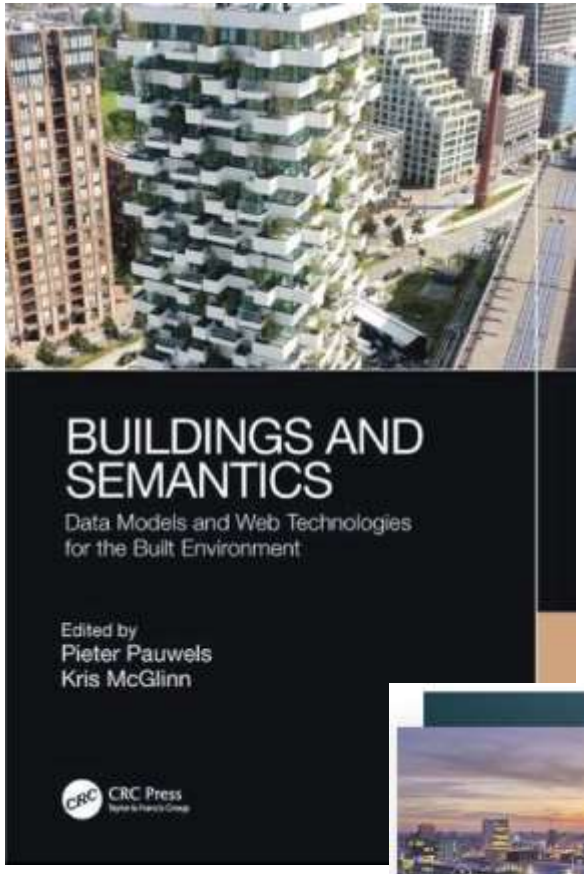
1+1=3 – Decentralizing data and systems for a better built environment – Right??

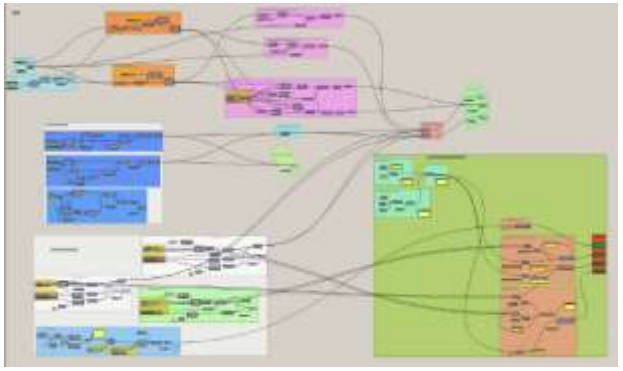
25 JUNE 2024 - SYMPOSIUM WOI & TU/E: DATAGEDREVEN SLIMME GEBOUWDE OMGEVING

Pieter Pauwels, Associate Professor

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

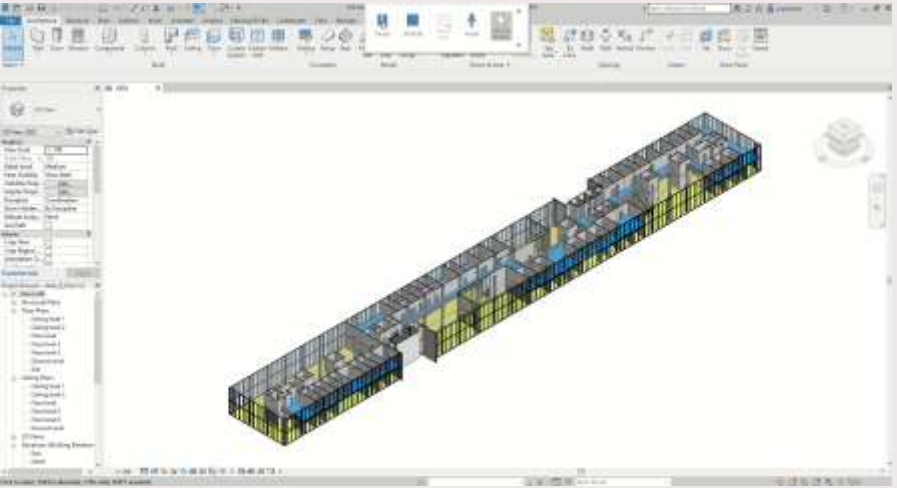
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

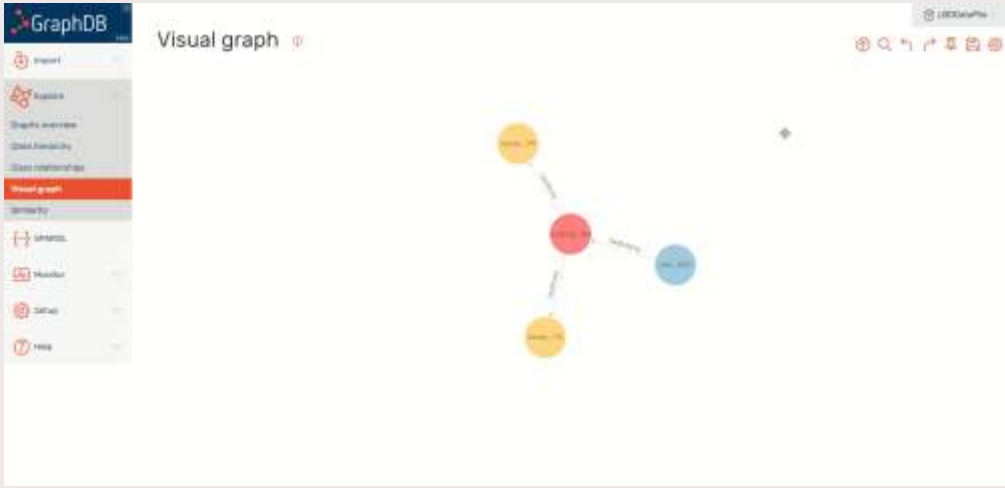




BUILDING DATA

Linked Building Data and moving building data to the web using graph databases





Building Information Modelling (BIM)

Graph Databases

Research projects

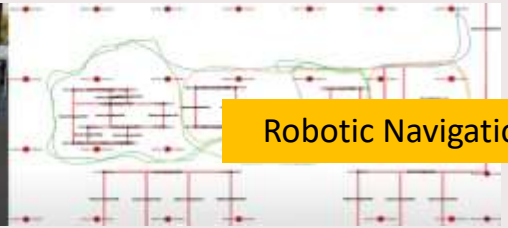
Smart Buildings

N - Distributed data modelling and Federated Digital ...ining for lifecycle data-driven sustainable operation and management of buildings and districts (2024-2028)

Brains4Buildings' Energy Systems project (2021-2025)

UPSCALE - Cross-linking, Tracing and Reusing Construction and Demolition Waste across Circular Supply Networks in Construction (2024-2029)

Circularity



Robotic Navigation

Cooperative Mobile Robots - EuroTech PhD Project (2024-2028)

Modular Prefabricated Construction: a circular asset management system for closed-loop supply and logistics chains – TKI Dinalog Project (2024-2028)

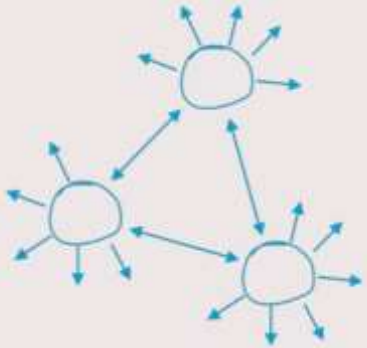
Decentralizing Building Data

Democratizing Building Data

Making Building Data available over the Web

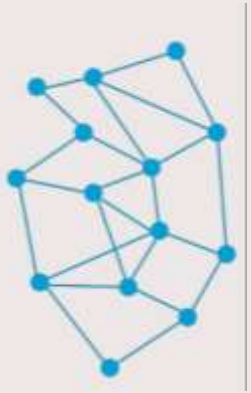
The big … decentralization of data and systems!!

Centralized



- Central authority
- Data outdated
- Data inaccessible

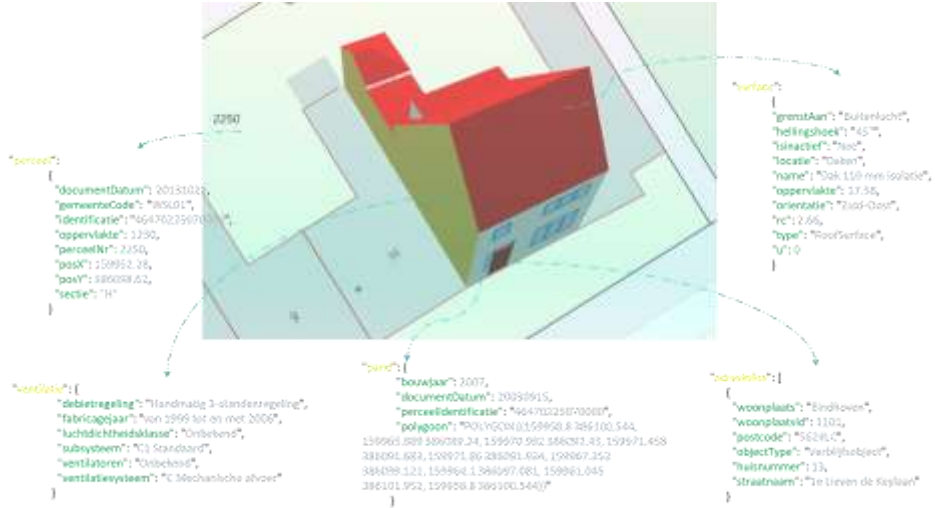
Decentralized

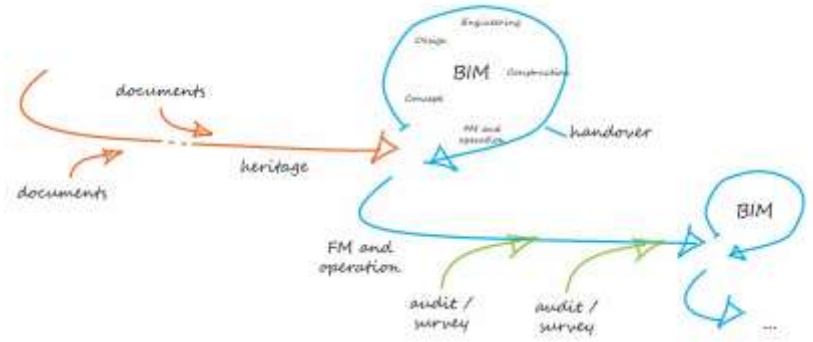


- Data with owner
- Versioning and updating
- Granular access

- Plenty of advantages!!

Every building is a data hub with many interconnections that change over time



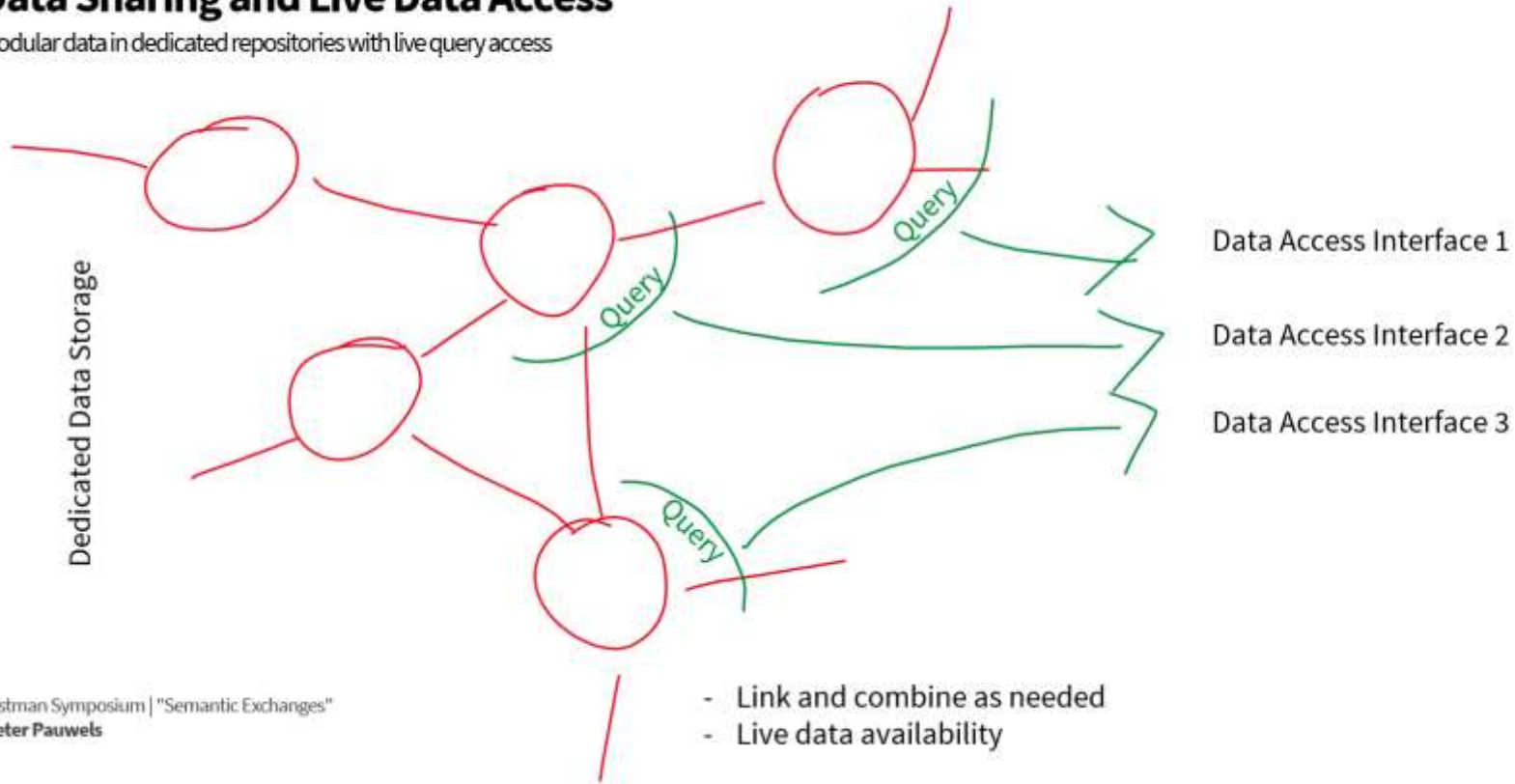


Kafaei, M. (2022). Design and development of a data platform for managing the residential buildings' physical and geospatial information required for large-scale renovations. Technische Universiteit Eindhoven. https://research.tue.nl/en/publications/design-and-development-of-a-data-platform-for-managing-the-reside

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

Data Sharing and Live Data Access

Modular data in dedicated repositories with live query access



- Link and combine as needed
- Live data availability

Smart Buildings

https://brains4buildings.org/

Data sources to integrate

- Plenty of **semantic data** models (RDF/OWL) allowing semantic inference:
  - » LBD: BOT, BEO, MEP, FOG, BPO, BRICK, HTO, IFC, SSN, SOSA, …
  - » Modular approach of smaller scale specialized semantic models in graphDBs
  - » Rules, queries, and inference readily available (declarative coding)
- **Tabular and/or timeseries data** allowing list-oriented and statistic machine learning (pattern recognition, fault detection, etc.)
  - » Plenty of data wrangling => ML
- **Specialised** 2D and 3D data, images, point clouds and documents
  - » Specialised algorithms (procedural coding): 3D computations and analysis, NLP, image recognition, visual data analysis, etc.

Pauwels, P., & Fierro, G. (2022). A Reference Architecture for Data-Driven Smart Buildings Using Brick and LBD Ontologies. In Proceedings of the REHVA 14th HVAC World Congress (CLIMA 2022) https://doi.org/10.34641/clima.2022.425

Semantic graph of sensors

See presentation Lasitha Chamari on Wednesday 25 May 2022.

```
@prefix brick: <https://brickschema.org/schema/Brick#> .
@prefix inst: <http://linkedbuildingdata.net/ifc/resources20201208_005325/> .
@prefix ph: <https://project-haystack.org/def/ph/3.9.11#> .
@prefix phIoT: <https://project-haystack.org/def/phIoT/3.9.11#> .
@prefix phScience: <https://project-haystack.org/def/phScience/3.9.11#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .

inst:11NR008LT-001PIRTM a brick:Occupancy_Sensor,
        phIoT:sensor ;
    rdfs:label "PRESENCE_8_128"^^xsd:string ;
    brick:hasLocation inst:space_892 ;
    ph:dis "PRESENCE_8_128"^^xsd:string ;
    ph:hasTag phIoT:his,
        phIoT:occupancy ;
    phIoT:spaceRef inst:space_892 .

inst:11NR008LT-003PIRTM a brick:Occupancy_Sensor,
        phIoT:sensor ;
    rdfs:label "PRESENCE_8_127"^^xsd:string ;
    brick:hasLocation inst:space_1023 ;
    ph:dis "PRESENCE_8_127"^^xsd:string ;
    ph:hasTag phIoT:his,
        phIoT:occupancy ;
    phIoT:spaceRef inst:space_1023 .
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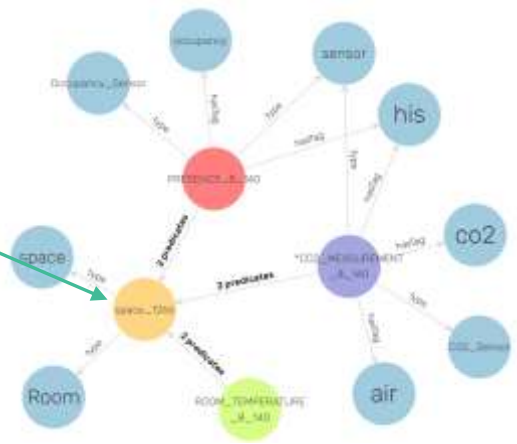
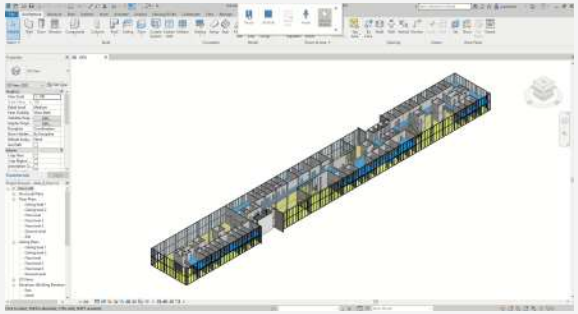


Server-based Digital Twinning

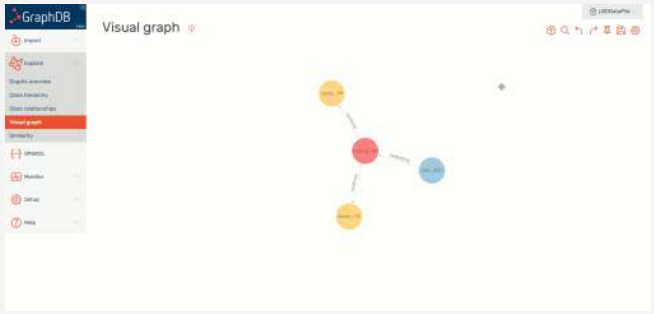
1. Three types of information: geometry, semantics, dynamic data streams
2. Dedicated storage desired
3. Well-organized server-based storage

SERVER-BASED DT

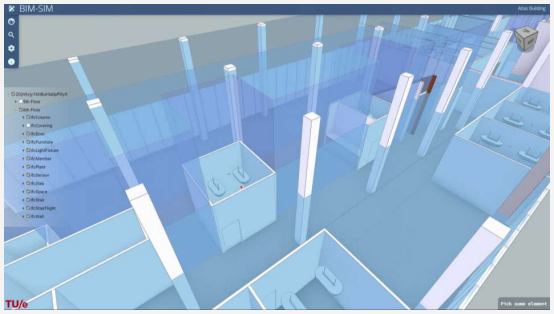
GEOMETRY

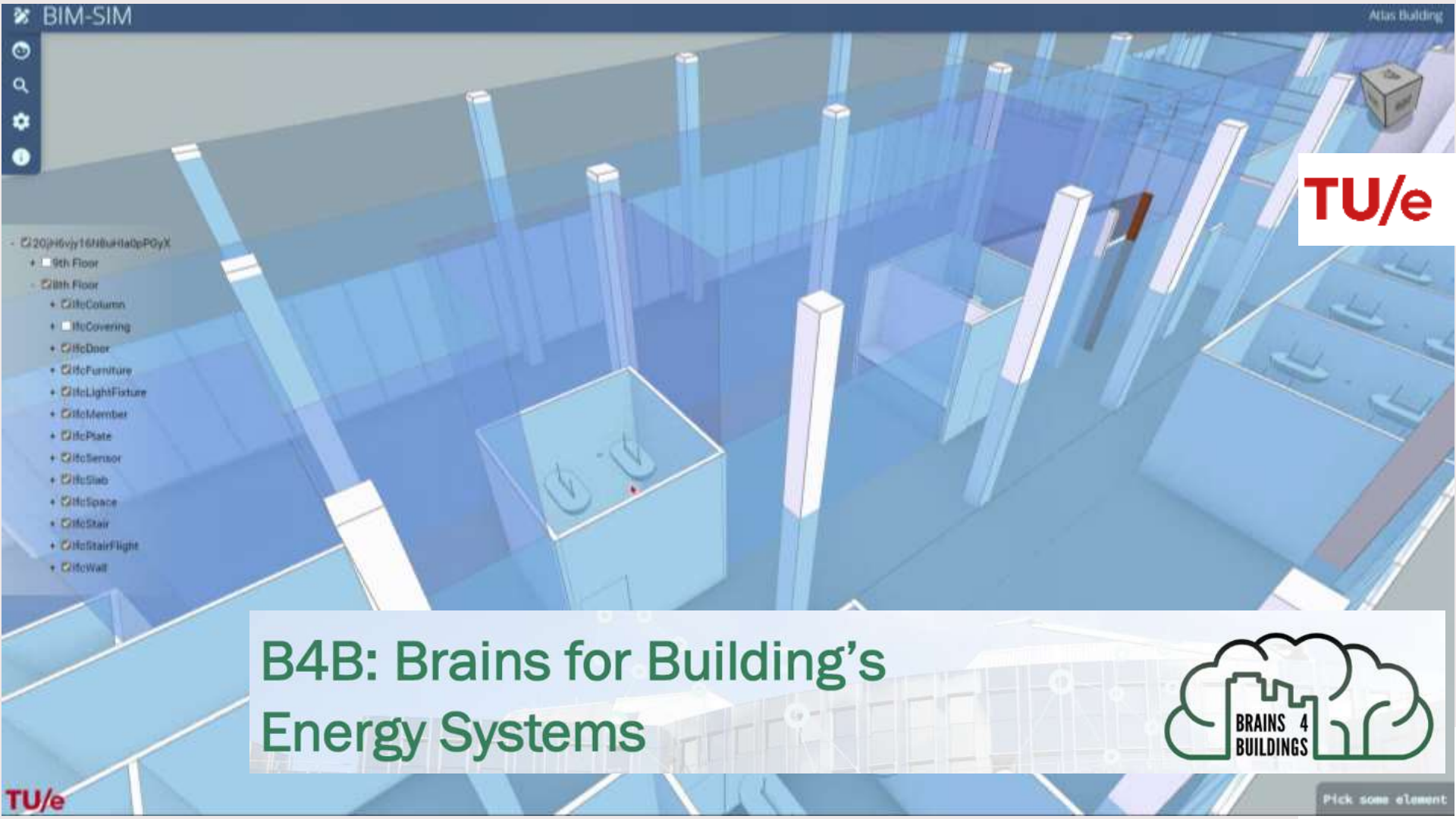


SEMANTICS



IoT DATA STREAMS




BIM-SIM
Atlas Building
TU/e
9th Floor
8th Floor
IfcColumn
IfcCovering
IfcDoor
IfcFurniture
IfcLightFixture
IfcMember
IfcPlate
IfcSensor
IfcSlab
IfcSpace
IfcStair
IfcStairFlight
IfcWall
B4B: Brains for Building's Energy Systems
BRAINS 4 BUILDINGS
TU/e
Pick some element

Digital Twinning of TUe Campus Buildings

EAISI EINDHOVEN AI SYSTEMS INSTITUTE

TU/e

TU/E CAMPUS DIGITAL TWIN FOR SMART BUILDING MANAGEMENT AND CONTROL

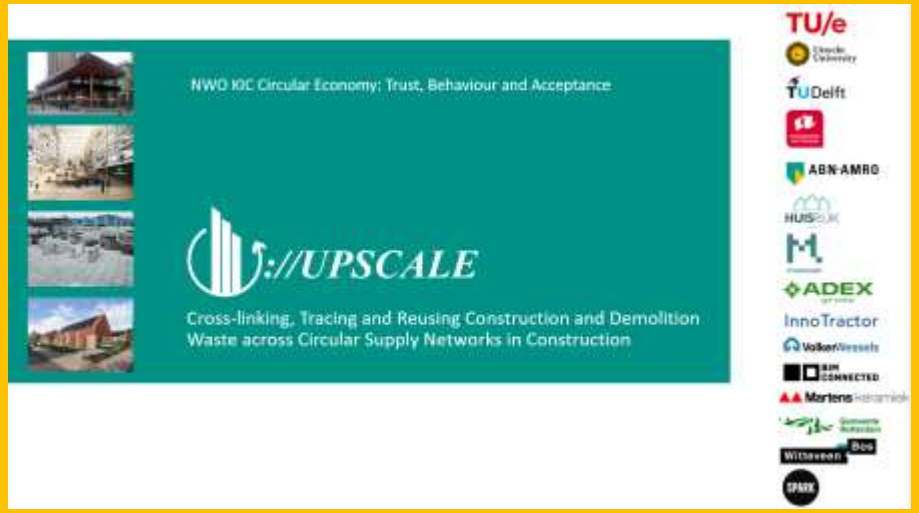
Pieter Pauwels (BE), Elena Torta (ME), Gamze Dane (BE), Sonja Rijlaarsdam (RE), Thijs Meulen (RE), and Annemieke Pelt (ME)

- Build a Digital Twin system for the Atlas and Gemini buildings (Zero Emission Lab, Gemini building)
- Smart management of facilities through on-site anomaly detection and device monitoring
- Unsupervised robot navigation through semantic (model-driven) path detection and real-time data analysis (data-driven)
- Developing a 3D campus information system for digital accessibility of campus facilities and services in buildings and open spaces

Under Development

https://www.tue.nl/en/research/institutes/eindhoven-artificial-intelligence-systems-institute/digital-twin-lab

Circular Material Reuse



https://upscaleproject.nl/

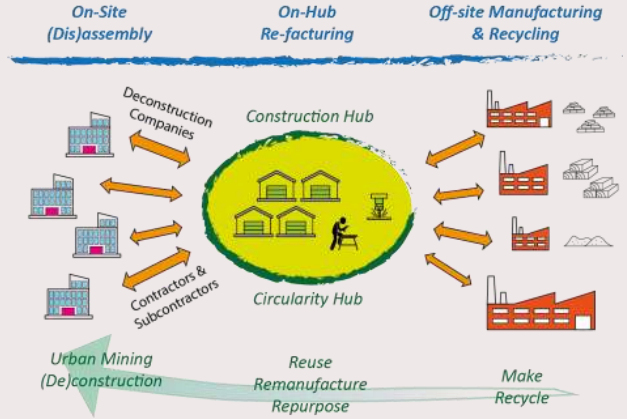
Bouwhubs in Nederland

https://www.bouwhub.amsterdam/

https://topsectorlogistiek.nl/wp-content/uploads/2022/07/Stills_Bouwhub04-800x450-1.jpeg

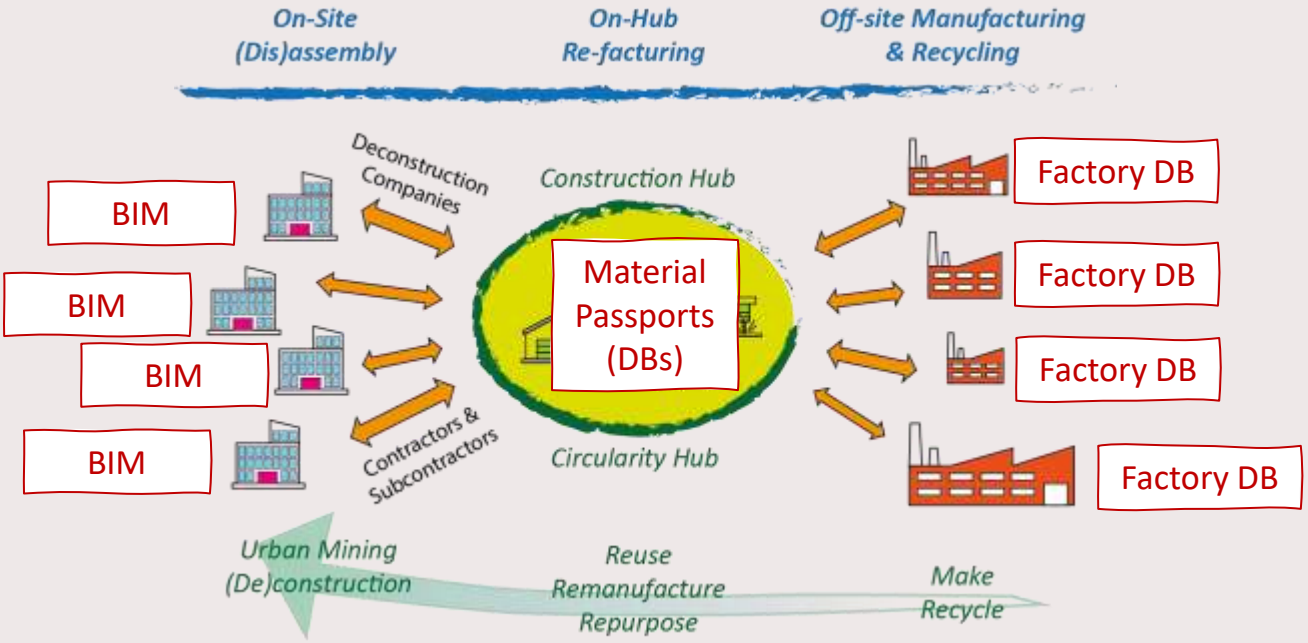
Realisatie in de praktijk

De circulaire bouwhub Amsterdam van ADEX group (voorheen Beelen Next)



afbeelding van Bouwcirculair, Landelijk netwerk van Circulaire BouwHubs, https://bouwcirculair.nl/nieuws/2021-2-23-landelijk-netwerk-van-circulaire-bouwhubs-lees-verder/

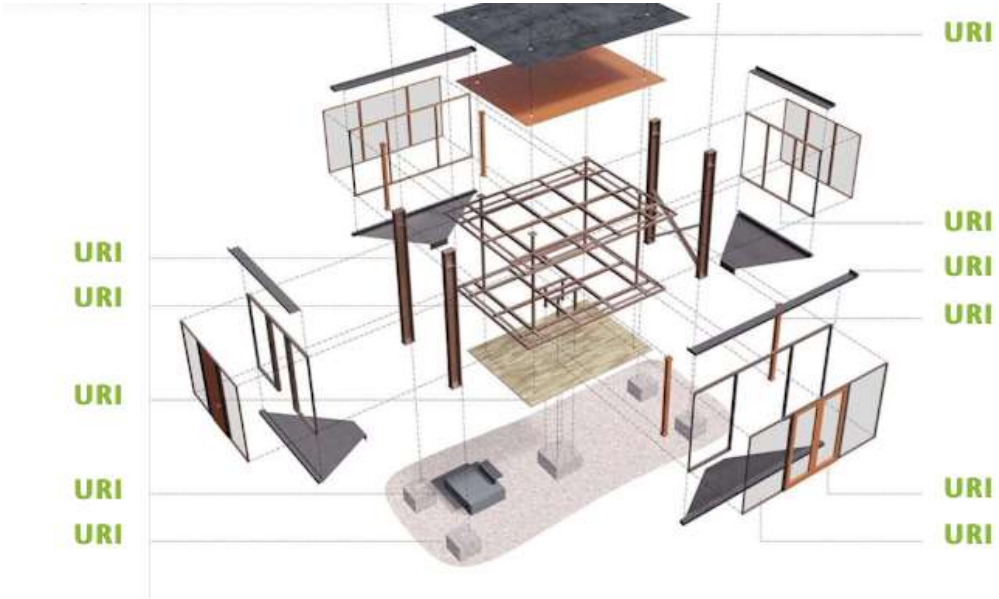
Circulariteit in de bouwhubs: veel meer nadruk op linkerzijde van keten



P. Pauwels (2023). De route naar circulaire ketens: impact op de installatiesector. TVVL Magazine, in press.

- Meer nadruk en vergroting van materiaalstromen en informatiestromen van gebouwen naar hubs.
- Minder gebruik van off-site productie- en recyclagefaciliteiten.
- De productiefaciliteiten op een bouwhub worden circulaire opwaarderingsfaciliteiten (pre-processing).
- Groot belang van digitale tracering van objecten:
  - Track-and-Trace models
  - Take back models

Every building is a data hub in a mesh of hubs



1.Every building element has its **authoritative Uinform Resource identifier (URI)**.
2.Data-follows-object principle for ownership and liability.
3.Layered and **versioned** information sharing.
4.Standardised information exchange (e.g. structure of ISO 19650).
5.Object-centric exchange instead of geometry-centric exchange.

UPSCALE research project
TKI Dinalog ModPrefabConstr research project

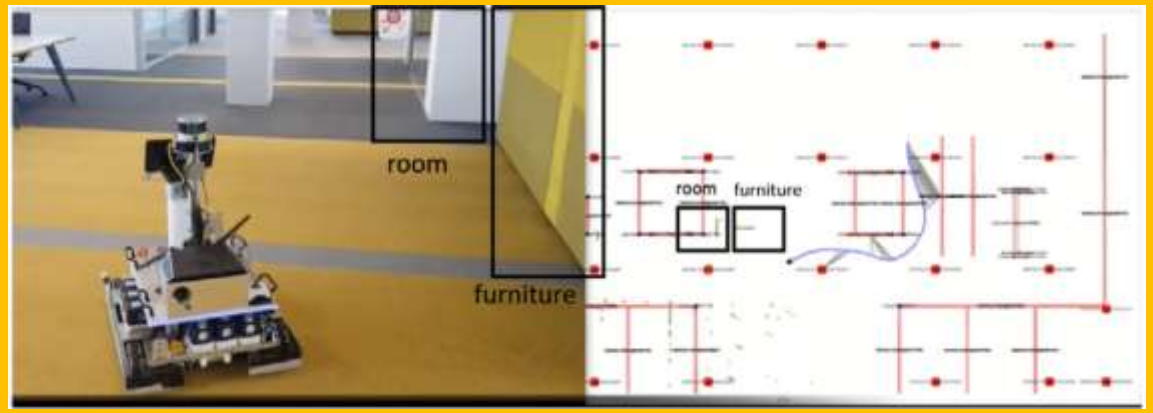
Circl demonstrator in Amsterdam

Circl. Toekomst van Circl: De volgende stap.
https://circl.nl/verdieping/toekomst-van-circl-de-volgendestap

Circulaire Flexbouw De Meeuw

afbeelding van De Meeuw, De Alliatie - Karmijn,
https://www.demeeuw.com/projecten/de-alliatie-karmijn/

Indoor Robotic Navigation



Data Sharing and Live Data Access

Outline

Show full outline

ELSEVIER

Advanced Engineering Informatics
Volume 56, April 2023, 101959

Full length article

Live semantic data from building digital twins for robot navigation: Overview of data transfer methods

Pieter Pauwels [a], Rens de Koning [b], Bob Hendrikx [b], Elena Torta [b]

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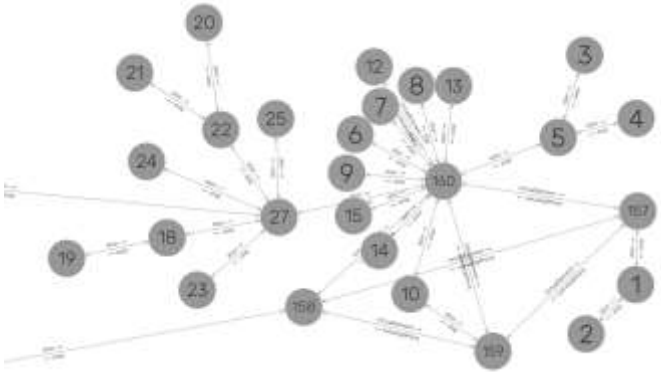
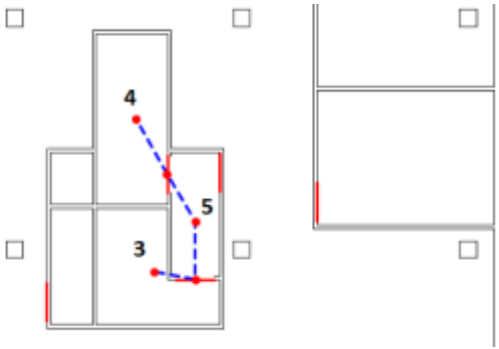
Pauwels, P., de Koning, R., Hendrikx, B., & Torta, E. (2023). Live semantic data from building digital twins for robot navigation: Overview of data transfer methods. Advanced Engineering Informatics, 56, [101959]. https://doi.org/10.1016/j.aei.2023.101959

Maps available from LBD Cloud

- A topological map abstracts metric information and represents, in a bidirectional undirected graph (unlike the RDF graphs), how spaces are connected to each other.
- A metric map includes all metric information needed for path planning



Topological map



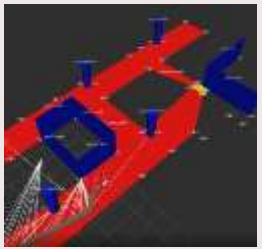
Metric map

de Koning, R., Torta, E., Pauwels, P., Hendrikx, 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

Investigation of an alternative method

SLAM

Manual creation



Digital Twin

Physical Twin

Semi-automatic DT-based creation

Third alternative

TU/e

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) (Accepted/In press).
https://www.youtube.com/watch?v=b7LKU3C6gCQ

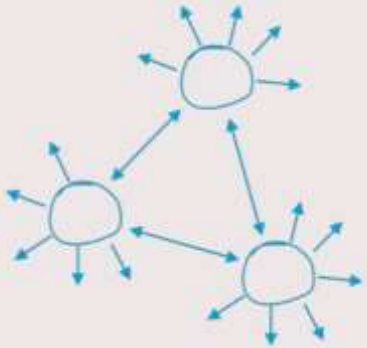
Context-aware robotics based on up-to-date Digital Twin data (BIM, geometry, telemetry)

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).

Decentralized Data and Systems

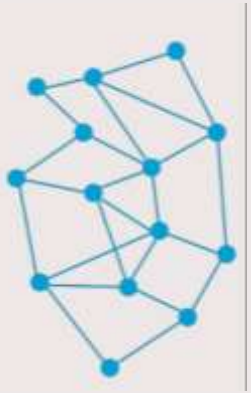
The big … decentralization of data and systems!!

Centralized



- Central authority
- Data outdated
- Data inaccessible

Decentralized



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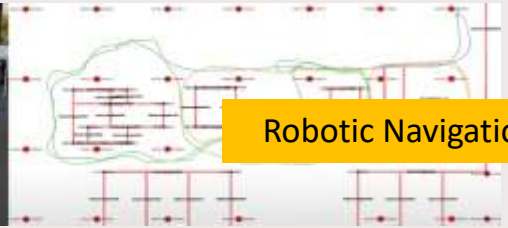

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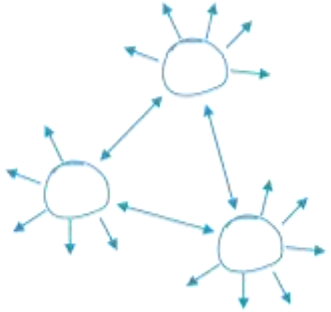
From Decentral Hubs to P2P Networks

1. Central Management
   - Who has data ownership?
   - Who pays the price?
   - Hard to scale in diverse communities
2. Decentral hubs
   - Achievable
   - Current trend and realisation
   - Dependency on shared use of infrastructure
   - Who has data ownership?
   - Who pays the price?
3. Peer-to-Peer (P2P) network
   - Not existing for the building sector
   - Scalable if done properly
   - Price and data ownership stays with the source
   - Infrastructure needed
   - How to manage this data mesh over time?

Central management

Decentral Hubs



P2P Network

The future?

Thank you

https://isbe.bwk.tue.nl/

Questions?

Pieter Pauwels - p.pauwels@tue.nl