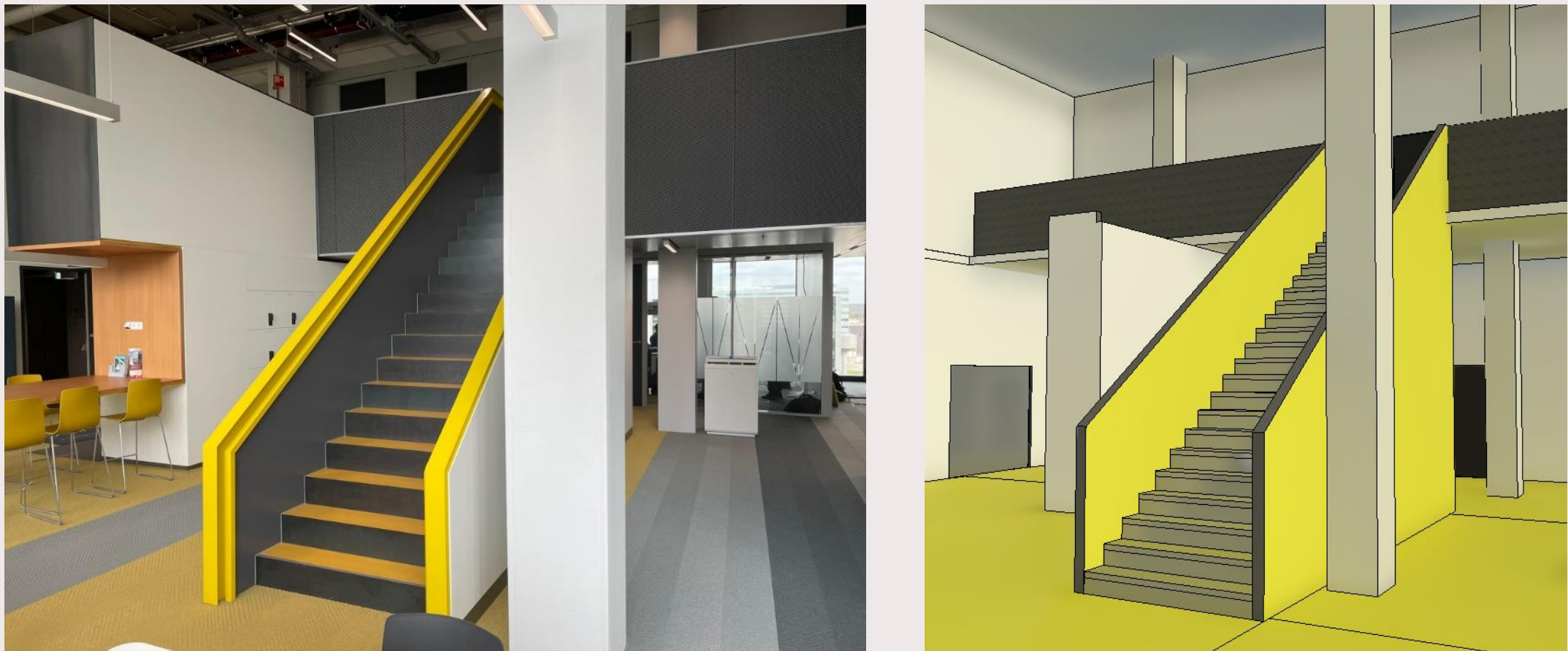
- Import
- Explore
- Graphs overview
- Class hierarchy
- Class relationships
- Visual graph**
- Similarity
- SPARQL
- Monitor
- Setup
- Help



OntoText graphDB interface showing the Atlas Digital Twin data at TU Eindhoven

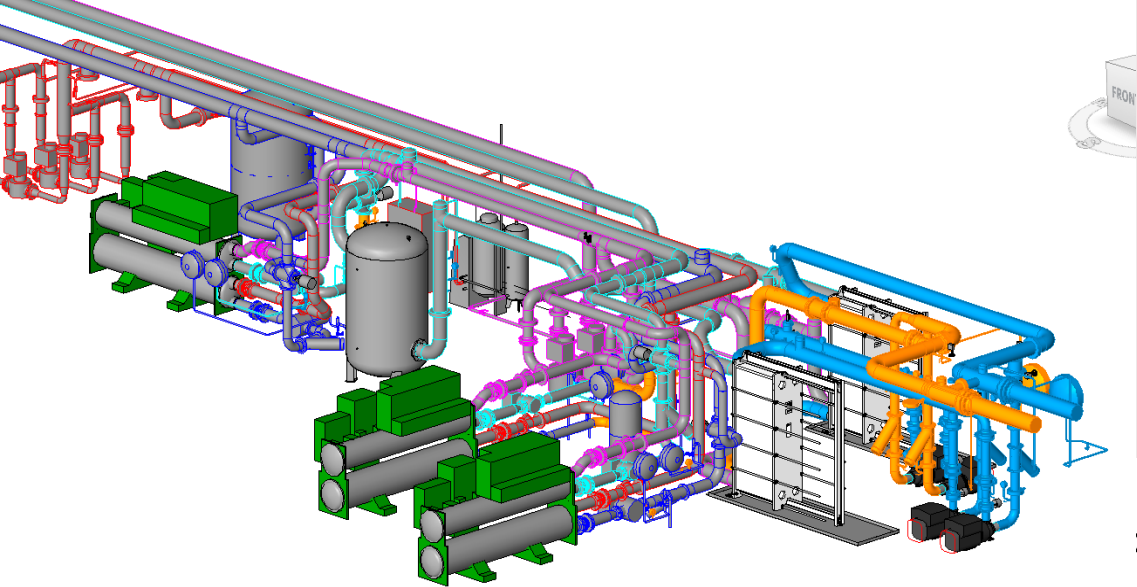
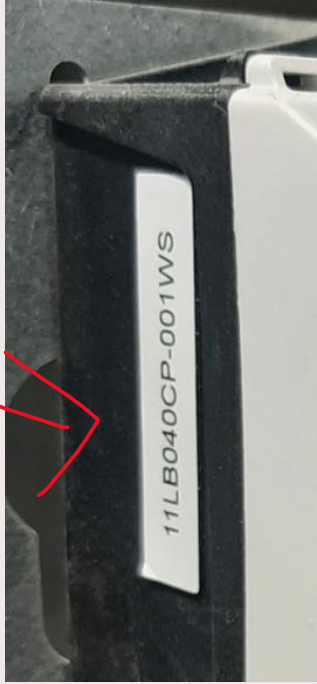
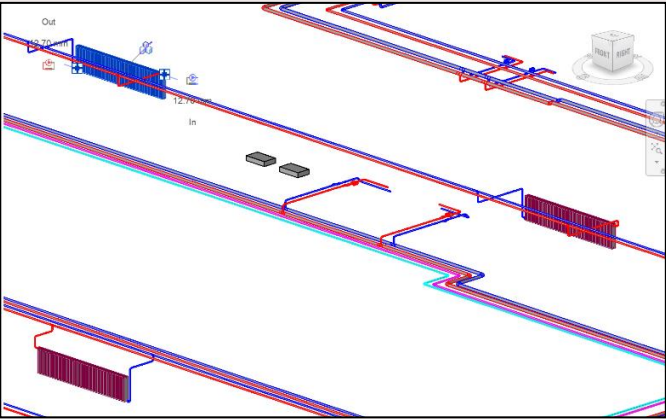


# Making building data available for a machine

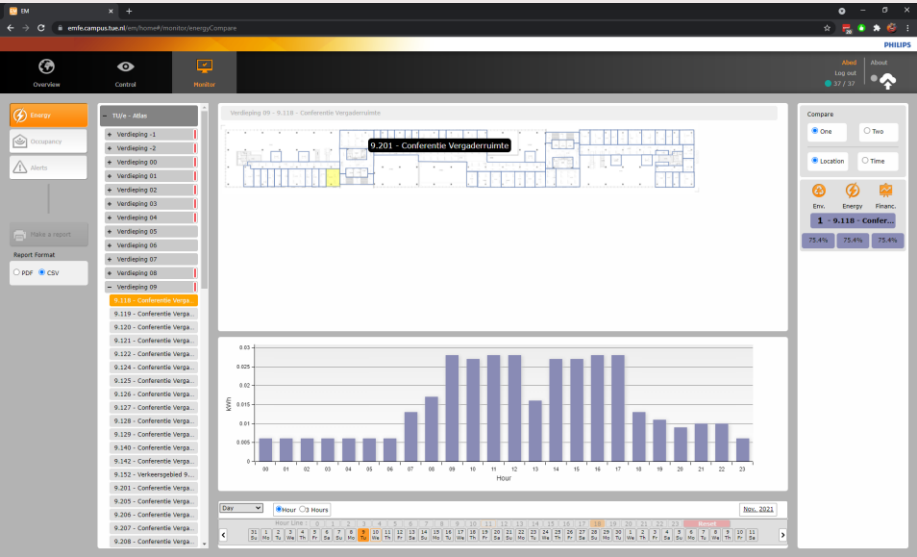


Left Atlas building interior at Tue; right the digital twin modelled as part of:  
A. de Barros Lima, A web-based application to integrate building management system sensor data and building information model data to support facility management tasks. MSc thesis. TU Eindhoven, 2020.

# Modelling of Systems in the BIM model

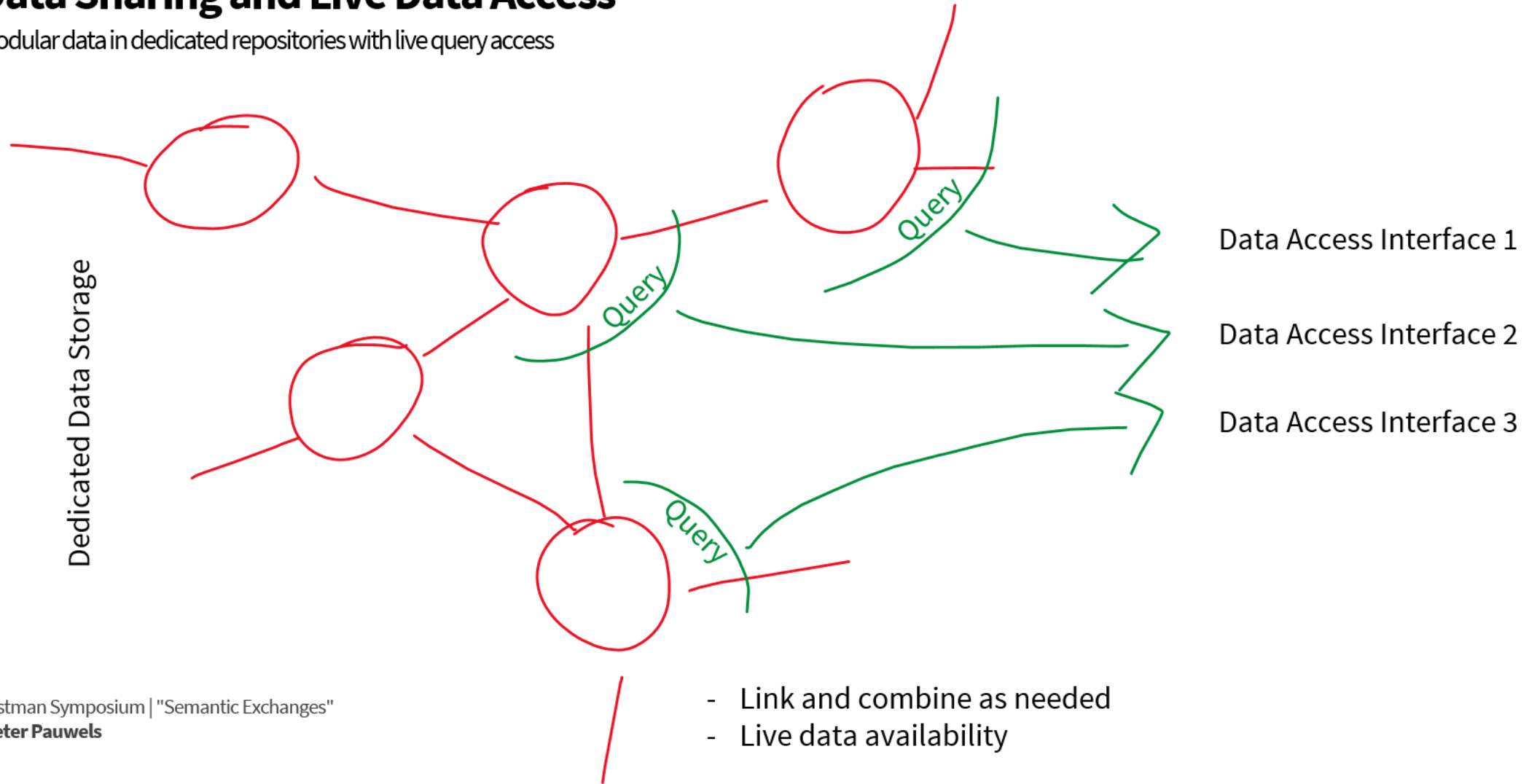


otico



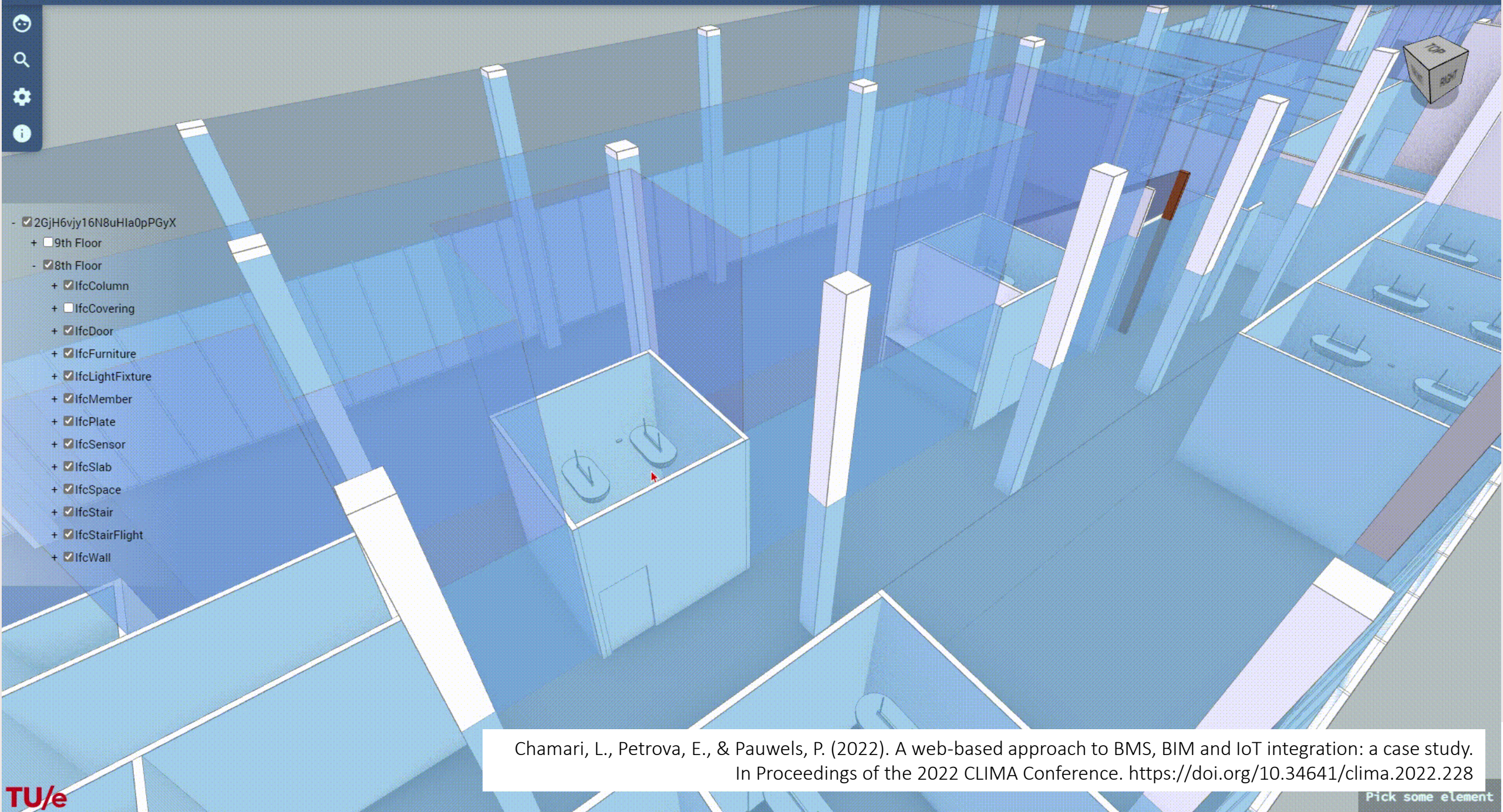
# Data Sharing and Live Data Access

Modular data in dedicated repositories with live query access



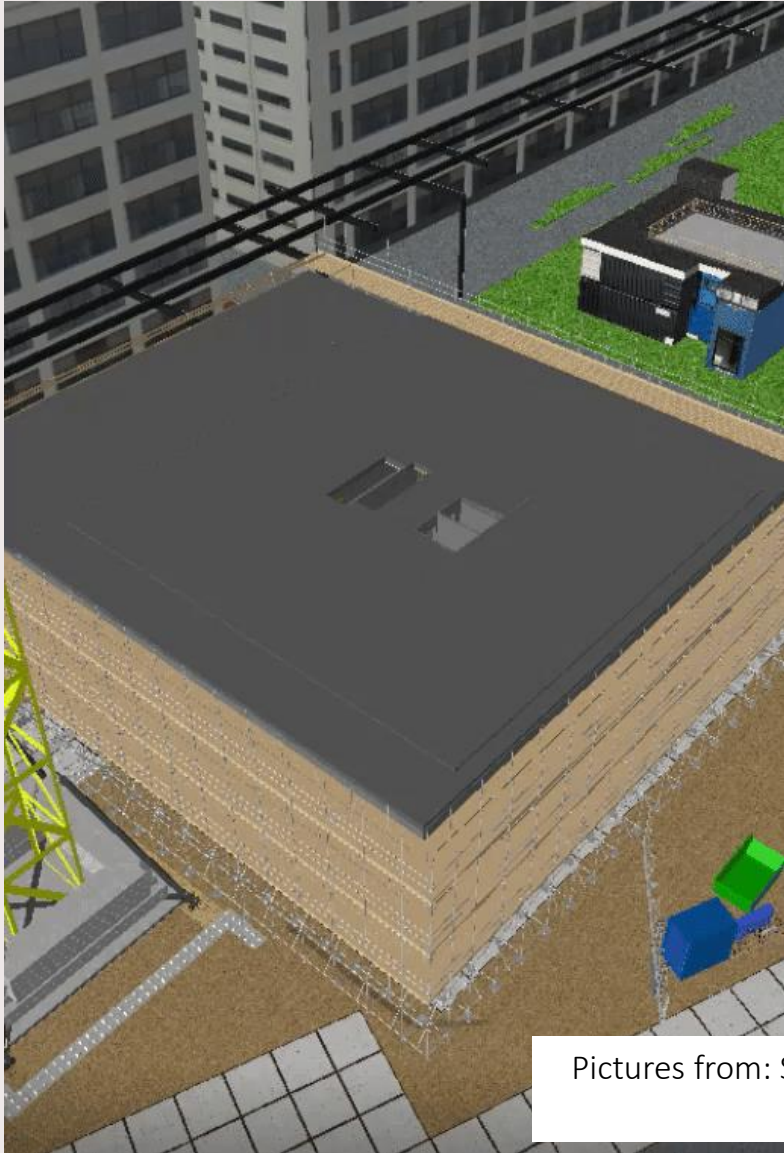


- 2GjH6vjy16N8uH1a0pPGyX
- +  9th Floor
- 8th Floor
- +  IfcColumn
- +  IfcCovering
- +  IfcDoor
- +  IfcFurniture
- +  IfcLightFixture
- +  IfcMember
- +  IfcPlate
- +  IfcSensor
- +  IfcSlab
- +  IfcSpace
- +  IfcStair
- +  IfcStairFlight
- +  IfcWall



Chamari, L., Petrova, E., & Pauwels, P. (2022). A web-based approach to BMS, BIM and IoT integration: a case study. In Proceedings of the 2022 CLIMA Conference. <https://doi.org/10.34641/clima.2022.228>

Part 2:  
Robotics in the Construction Phase



Pictures from: Selahattin Dülger, Using point cloud to automatically update the BIM 4D-model, MSc Thesis, ISBE TU Eindhoven, 2020. Strijp-S construction site, Stam + De Koning



# Suppliers

Industrialized Mass-Customization of Renovation Concepts by means of Construction 4.0

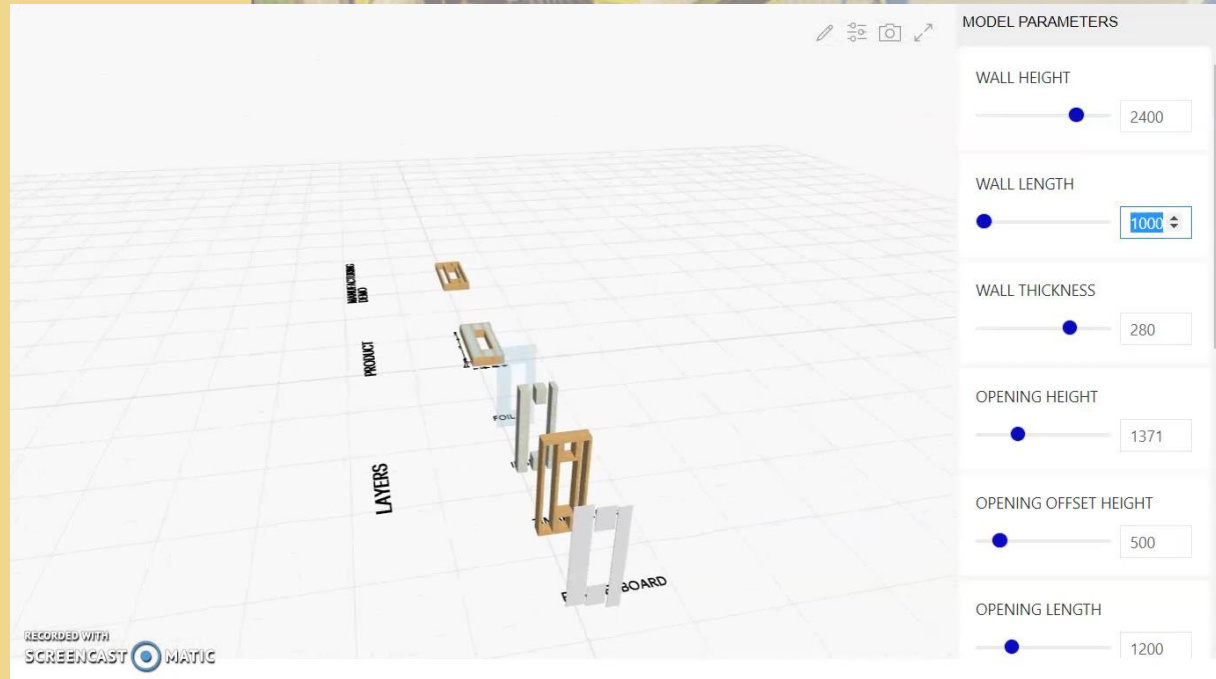


Wouter van Groesen, Industrialized Renovations: Towards Mass-Customization in the Construction Industry, EngD Thesis, Dept. of the Built Environment, TU Eindhoven, 2022.



# Suppliers

Industrialized Mass-Customization of Renovation Concepts by means of Construction 4.0



Wouter van Groesen, Industrialized Renovations: Towards Mass-Customization in the Construction Industry, EngD Thesis, Dept. of the Built Environment, TU Eindhoven, 2022.



# Robot navigation inside buildings

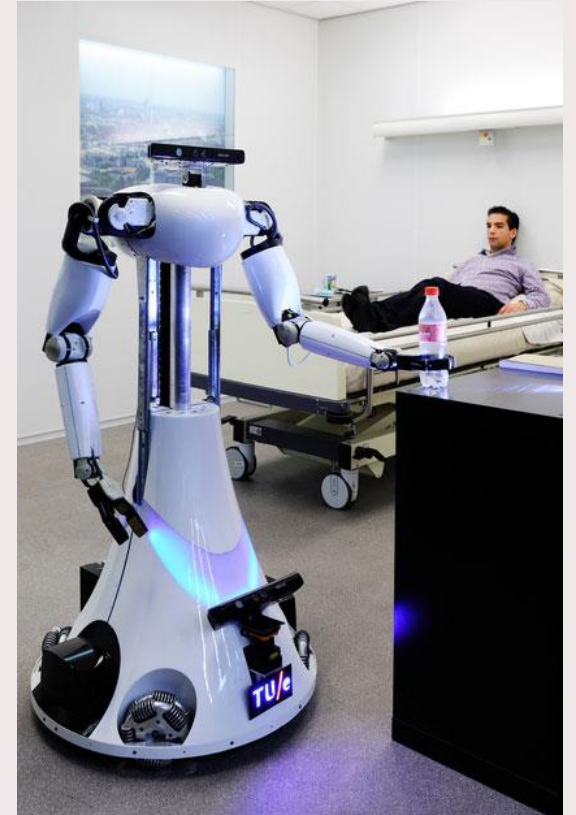
**Autonomous mobile robots** are starting to be deployed in complex built environments where they need to **navigate to complete the given tasks**.

- Routing for last mile delivery (e.g. package delivery, hospital navigation)
- Emergency navigation and evacuation (e.g. fire)
- Navigation in risky environments (e.g. risk for diseases)
- Tasks in places that are difficult to reach (e.g. maintenance and inspection)

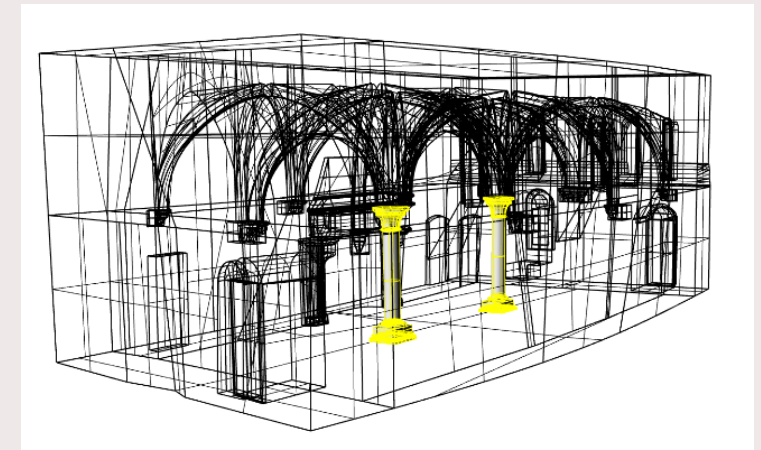
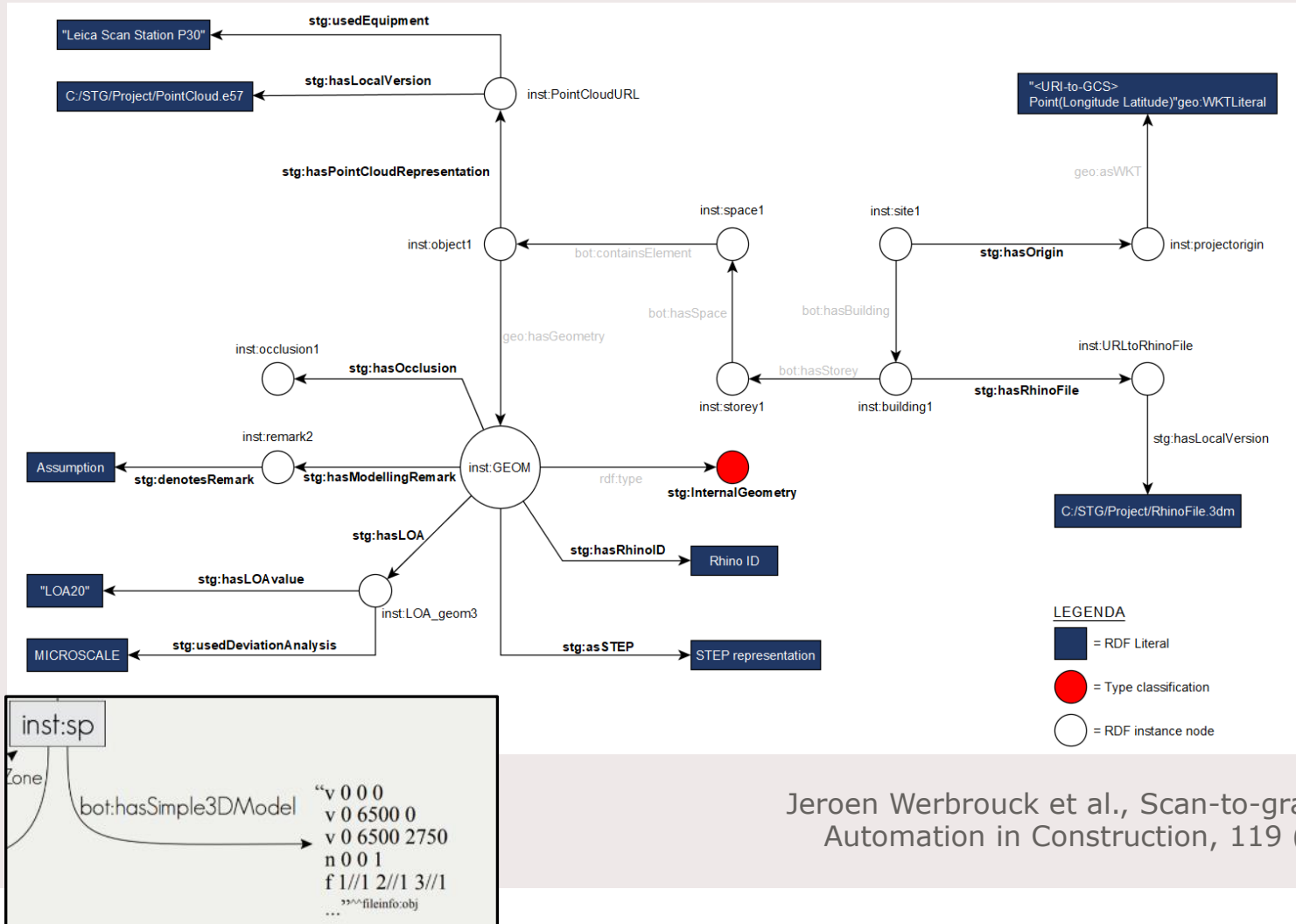
Autonomous mobile robots rely on **environmental maps** to do their navigation tasks:

- Topological map
- Metric map

Hendrikx, B., Pauwels, P., Torta, E., van de Molengraft, M. J. G. R. & Bruyninckx, H. P. J. (2021). Connecting Semantic Building Information Models and Robotics: An application to 2D LiDAR-based localization. In: IEEE International Conference on Robotics and Automation (ICRA).



# Linked Building Data including point cloud data and geometry

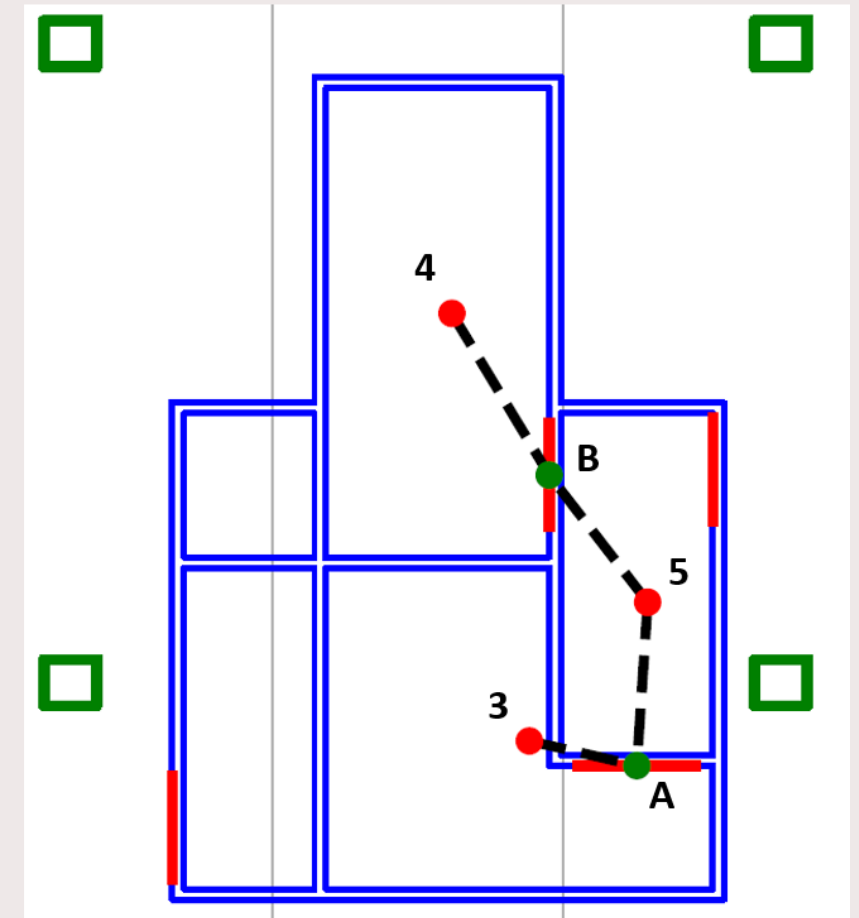


Jeroen Werbrouck et al., Scan-to-graph: Semantic enrichment of existing building geometry, Automation in Construction, 119 (2020). <https://doi.org/10.1016/j.autcon.2020.103286>.

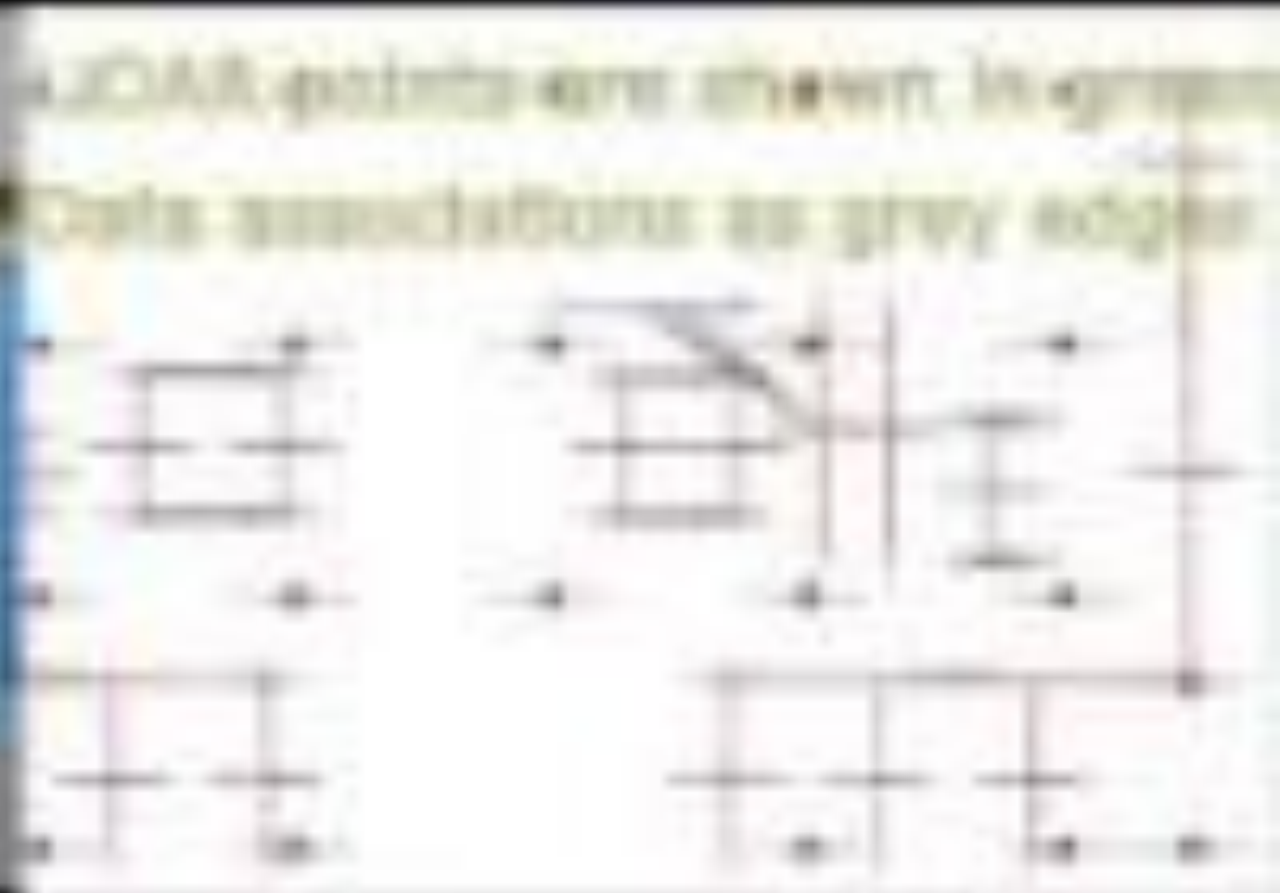
# The purpose of environmental maps

Robots use **environmental maps** for:

1. **Localization**: the process of determining where a mobile robot is located with respect to its environment
2. **Path planning**: to find a path from the current position to the target position.
3. **Reactive navigation**: controlling an autonomous mobile robot, which suggests making all control decisions through some light processing of the current/recent sensor data.



de Koning, R., Torta, E., Pauwels, P., Hendriks, R. W. M., & van de Molengraft, M. J. G. (2021). Queries on Semantic Building Digital Twins for Robot Navigation. In 9th Linked Data in Architecture and Construction Workshop (pp. 32-42). CEUR Workshop Proceedings; Vol. 3081. CEUR-WS.org. <http://ceur-ws.org/Vol-3081/03paper.pdf>



# Thank you

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Eindhoven University of Technology

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