Worshop – EduBIM 2021

Conférence d'ouverture – Présentation

Édité le
01/12/2021

Facilitating Digital Twins for the Built Environment with Linked Data

Jakob Beetz

La captation de cette conférence est disponible sur Culture Sciences de l'Ingénieur à partir du lien suivant : https://eduscol.education.fr/sti/si-ens-paris-saclay/ressources_pedagogiques/edubim-2021-facilitating-digital-twins-for-the-built-environment-with-linked-data

Facilitating Digital Twins for the Built Environment with Linked Data

eduBIM 2021, Paris, Dec. 1st

Jakob Beetz
RWTH Aachen University

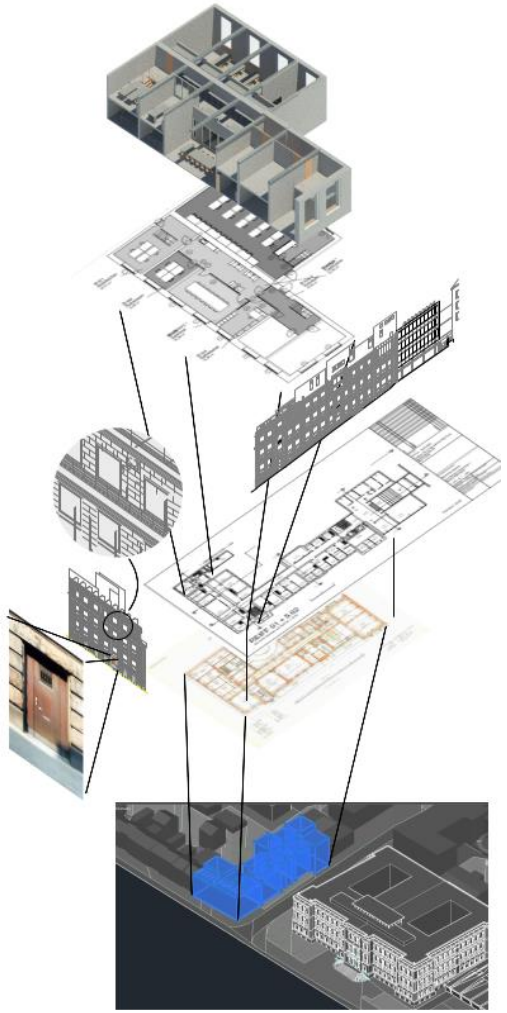
Design Computation | RWTH AACHEN UNIVERSITY

RWTH, Department of Architecture, DC Team

RWTH
- Since 1870
- 47.173 Students, 10k staff, 550 profs.
- “excellent”

Dept. of Architecture
- 1800 students, 22 chairs
- ~ 280 students BA per year
- MSc tracks: Architecture, Urban Planning, Construction Robotics, Transforming City Regions

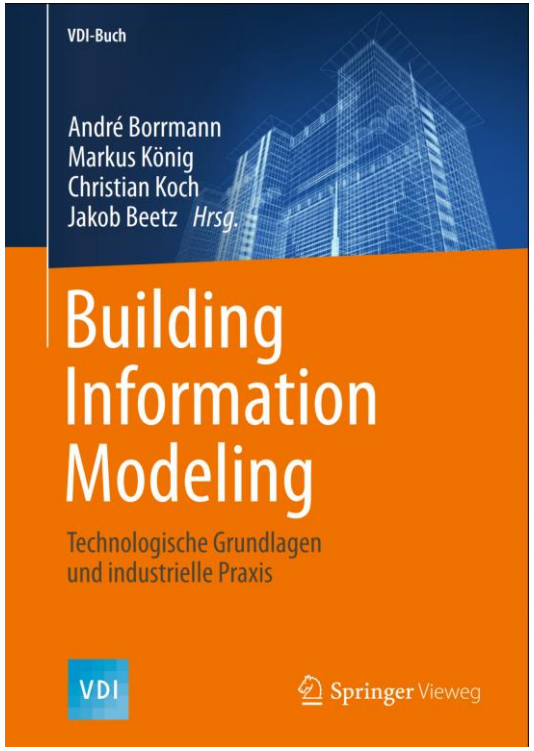
Design Compuation
- 1,5 permanent lecturer & research staff
- 4 researchers funded by projects
- 3 PhD students via scholarships (DAAD, CRC)
- 2 industry lecturers with 3 ECTS
- 4 ~ 7 student assistants

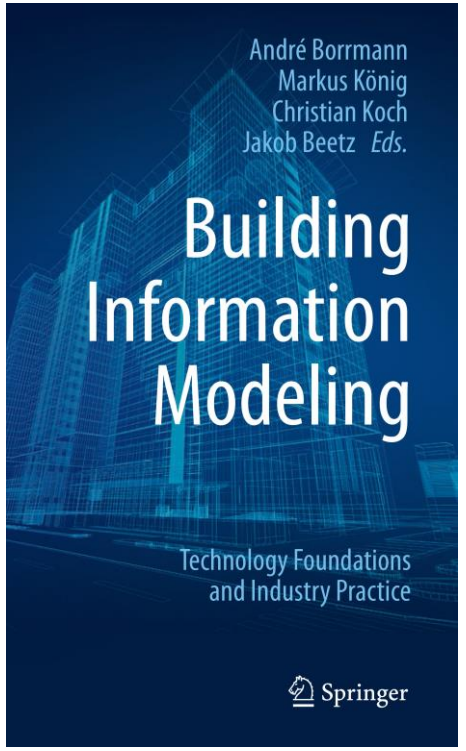


Design Computation

Prof. Dr. Jakob Beetz
chair

- > 15 years BIM in research, development and standardization, e.g. bimserver.org, ifcOWL
- EU-projects Inteligrid; DURRARK (Long term preservation BIM), BIM4Ren (BIM for existing buildings)
- DIN, CEN, ISO, bSI Technical Board, Board buildingSMART DACH
- CIB W78 Co-Chair. Board EG-ICE, ECPPM,
- Co-editor and -autor BIM books





Overview

The Challenges

- The Built Environment
- The Construction Sector

Digital Twin topics by example

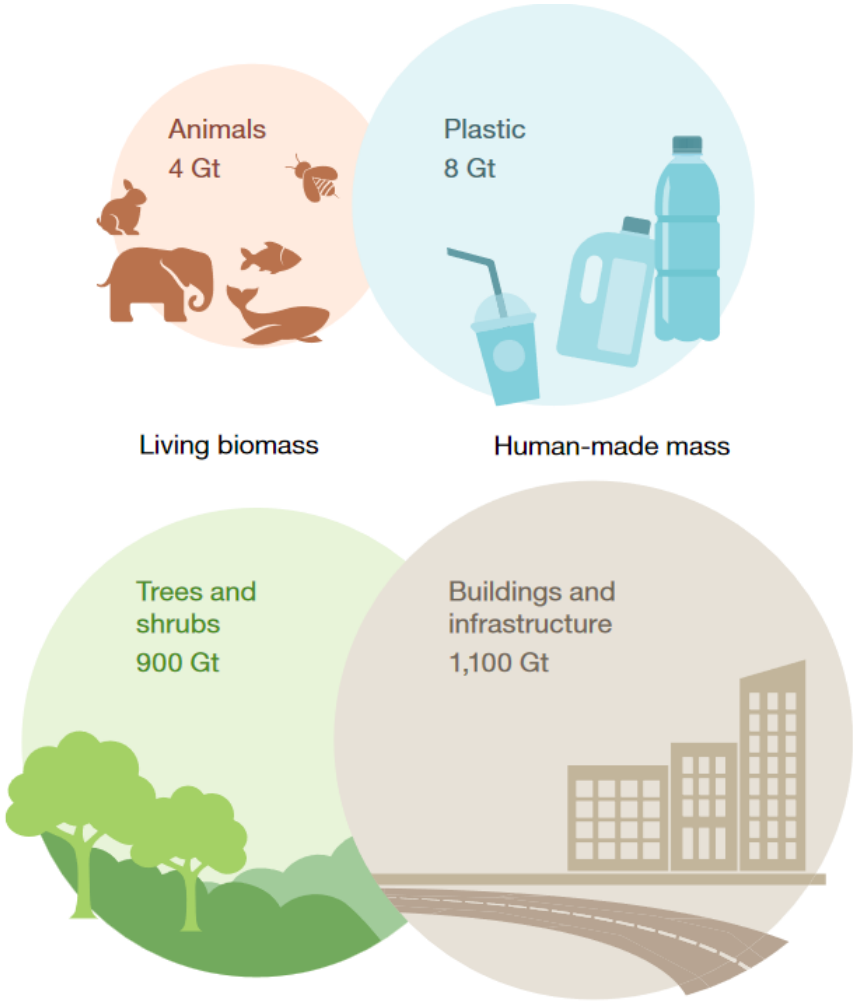
- Data Aquisition / Reality Capturing
- Micro: Sensors
- Meso: Bridges
- Macro: System of Systems: Road Networks

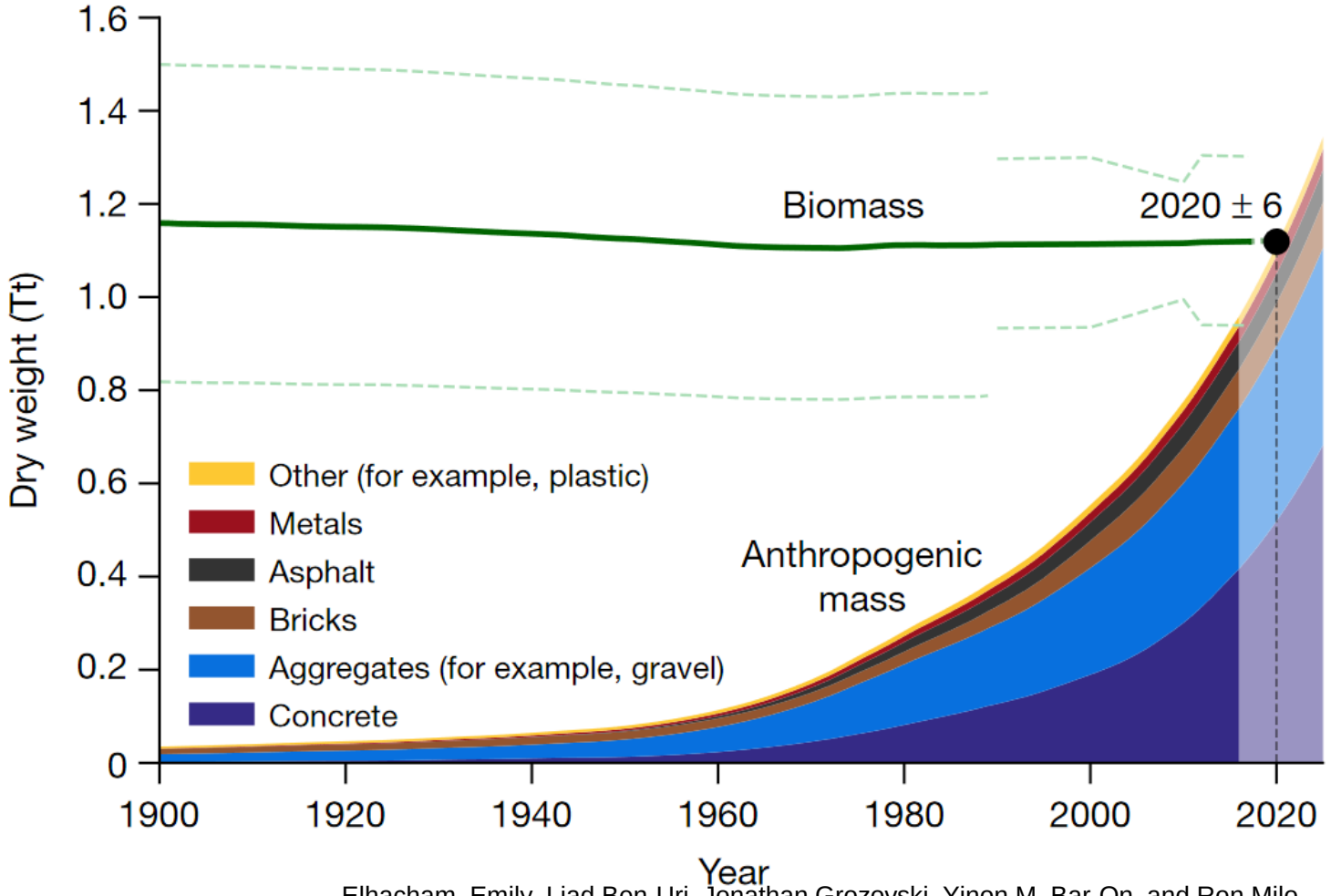
Academic Teaching

- Some tools
- IfcOpenShell-Jupyter-Notebooks

Some opinions & recommendations

The Built Envrionment : Scale and impact

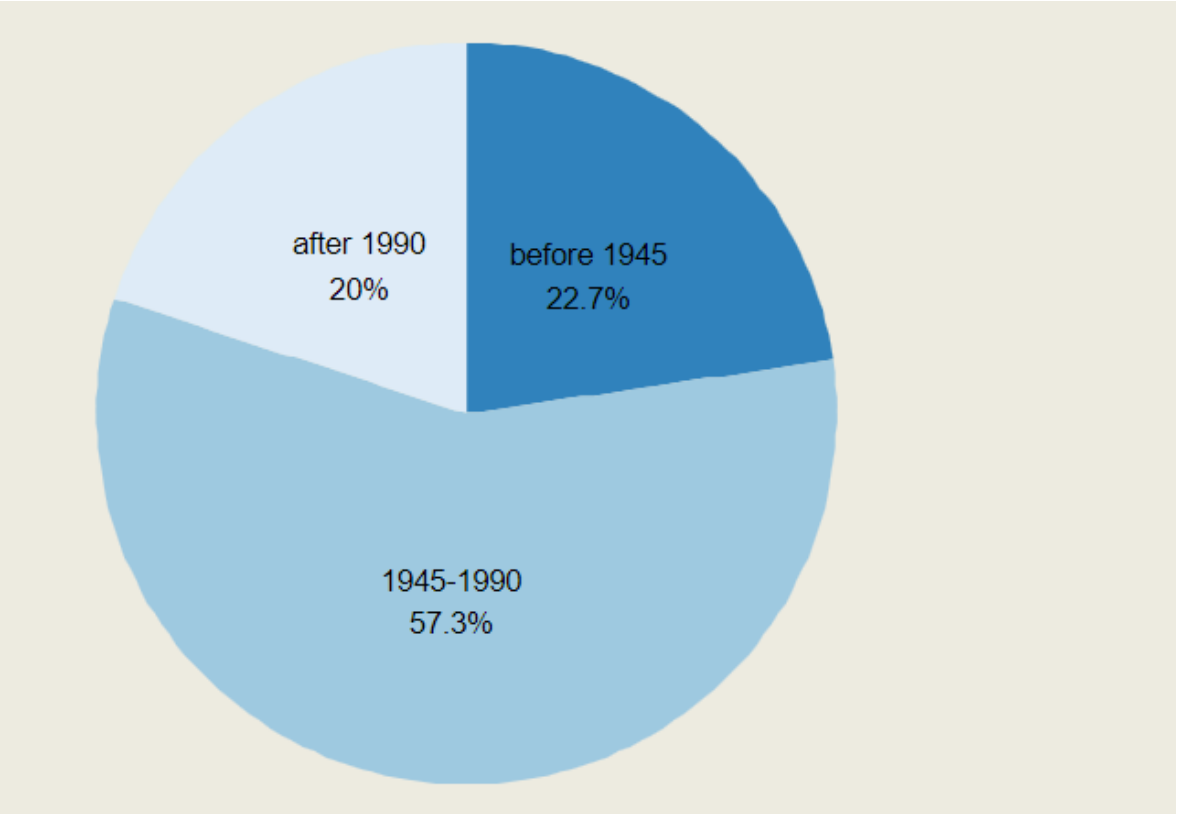




Elhacham, Emily, Liad Ben-Uri, Jonathan Grozovski, Yinon M. Bar-On, and Ron Milo. "Global Human-Made Mass Exceeds All Living Biomass." *Nature* 588, no. 7838 (December 2020): 442–44. https://doi.org/10.1038/s41586-020-3010-5.

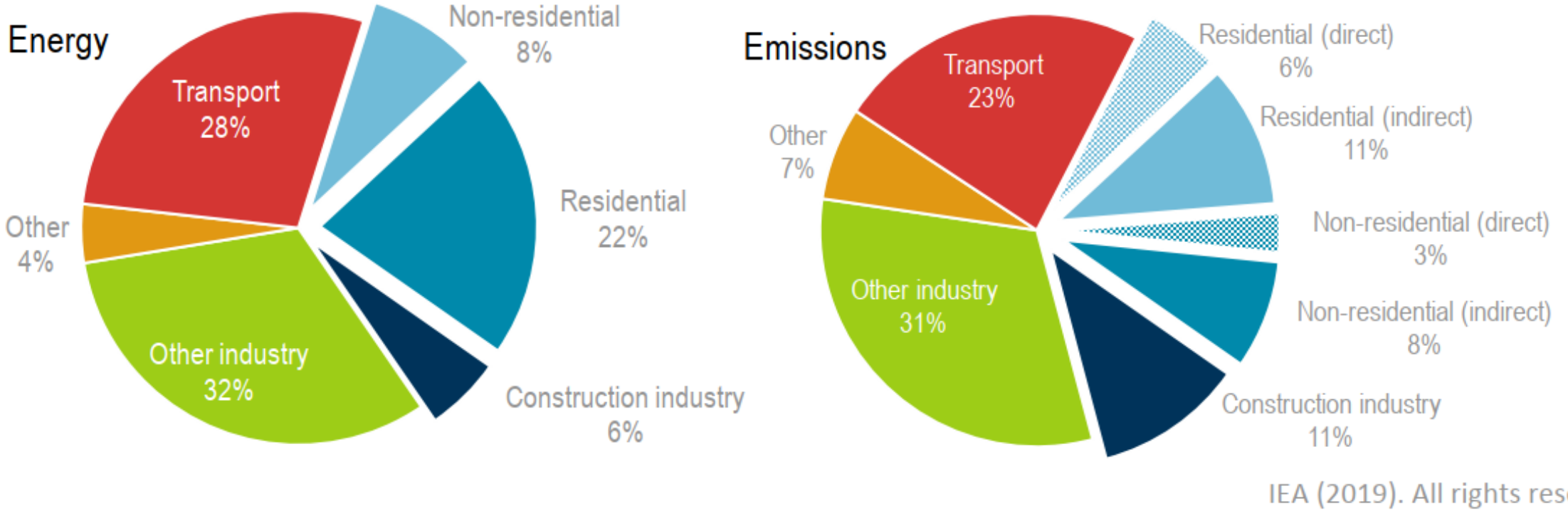
The Built Environment : State of the Products

- About 80% built before 1990



The Built Envrionment : Scale and impact

Figure 2 • Global share of buildings and construction final energy and emissions, 2018



IEA (2019). All rights reserved.

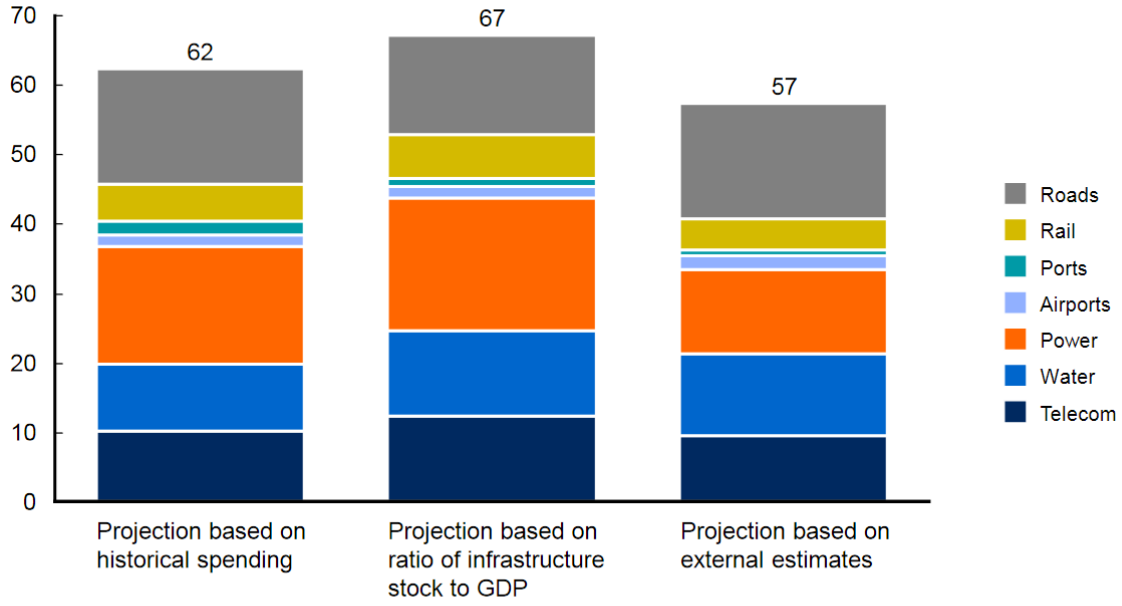
United Nations Environment Programme with International Energy Agency IEA. (2019). *2019 Global Status Report for Buildings and Construction*. ISBN 978-92-807-3768-4

The Built Envrionment : Scale and impact

Dobbs, Richard, H Pohl, D Lin, J Mischke, N Garemo, J Hexter, S Matzinger, R Palter, and R Nanavatty. "Infrastructure Productivity: How to Save $1 Trillion a Year. McKinsey Global Institute." *McKinsey Co January*, 2013.

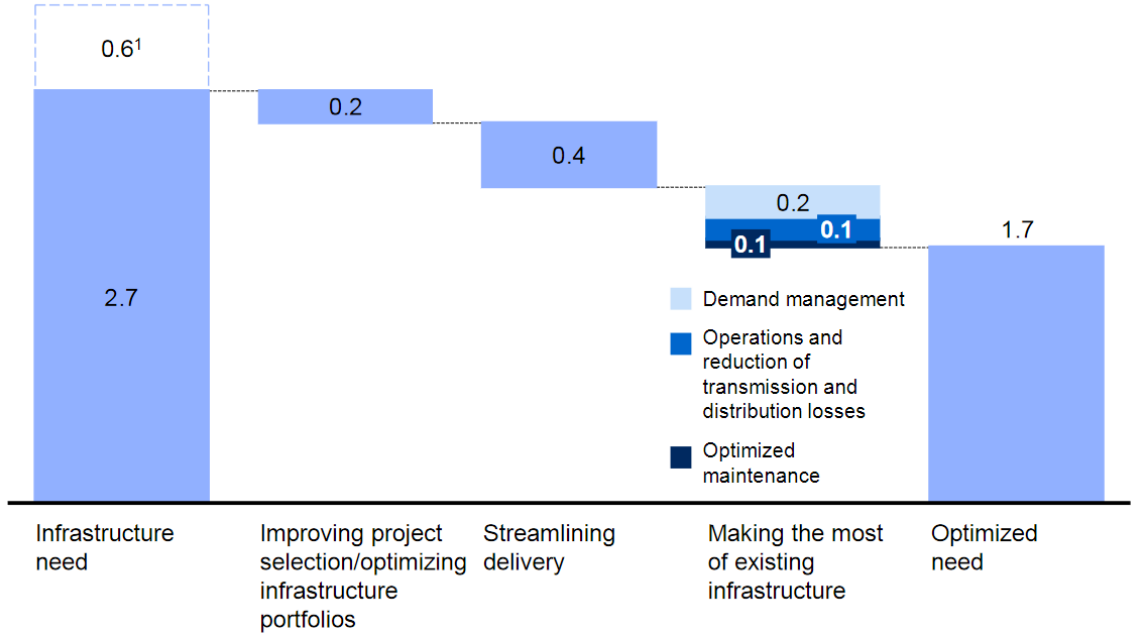
The Built Envrionment : Scale and impact

Estimates of needed infrastructure investments, 2013–30
$ trillion, constant 2010 dollars



SOURCE: Organisation for Economic Co-operation and Development (OECD); International Energy Agency (IEA), 2011; International Transport Forum (ITF); Global Water Intelligence (GWI); McKinsey Global Institute analysis

The $1 trillion-a-year infrastructure productivity opportunity
Global infrastructure investment need and how it could be reduced
Yearly average, 2013–30
$ trillion, constant 2010 dollars



Dobbs, Richard, H Pohl, D Lin, J Mischke, N Garemo, J Hexter, S Matzinger, R Palter, and R Nanavatty. "Infrastructure Productivity: How to Save $1 Trillion a Year. McKinsey Global Institute." *McKinsey Co January*, 2013.

The Construction Sector: !Innovation

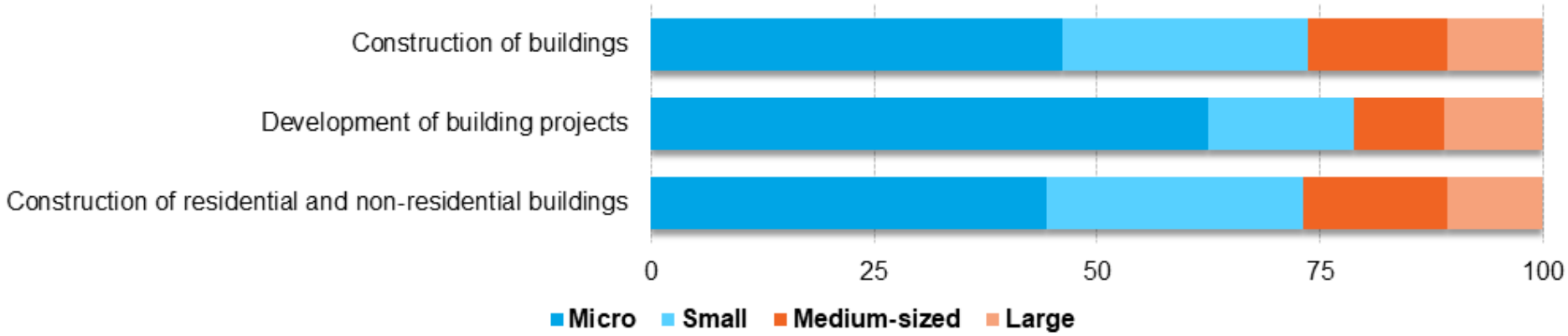
Welcome to the building industry!

idea: A. Kiviniemi. Image Sources:
[Dailymail 2015], [Protocars 2015] [Uregiana 2015]

The Construction Sector: People

Sectoral analysis of employment by enterprise size class, Construction of buildings (NACE Division 41), EU-27, 2017

(% share of sectoral employment)

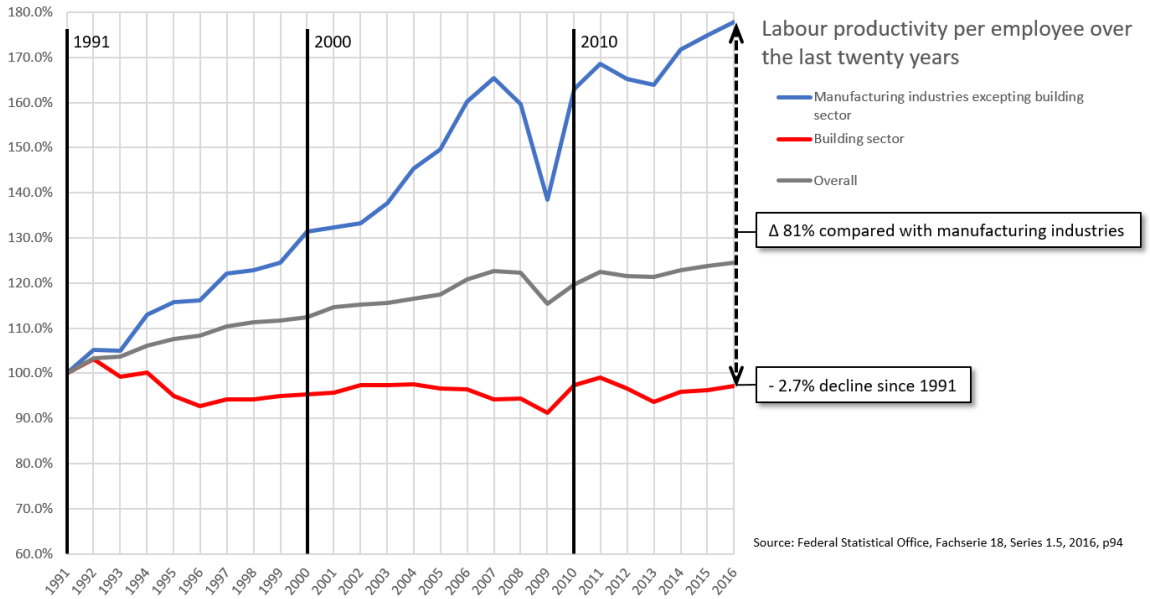


Note: Activities which are not shown are incomplete. For the purpose of the article some percentages have been calculated for confidential data, which causes a lower reliability.

Source: Eurostat (online data code: sbs_sc_con_r2)

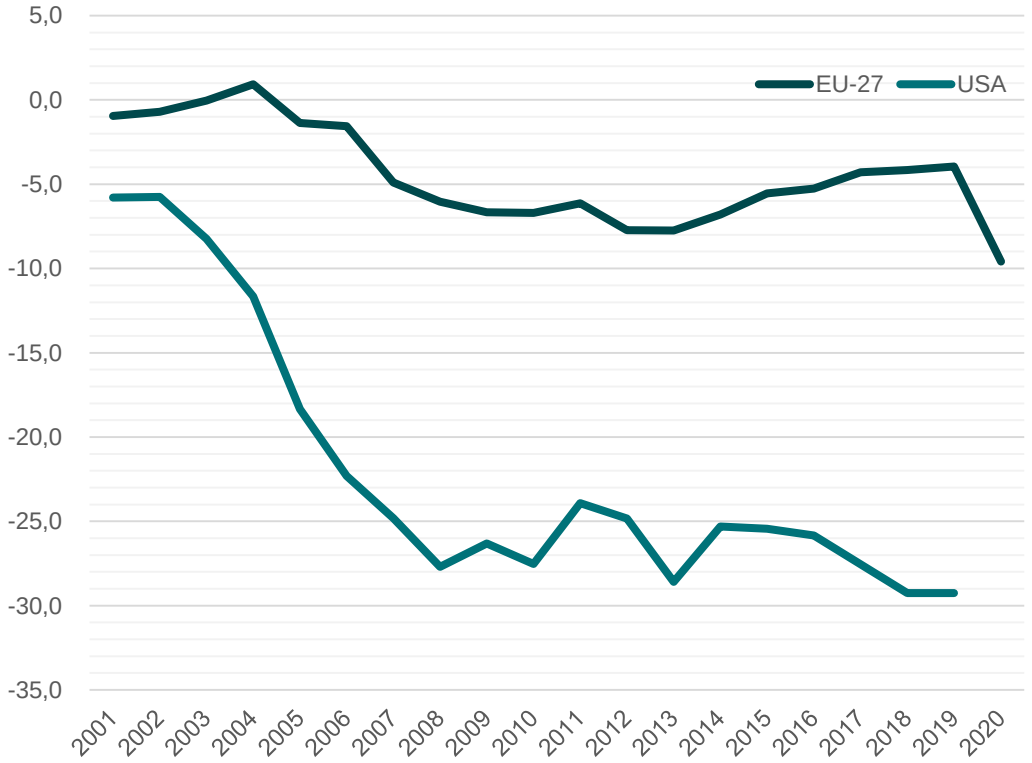
eurostat

The Construction Sector: Productivity



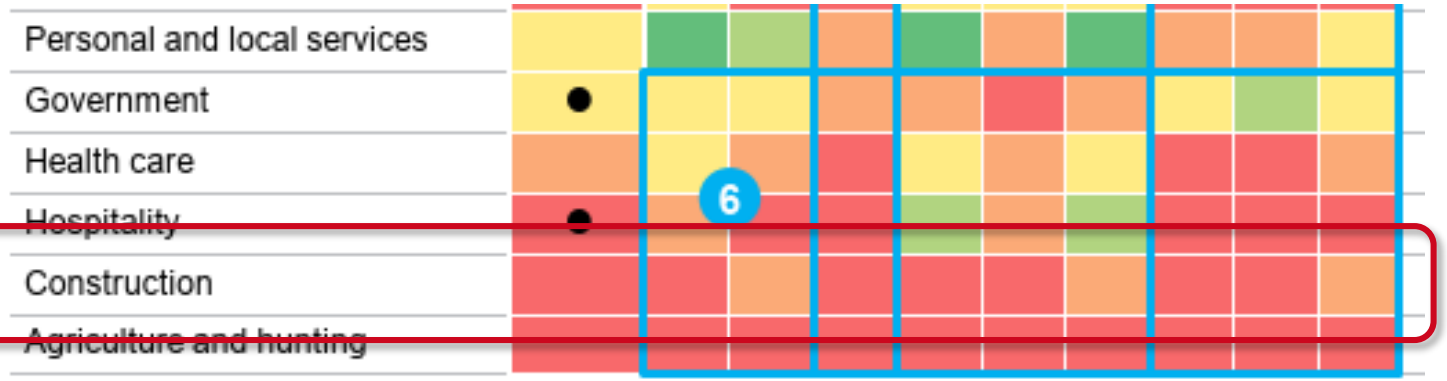
Source: OECD (2021), "Productivity and unit labour cost by industry, ISIC Rev. 4", *OECD Productivity Statistics* (database), https://doi.org/10.1787/data-00687-en

Construction sector:
Gross value added per person employed, constant prices (cumulative)



The Construction Sector: Digitalization

Source: unknown. Cobie Man "Lyle" from Bill East presentation



The MGI Industry Digitization Index

2015 or latest available data

Relatively low digitization — Relatively high digitization

● Digital leaders within relatively undigitized sectors

Sector	Over-all digiti-zation[1]	Assets: Digital spending	Assets: Digital asset stock	Usage: Transactions	Usage: Interactions	Usage: Business processes	Usage: Market making	Labor: Digital spending on workers	Labor: Digital capital deepening	Labor: Digitization of work	GDP share %	Em-ploy-ment share %	Produc-tivity growth, 2005–14[2] %
ICT											5	3	4.6
Media			1								2	1	3.6
Professional services											9	6	0.3
Finance and insurance											8	4	1.6
Wholesale trade					4						5	4	0.2
Advanced manufacturing											3	2	2.6
Oil and gas		2									2	0.1	2.9
Utilities											2	0.4	1.3
Chemicals and pharmaceuticals											2	1	1.8
Basic goods manufacturing									5		5	5	1.2
Mining											1	0.4	0.5
Real estate	●										5	1	2.3
Transportation and warehousing	●								5		3	3	1.4
Education	●			3							2	2	-0.5
Retail trade	●										5	11	-1.1
Entertainment and recreation											1	1	0.9
Personal and local services											6	11	0.5
Government	●										16	15	0.2
Health care		6									10	13	-0.1
Hospitality	●										4	8	-0.9
Construction											3	5	-1.4
Agriculture and hunting											1	1	-0.9

1 Knowledge-intensive sectors that are highly digitized across most dimensions

2 Capital-intensive sectors with the potential to further digitize their physical assets

3 Service sectors with long tail of small firms having room to digitize customer transactions

4 B2B sectors with the potential to digitally engage and interact with their customers

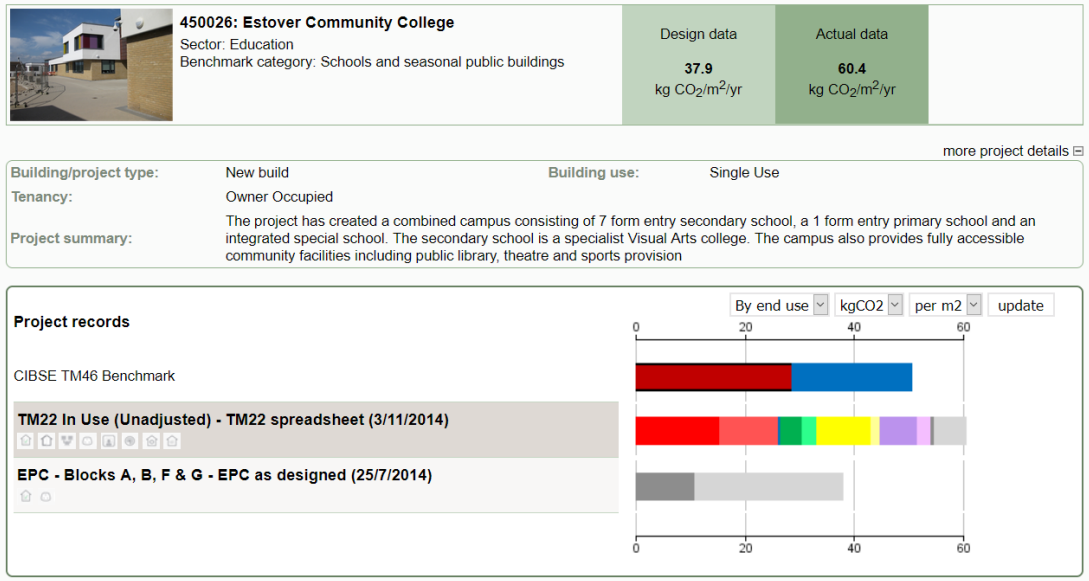
5 Labor-intensive sectors with the potential to provide digital tools to their workforce

6 Quasi-public and/or highly localized sectors that lag across most dimensions

Manyika, et al ,2015 “Digital America: A Tale of the Haves and Have-Mores.”

The Construction Sector: Building Performance Gaps

- Multiple gaps between what is designed / simulated / "twinned" and how it actually perfoms!



source:carbonbuzz.org

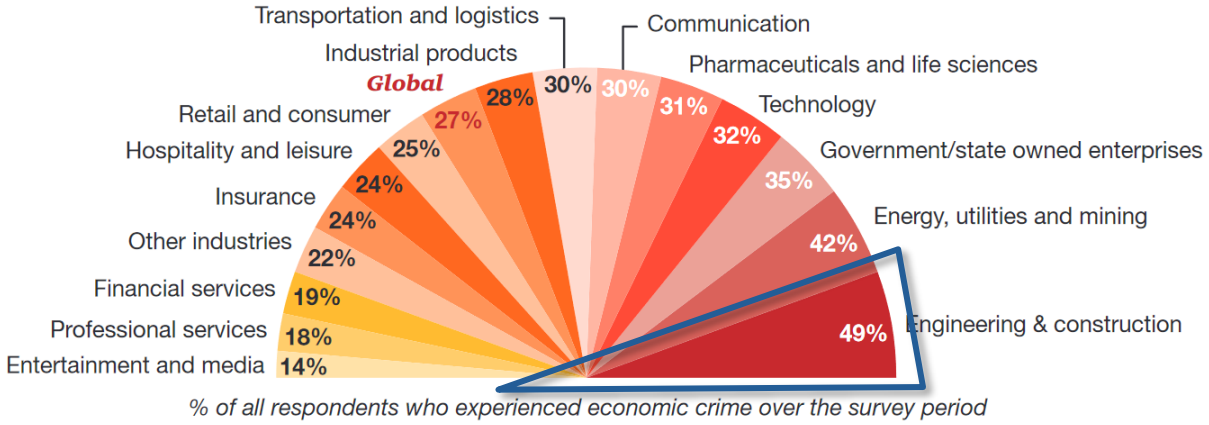
Design Computation | RWTH AACHEN UNIVERSITY

The Construction Sector: Corruption

Engineering and construction sector analysis of PwC's 2014 Global Economic Crime Survey

Fighting corruption and bribery in the construction industry

Figure 2: Reported bribery and corruption, by industry



% of all respondents who experienced economic crime over the survey period

49%
Nearly half of respondents reporting economic crime say it includes bribery and corruption. That's the highest level of any industry.

76%
Asset misappropriation tops the list of types of economic crime experienced by engineering & construction respondents.

70%
Seven out of ten of the most serious economic crimes suffered by engineering & construction companies were perpetrated by insiders.

How can Semantic Digital Twins for the BE help?

1. **What is what**: **Acquisition** of information from static model to **"living" Twin** for **the existing environment**
   - inventory: what do we have, what is it made of?
   - different models at different levels of scale,
   - with design intent (not just "what we see")
2. **how are things?** status monitoring
   - by the minute
   - by the day
   - by the year
   - throughout an ownership lifecycle
   - across generations (!)
3. **who else is out there?**
   – Connect, align, map
   – orchestrate systems of systems
4. **Planning**
   – informed decision making based on the above

Semantic Digital Twins in the Built Environment

buildingSMART

- Positioning Paper "Enabeling an Ecosystems of Digital Twins", 2020
  - Jakob Beetz, Aachen University
  - Léon van Berlo, buildingSMART International
  - André Borrmann, The Technical University of Munich
  - Mark Enzer, Mott MacDonald/the Centre for Digital Built Britain
  - Christian Frey, Siemens
  - Ulrich Hartmann, Oracle
  - Wolfgang Hass, Siemens
  - Aidan Mercer, buildingSMART International
  - Frank Weiß, Oracle
  - Natalie Weiß, Oracle

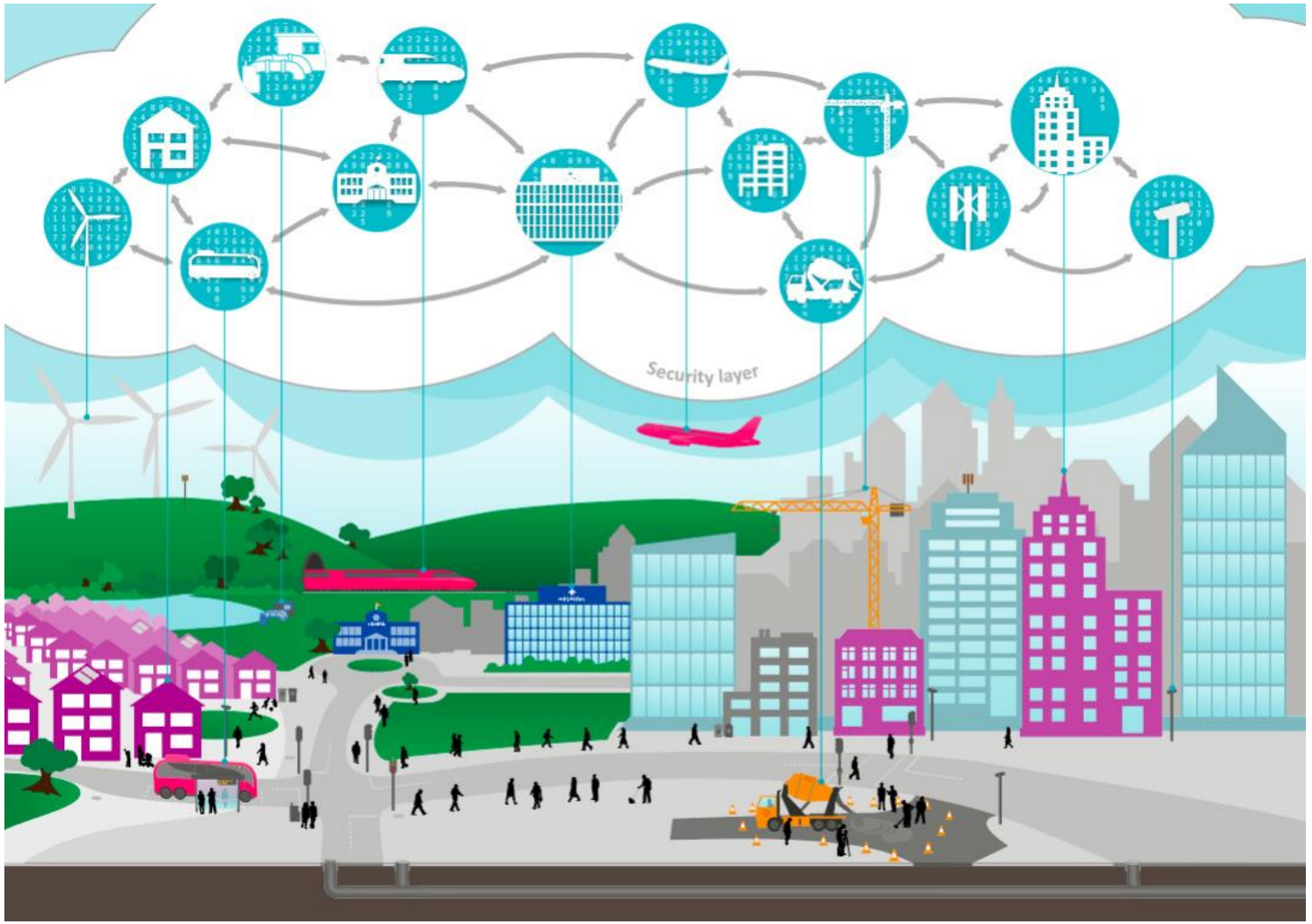


illustration: David McNamara, Oracle

Semantic Digital Twins in the Built Environment

buildingSMART

- Positioning Paper "Enabeling an Ecosystems of Digital Twins", 2020
  - Jakob Beetz, Aachen University
  - Léon van Berlo, buildingSMART International
  - André Borrmann, The Technical University of Munich
  - Mark Enzer, Mott MacDonald/the Centre for Digital Built Britain
  - Christian Frey, Siemens
  - Ulrich Hartmann, Oracle
  - Wolfgang Hass, Siemens
  - Aidan Mercer, buildingSMART International
  - Frank Weiß, Oracle
  - Natalie Weiß, Oracle

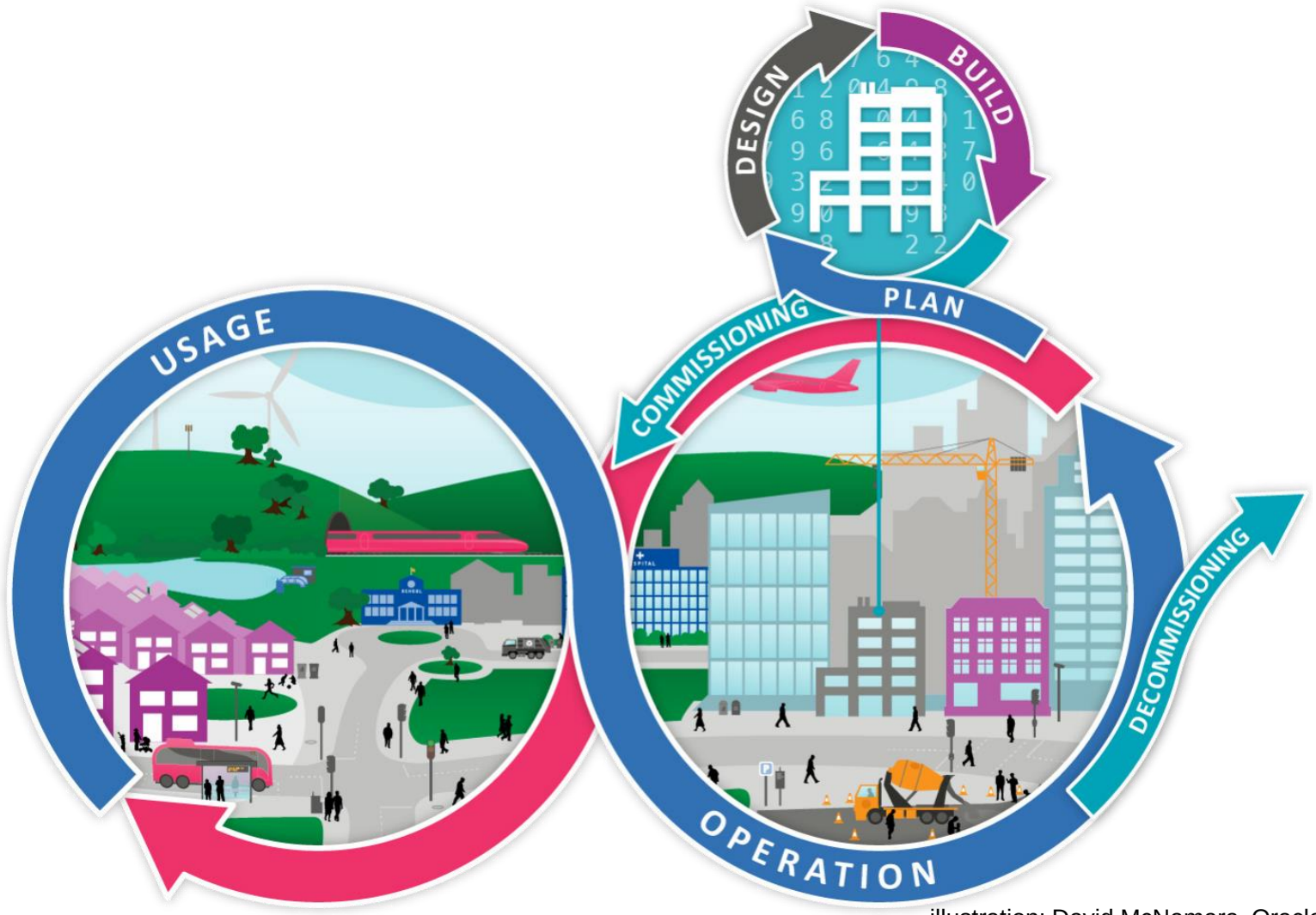
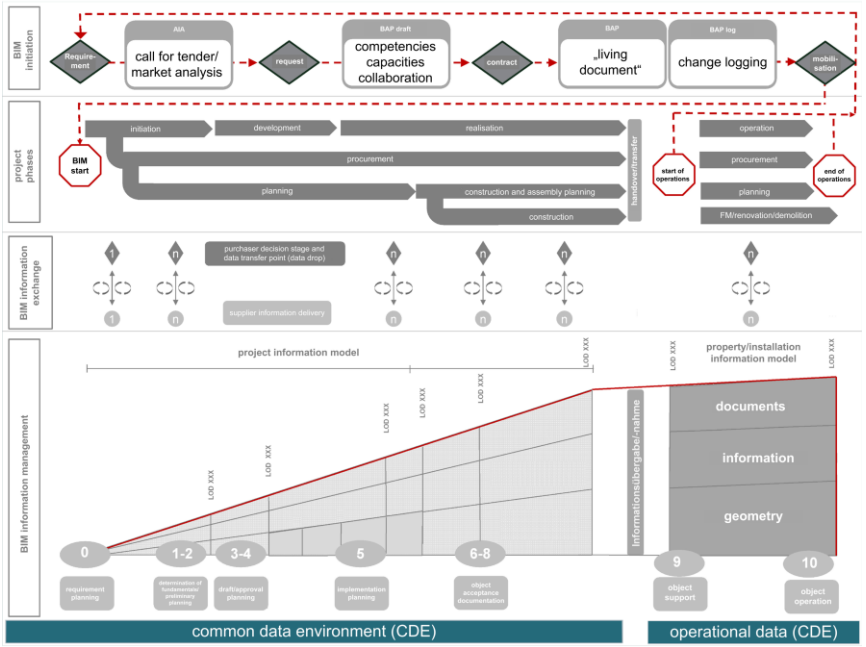
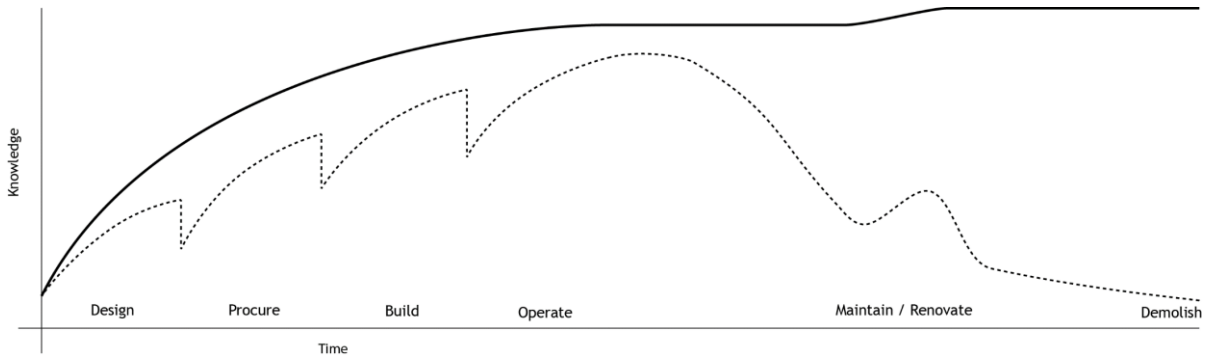
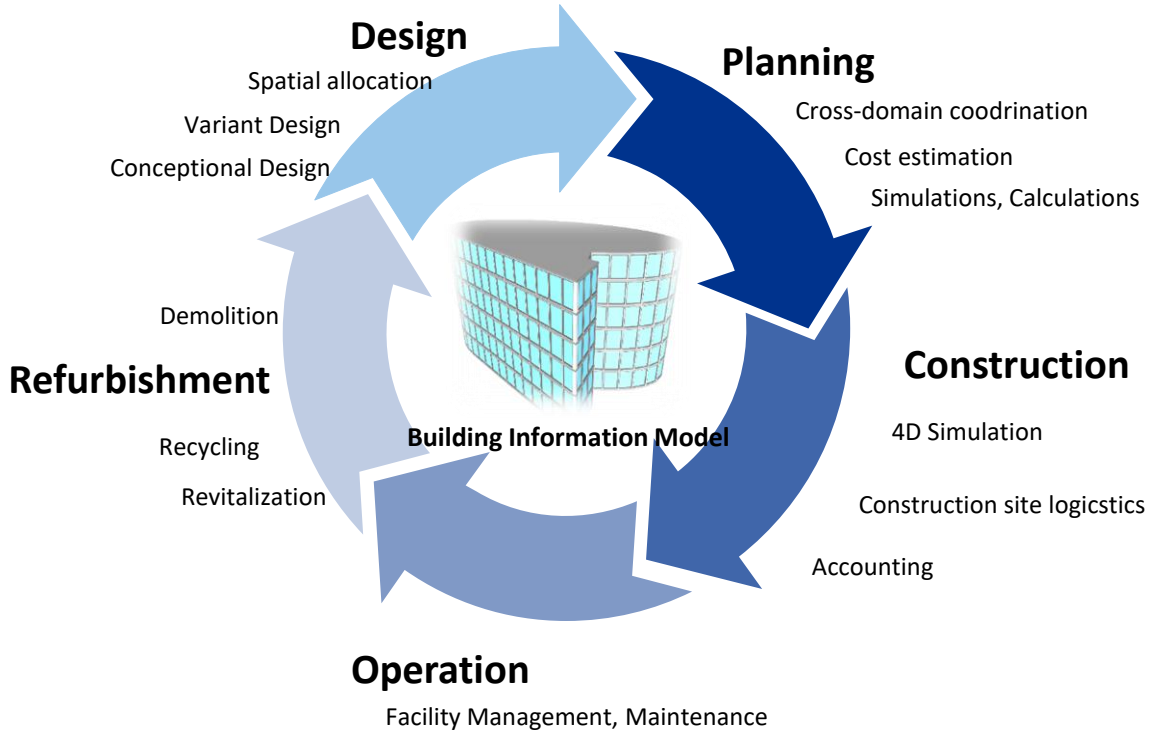


illustration: David McNamara, Oracle

Digital Twins for the built environment: Lifecycle concepts



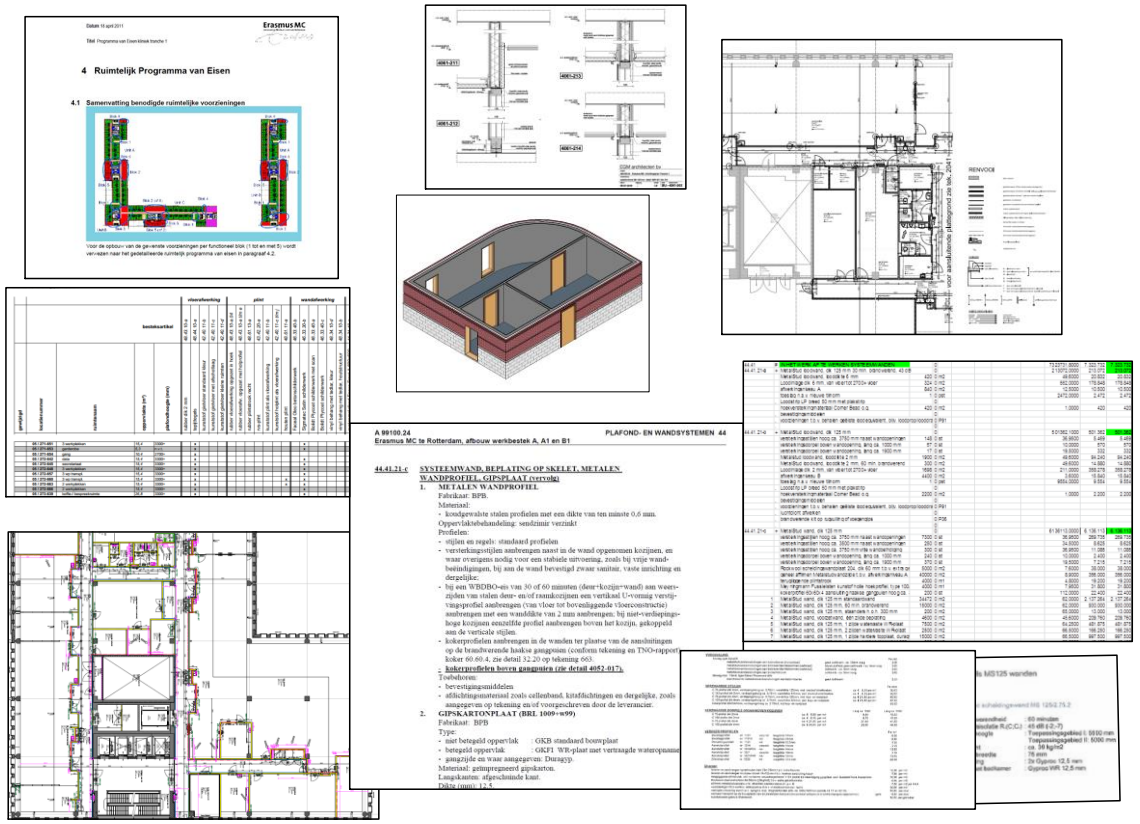


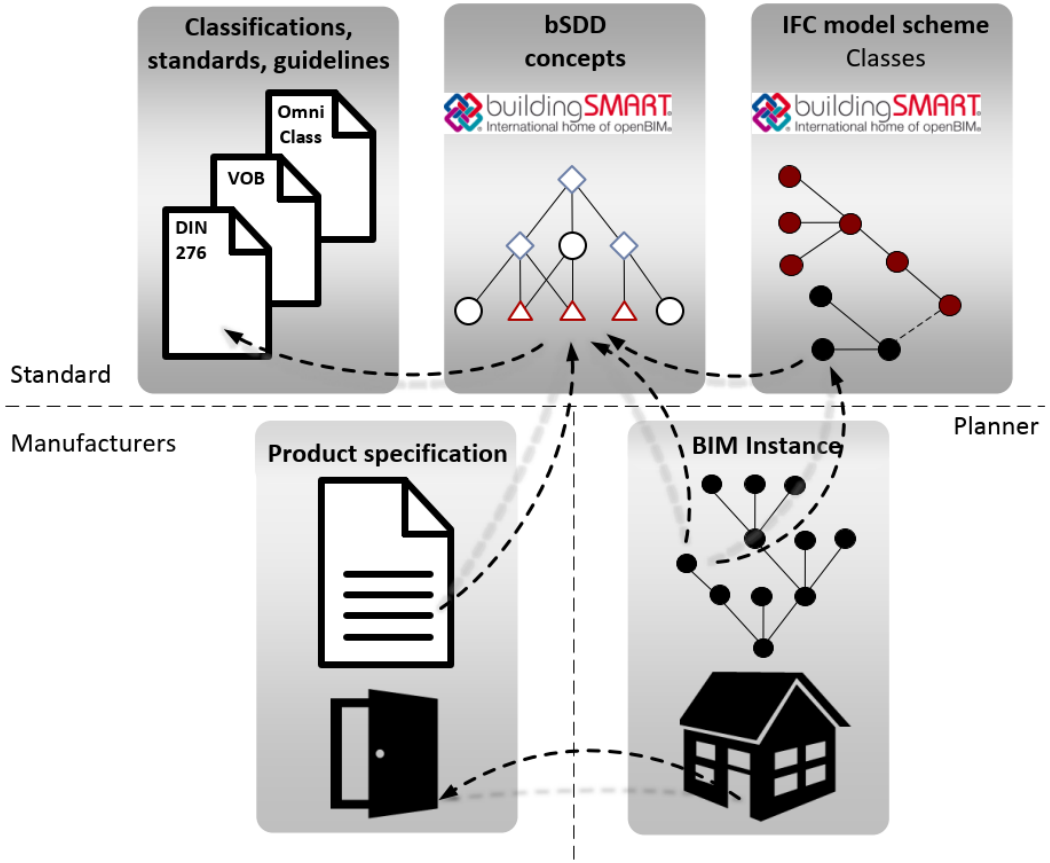


Source: Bormann, König, Koch, Beetz 2015

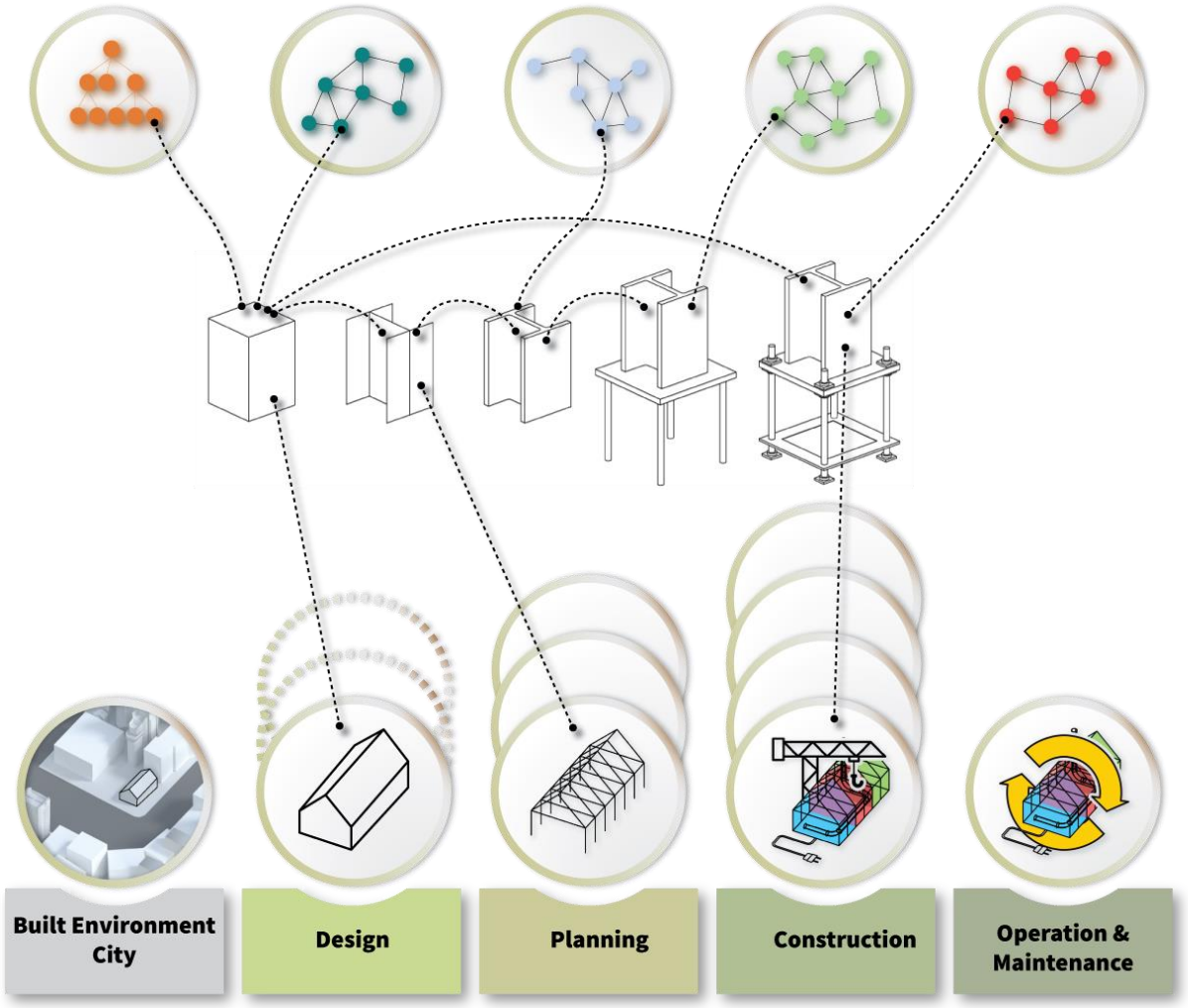
Linked, heterogeneous Building Information Modelling – BIM

Interoperability buildingSMART IFC and beyond



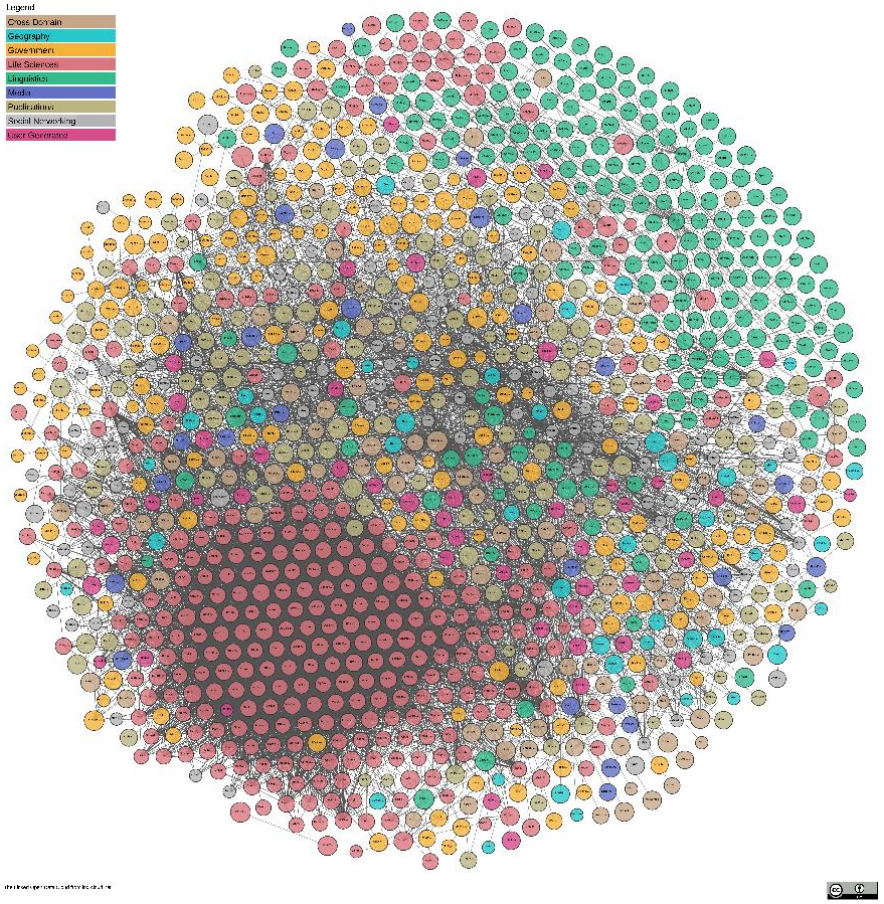


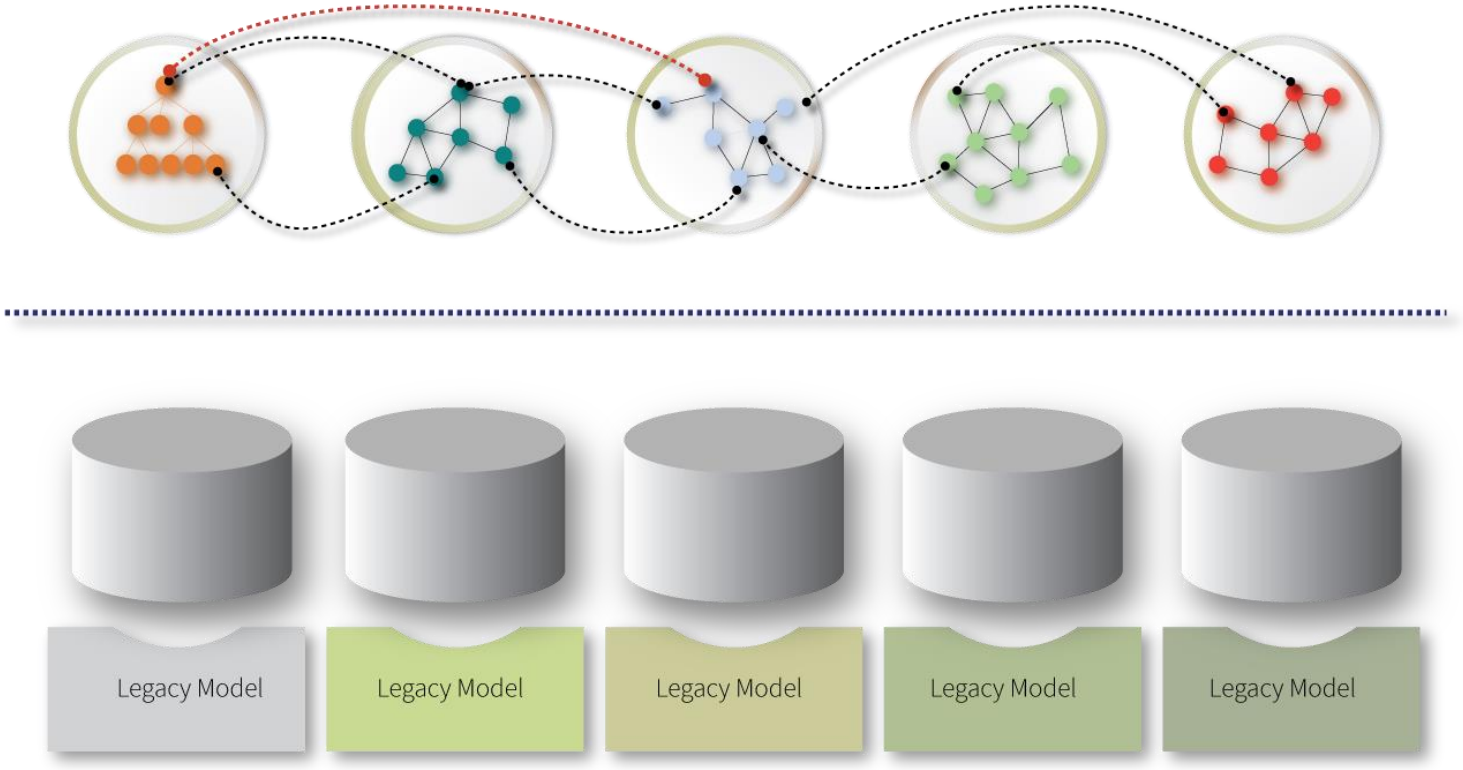
Semantic DTs: interlinked, interoperable information : W3C Linked Data for DT



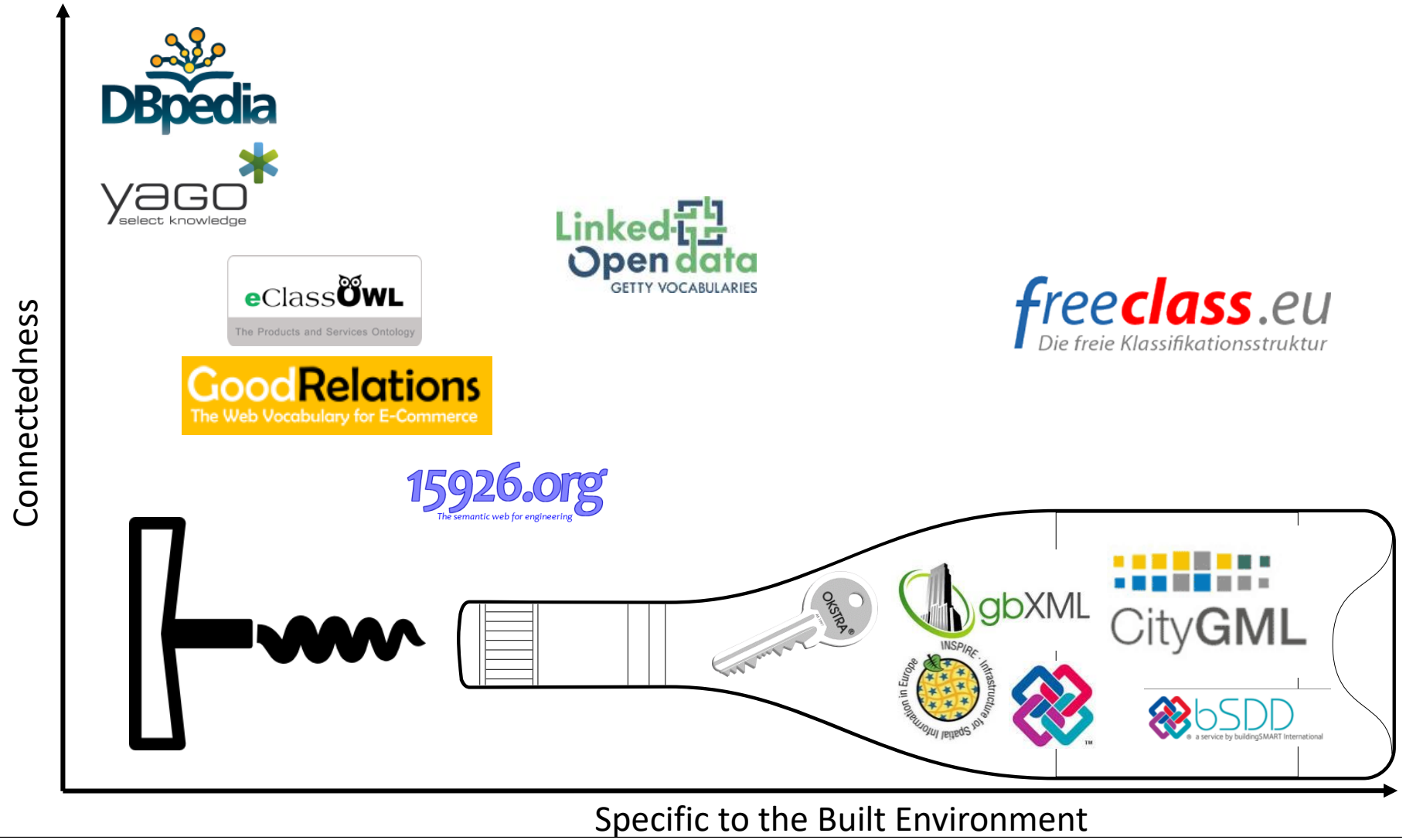
Semantic DTs: interlinked, interoperable information : W3C Linked Data for DT

Breaking out of the silos…

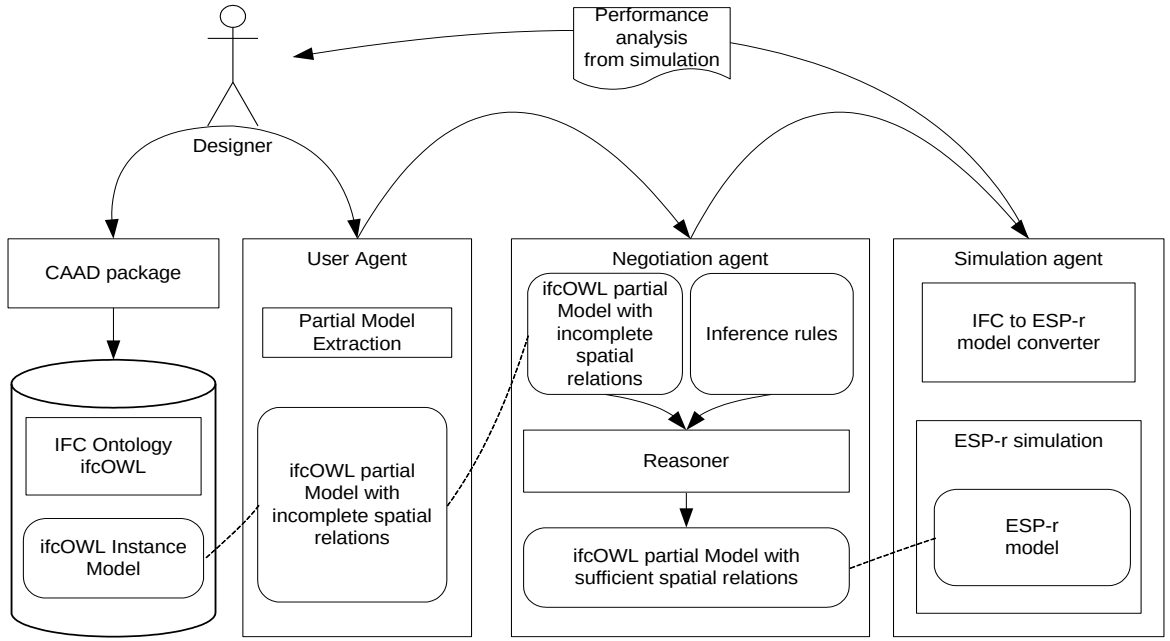


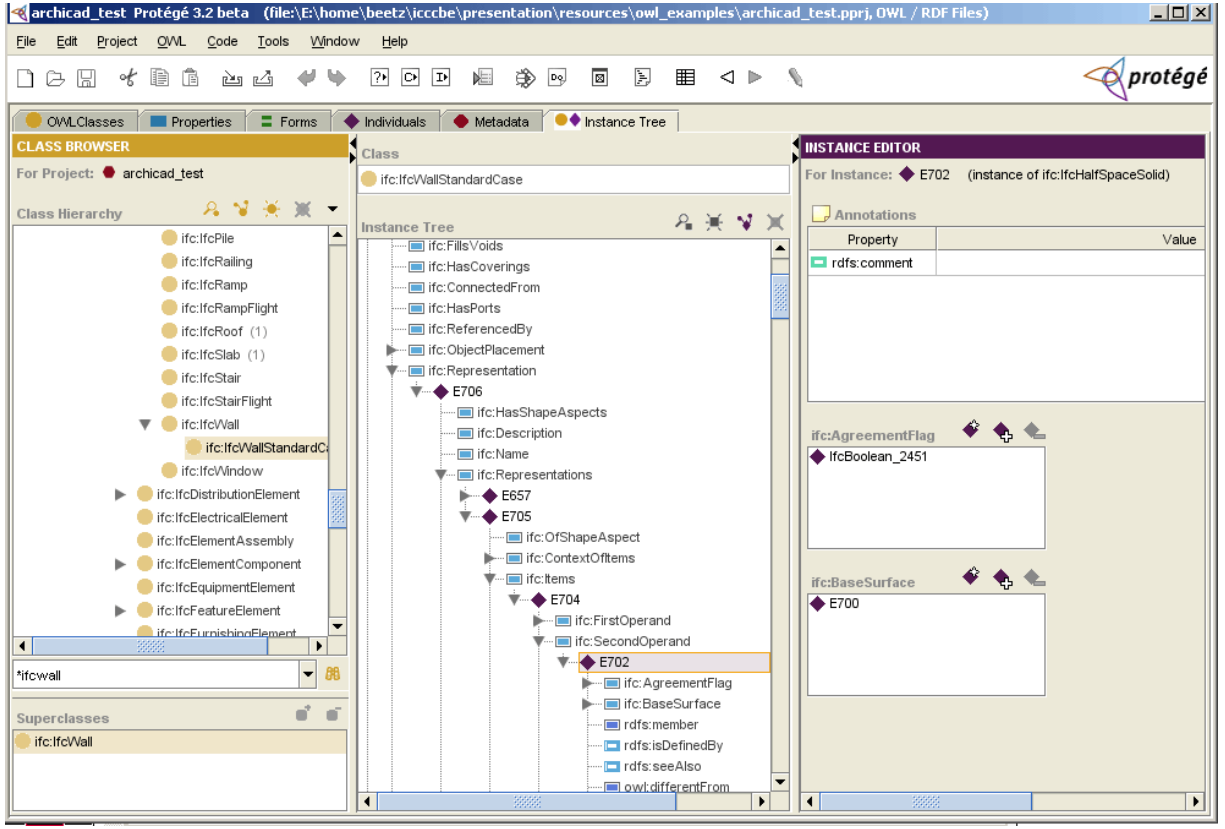


Linked Data and legacy Building Information Models



Greetings from the past : Reasoning with Linked Data | Semantic Web [Beetz 2006]





ifcOWL official buildingSMART standard

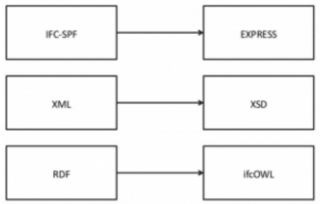
buildingSMART International

Home Standards Services Resources

ifcOWL

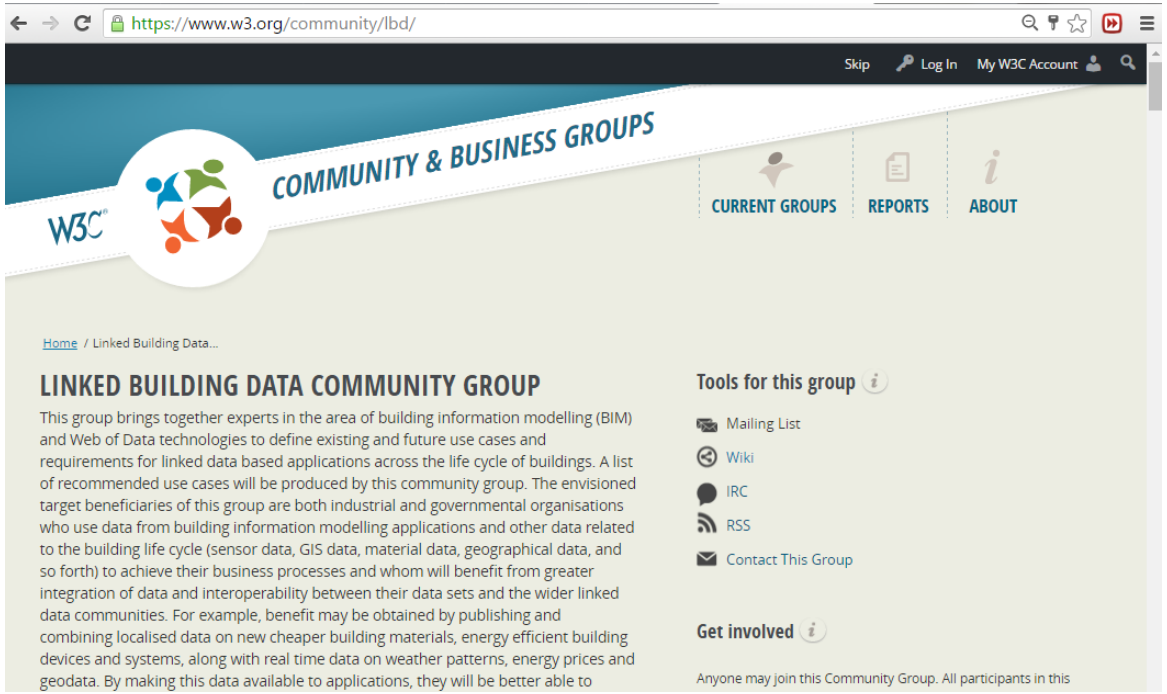
What is ifcOWL?

ifcOWL provides a Web Ontology Language (OWL) representation of the Industry Foundation Classes (IFC) schema. IFC is the open standard for representing building and construction data (see BuildingSMART). The ifcOWL ontology has the same status as the EXPRESS and XSD schemas of IFC.

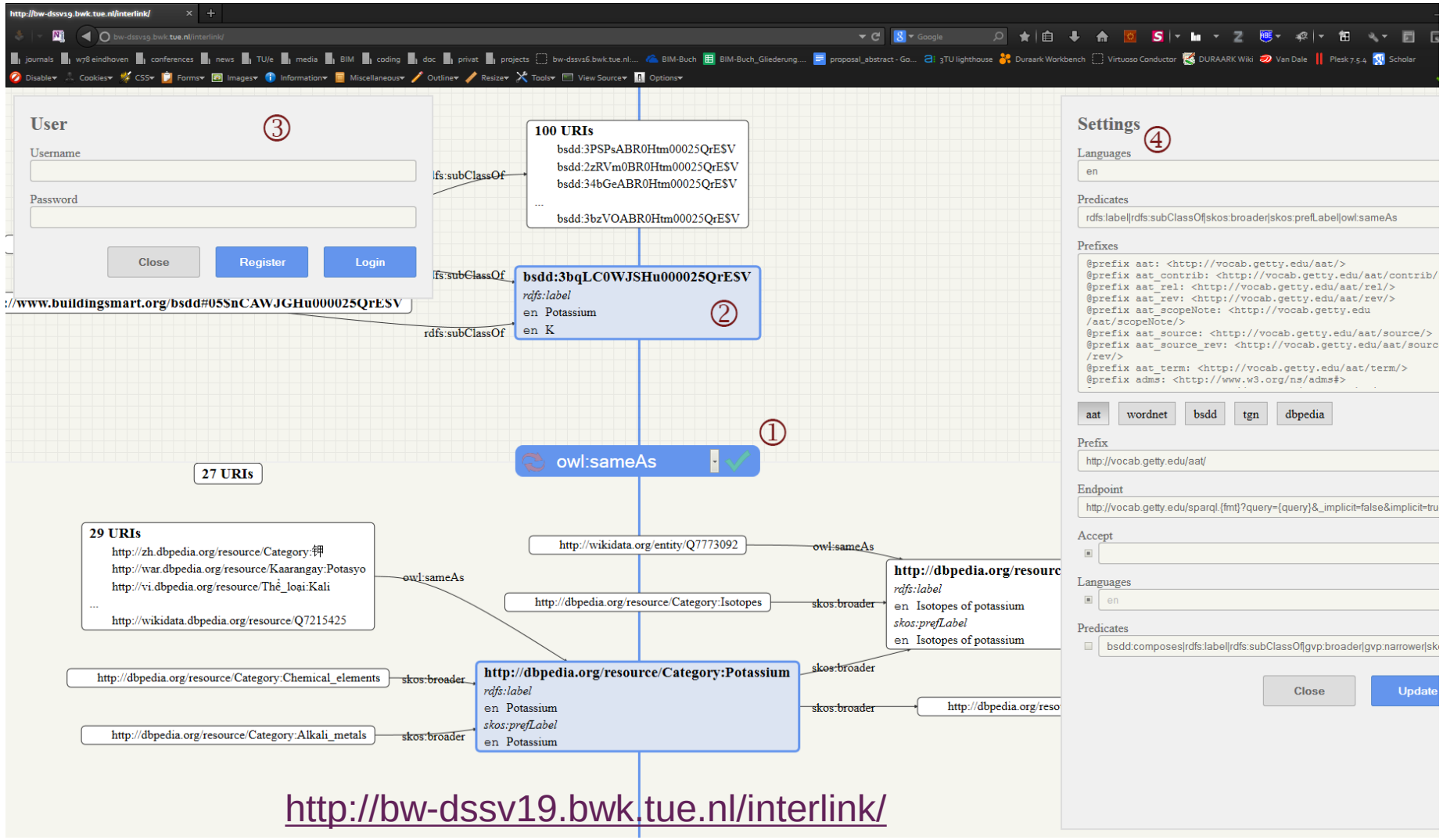


What is it good for?

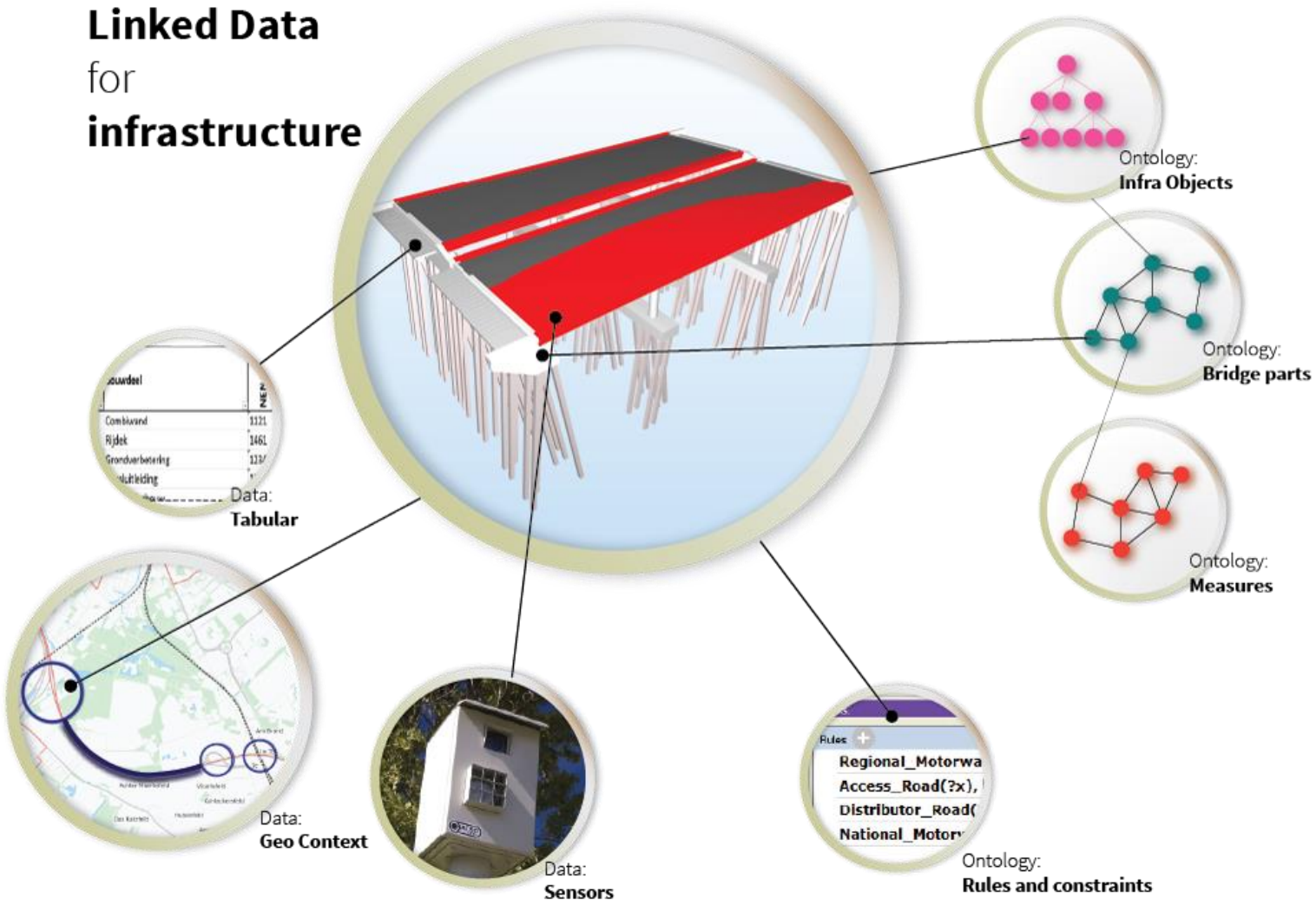
Using the ifcOWL ontology, one can represent building data using state of the art web technologies (semantic web and linked data technologies). IFC data thus becomes available in directed labelled graphs (RDF). This graph model and the underlying web technology stack allows building data to be easily linked to material data, GIS data, product manufacturer data, sensor data, classification schemas, social data, and so forth. The result is a web of linked building data that brings major opportunities for data management and exchange in the construction industry and beyond.



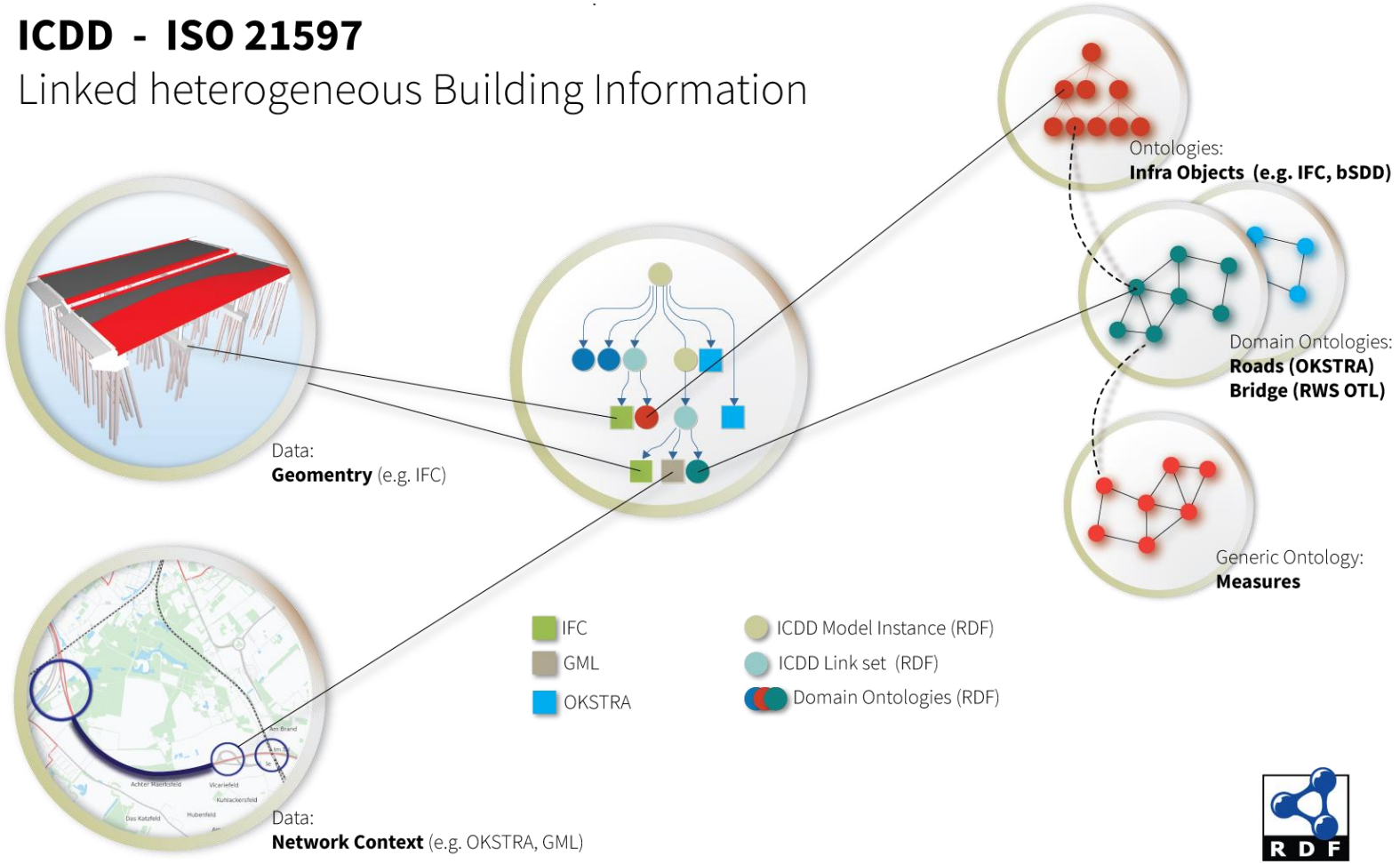
Validation of pre-alignments by experts/crowds



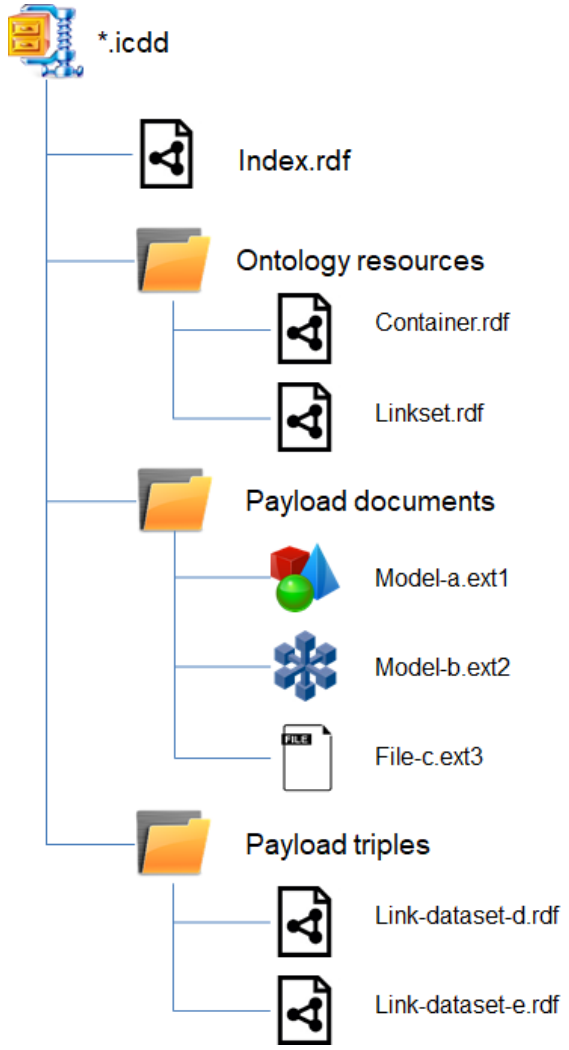
Linked DT Data Breaking out of the silos…



Future: Linked DT Data Information Container Document Delivery – ISO 21597

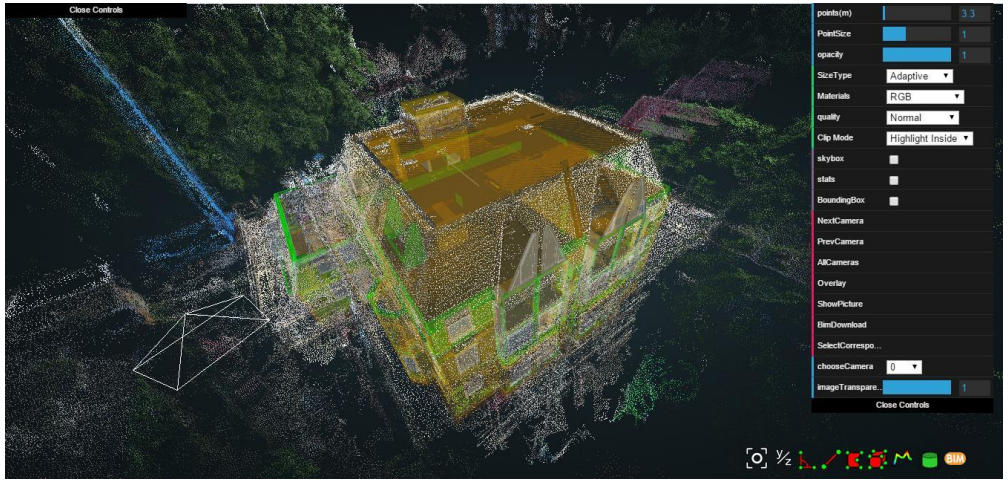


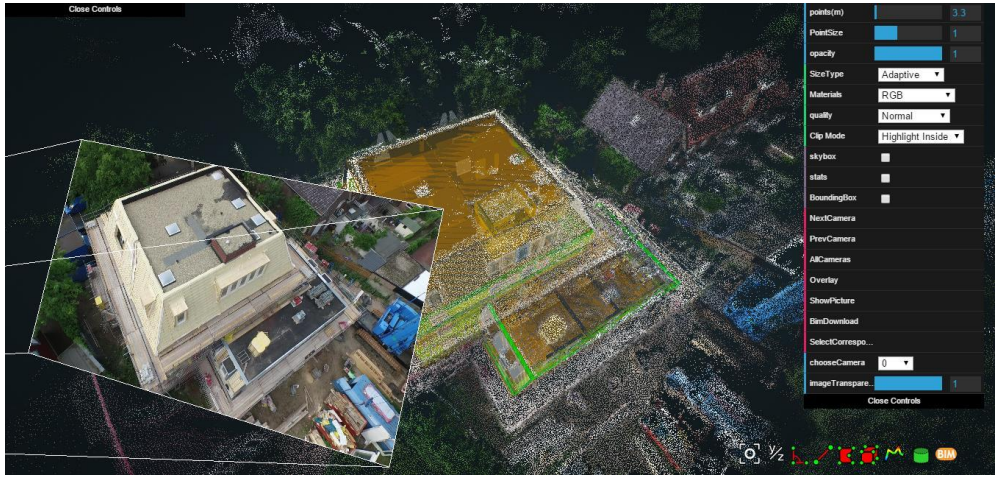
[Beetz et al 2015]

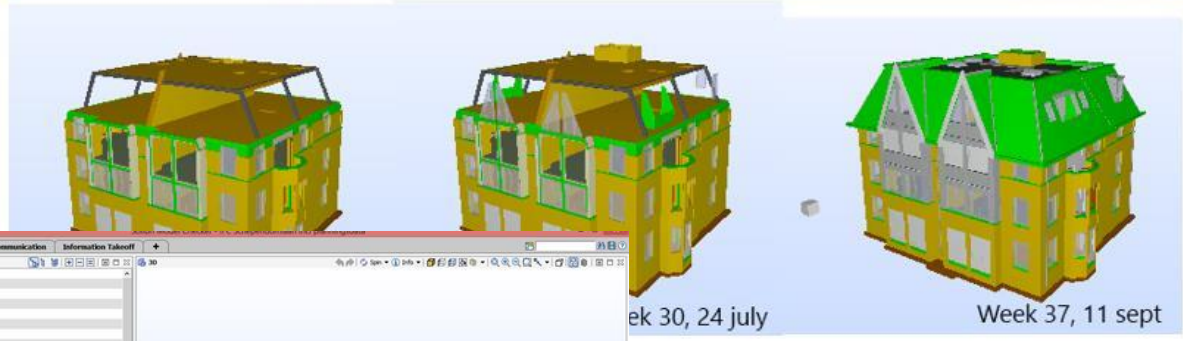


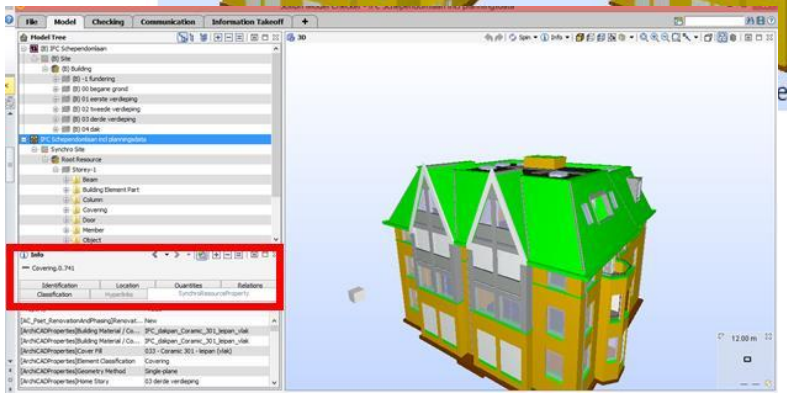
Digital Twins Reality Capturing:
Why we need more annotated data

Source: [Fisher et al 2018] BDD100K: A Diverse Driving Video Database with Scalable Annotation Tooling



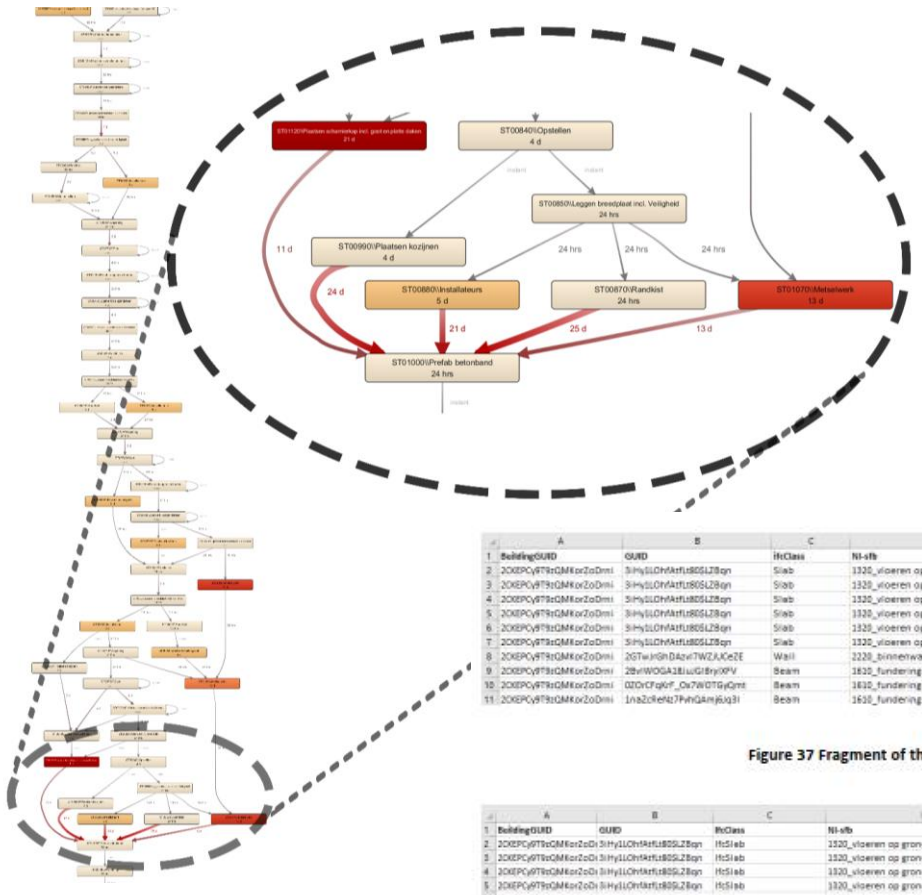


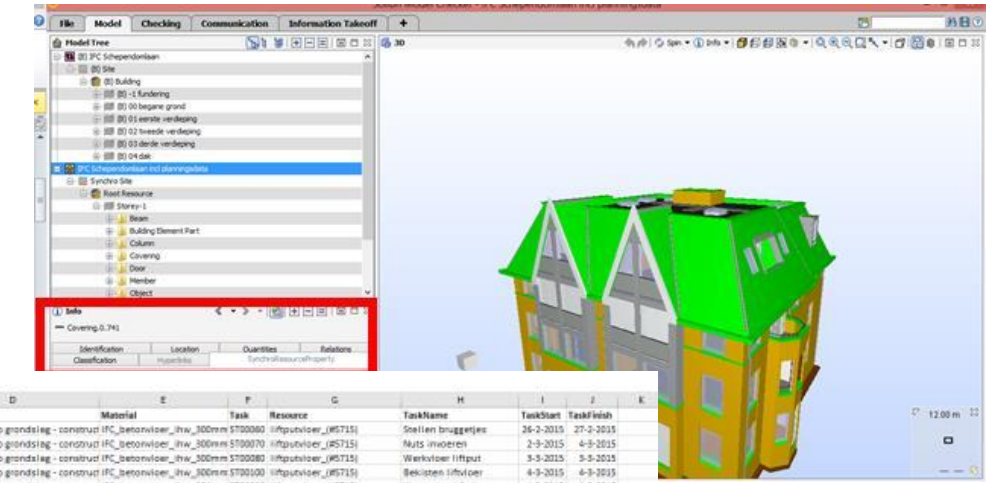




[van Schaijk 2016]

Publicly available dataset Schependomlaan





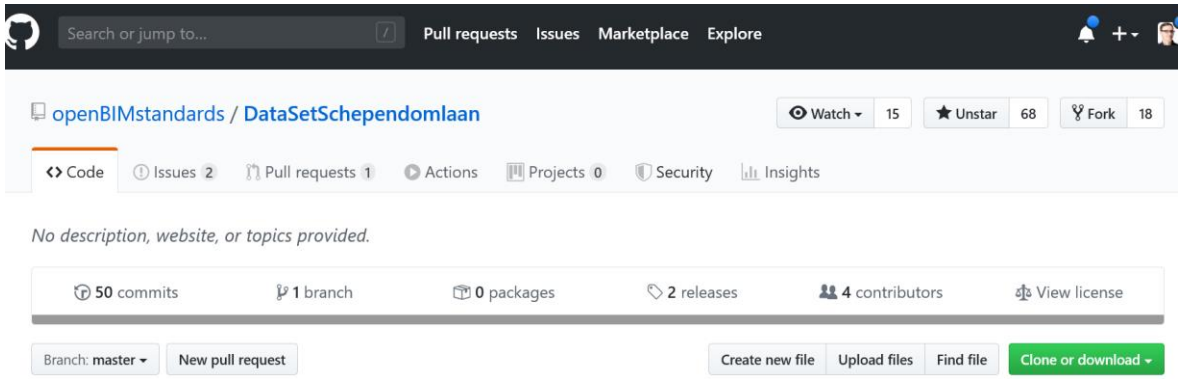
	A	B	C	D	E	F	G	H	I	J	K
1	BuildingGUID	GUID	IfcClass	NI-sfb	Material	Task	Resource	TaskName	TaskStart	TaskFinish	
2	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00060	liftputvloer_(#5715)	Stellen bruggetjes	26-2-2015	27-2-2015	
3	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00070	liftputvloer_(#5715)	Nuts invoeren	2-3-2015	4-3-2015	
4	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00080	liftputvloer_(#5715)	Werkvloer liftput	3-3-2015	3-3-2015	
5	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00100	liftputvloer_(#5715)	Bekisten liftvloer	4-3-2015	4-3-2015	
6	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00090	liftputvloer_(#5715)	Wapening liftvloer	4-3-2015	4-3-2015	
7	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	Slab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lhv_300mm	ST00110	liftputvloer_(#5715)	Stort liftvloer	5-3-2015	5-3-2015	
8	2OKEPCy9T9zQMKorZoDmi	2GTwJnGhDAzvI7WZAJCeZE	Wall	2220_binnenwanden - constructief	IFC_kalkzandsteen_214mm	ST00130	liftputwand_(#2990)	Bekisten liftwanden	6-3-2015	6-3-2015	
9	2OKEPCy9T9zQMKorZoDmi	2BvWOGA1BJuGI8ryIXPV	Beam	1630_funderingsconstructies - voeten	IFC_betonopstort_370x965	ST00130	liftputwand_(#5543)	Bekisten liftwanden	6-3-2015	6-3-2015	
10	2OKEPCy9T9zQMKorZoDmi	0ZOrCFqKrF_Ow7WDTGyQmt	Beam	1630_funderingsconstructies - voeten	IFC_betonopstort_220x965	ST00130	liftputwand_(#5377)	Bekisten liftwanden	6-3-2015	6-3-2015	
11	2OKEPCy9T9zQMKorZoDmi	1naZcReNz7PvhQAmjGJq3I	Beam	1630_funderingsconstructies - voeten	IFC_betonopstort_220x345	ST00130	liftputwand_(#4278)	Bekisten liftwanden	6-3-2015	6-3-2015	

Figure 37 Fragment of the as-planned event log from the case study project

	A	B	C	D	E	F	G	H	I	J	K
1	BuildingGUID	GUID	IfcClass	NI-sfb	Material	TaskID	Resource	TaskName	TaskStart	TaskFinish	Element on time or not
2	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00060	liftputvloer_(#5715)	Stellen bruggetjes	26-2-2015	27-2-2015	On time
3	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00070	liftputvloer_(#5715)	Nuts invoeren	2-3-2015	4-3-2015	On time
4	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00080	liftputvloer_(#5715)	Werkvloer liftput	3-3-2015	3-3-2015	On time
5	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00100	liftputvloer_(#5715)	Bekisten liftvloer	4-3-2015	4-3-2015	On time
6	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00090	liftputvloer_(#5715)	Wapening liftvloer	4-3-2015	4-3-2015	On time
7	2OKEPCy9T9zQMKorZoDmi	3cHy1LOhfAkfUt8OSLZBqn	IfcSlab	1320_vloeren op grondslag - constructief	IFC_betonvloer_lh	ST00110	liftputvloer_(#5715)	Stort liftvloer	5-3-2015	5-3-2015	On time
8	2OKEPCy9T9zQMKorZoDmi	0n5uFweooDDwekFsYzTtt4	IfcWall	2220_binnenwanden - constructief	IFC_kalkzandsteen	ST00130	binnenwand_(#44016)	Bekisten liftwanden	6-3-2015	6-3-2015	On time
9	2OKEPCy9T9zQMKorZoDmi	2nEf55c1BfBMAjC0WeurmI	IfcBeam	1610_funderingsconstructies - voeten en bal	IFC_betonopstort_ST00130	ST00130	liftputwand_(#1515)	Bekisten liftwanden	6-3-2015	6-3-2015	On time
10	2OKEPCy9T9zQMKorZoDmi	2Y5ehOohrDEapO4_LFdoBr	IfcBeam	1610_funderingsconstructies - voeten en bal	IFC_betonopstort_ST00130	ST00130	liftputwand_(#1963)	Bekisten liftwanden	6-3-2015	6-3-2015	On time
11	2OKEPCy9T9zQMKorZoDmi	1naZcReNz7PvhQAmjGJq3I	IfcBeam	1610_funderingsconstructies - voeten en bal	IFC_betonopstort_ST00130	ST00130	liftputwand_(#4278)	Bekisten liftwanden	6-3-2015	6-3-2015	On time

Figure 38 Fragment of the as-built event log from the case study project. This log differs from the log in figure 37 with the parameter 'Element on time or not'

Publicly available dataset Schependomlaan



DOI 10.17605/OSF.IO/NE2YU

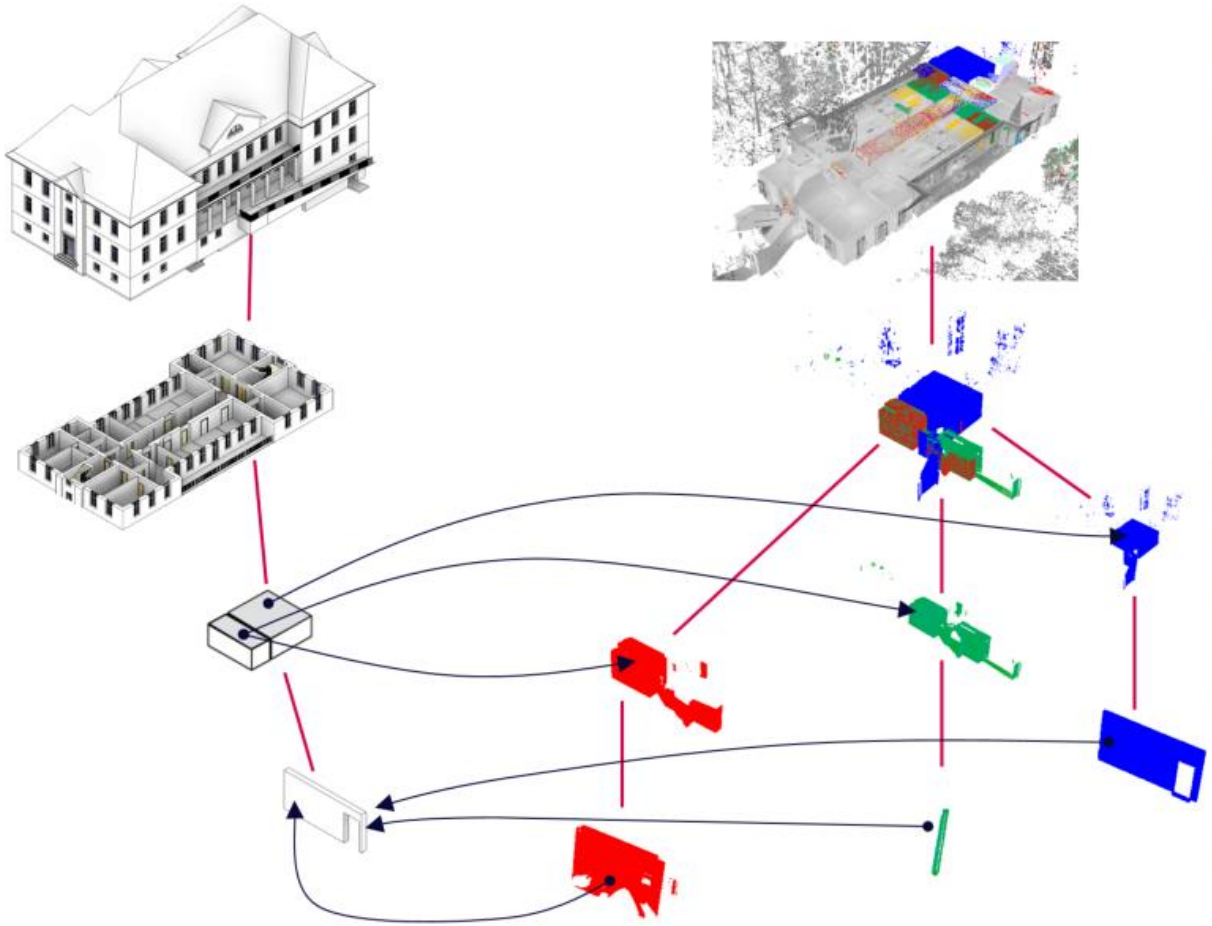
Dataset Schependomlaan

All data owners have given permission to use the data for scientific and academic purposes. The data is gathered during the master thesis project of Stijn van Schaijk at the Information Systems for the Built Environment (ISBE) group of the TU Eindhoven. In collaboration with Hendriks Bouw en Ontwikkeling[1], ROOT[2], TNO[3] and RAAMAC[4] the data is collected. General information about the project can be found at the website http://www.schependomlaan.nl/ .

Please pay attention: Do not download seperate files, they will give errors. Download the full dataset please use the zip from the release section

The dataset contains the following elements:

- Design model in .IFC and .PLA (Archicad)
- Issues (collision / clash detection) in BCF (.bzfzip) and in Tekla BIMsight Package.
- Subcontractor models in .IFC and .DWG - Flooring - Walls - Stairs - Fencing - Steel - Roofs - Prefab
- Coordination models in .TBP (Tekla BIMsight Package)
- Schedule/Planning in .pdf and .xml
- As-planned models in .IFC and Synchro file format.
- As-built models in point cloud formats .ASCII and .PLY
- Results comparison as-planned and as-built models in .xls
- As-planned Event log in .xlsx and .csv
- As-built Event log in .xlsx and .csv
- Event log with actors in .xlsx and .csv
- Download link to drone images and videos



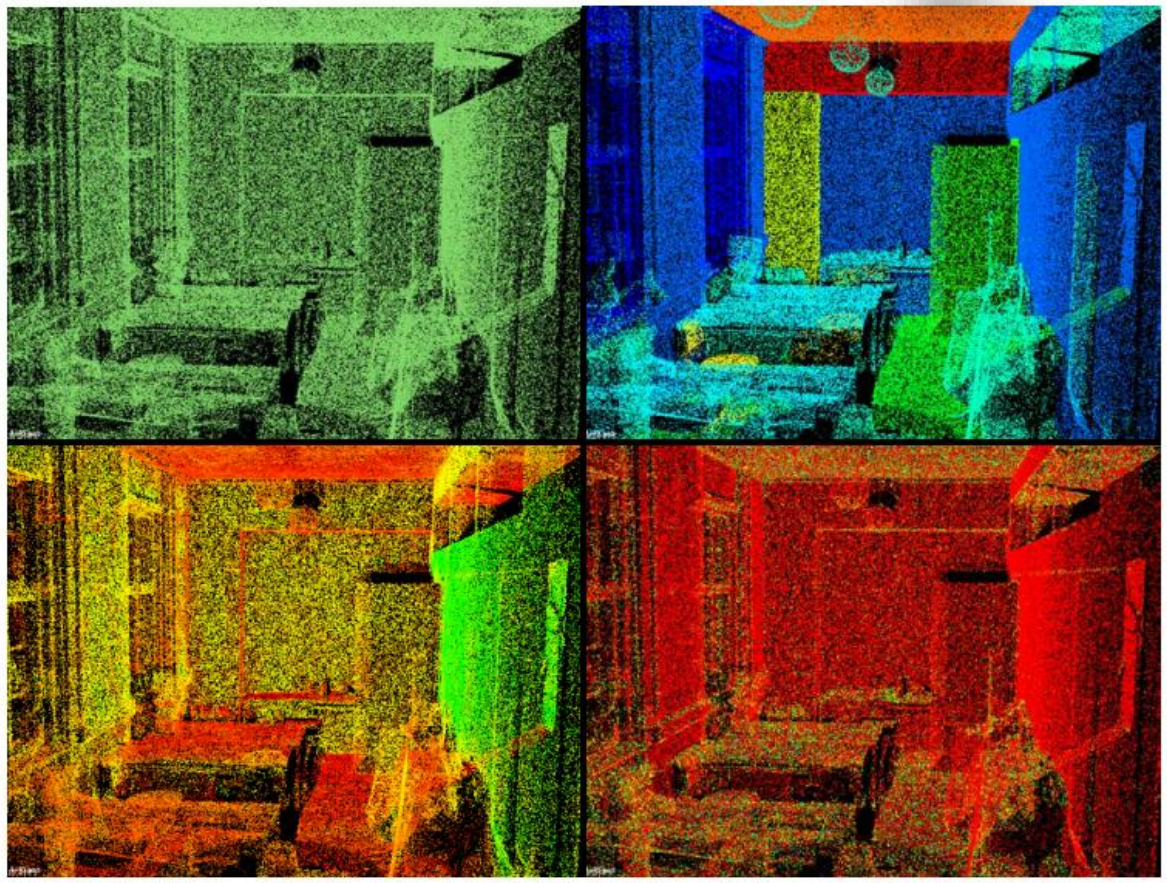
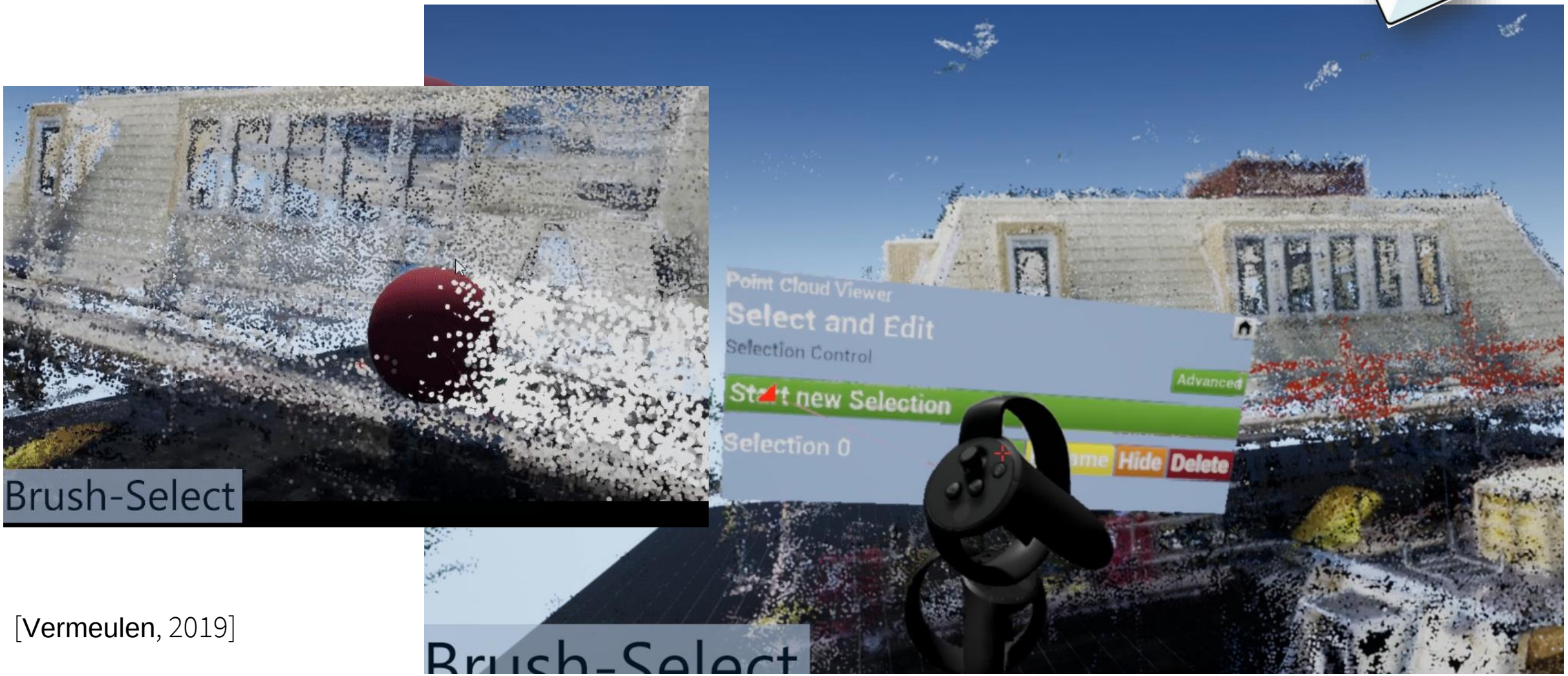
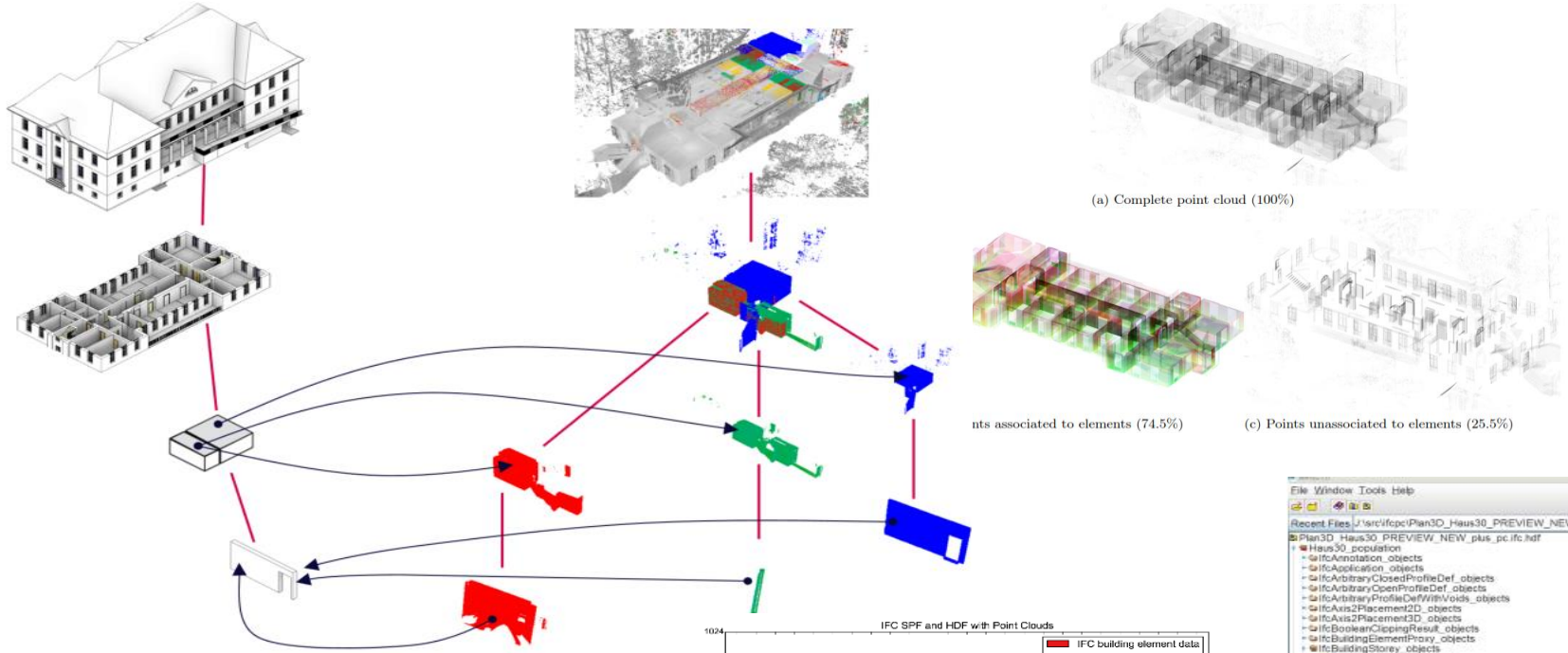


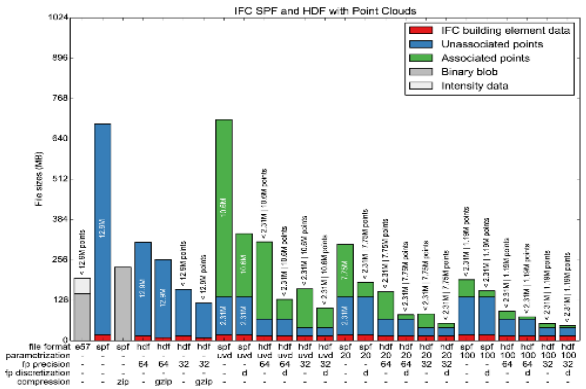
Figure 27: Scene from the pre-processed Byg72 point cloud dataset; (1) un-classified view, (2) classified point cloud data, (3) FPFH desciptor and (4) curvature

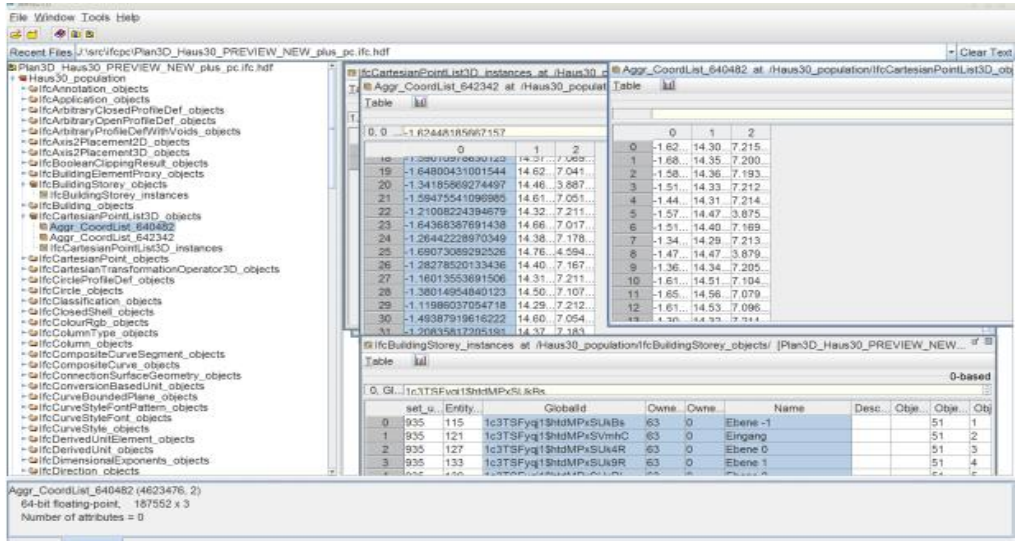


[Vermeulen, 2019]

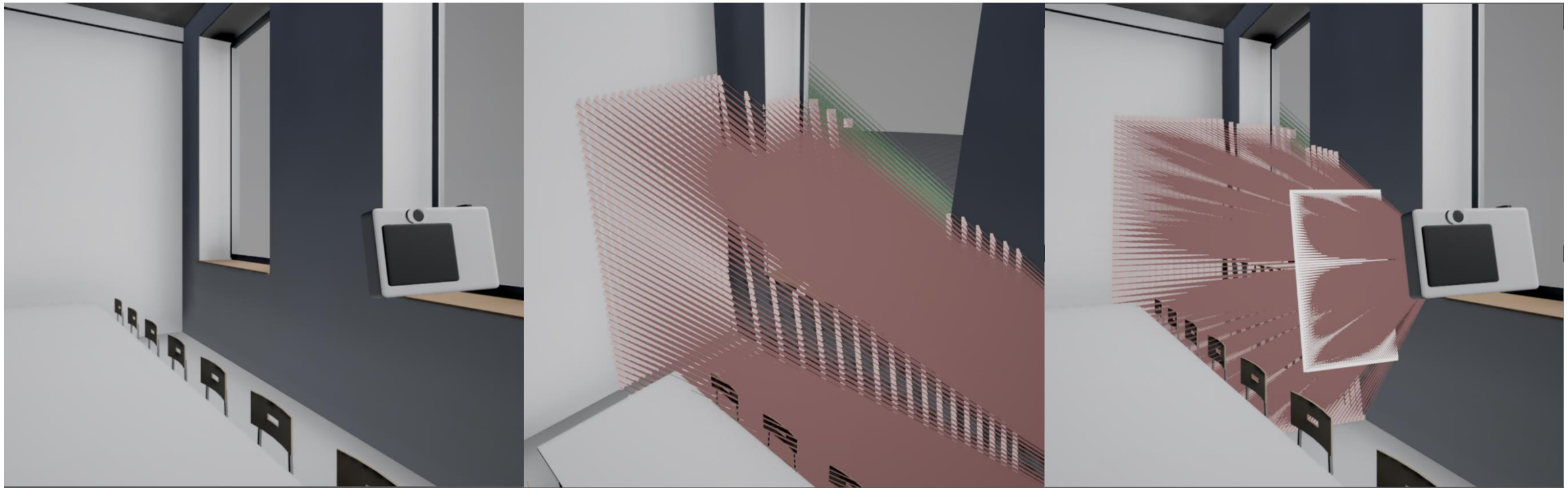
Massive PC Data for DTs in IFC with HDF5



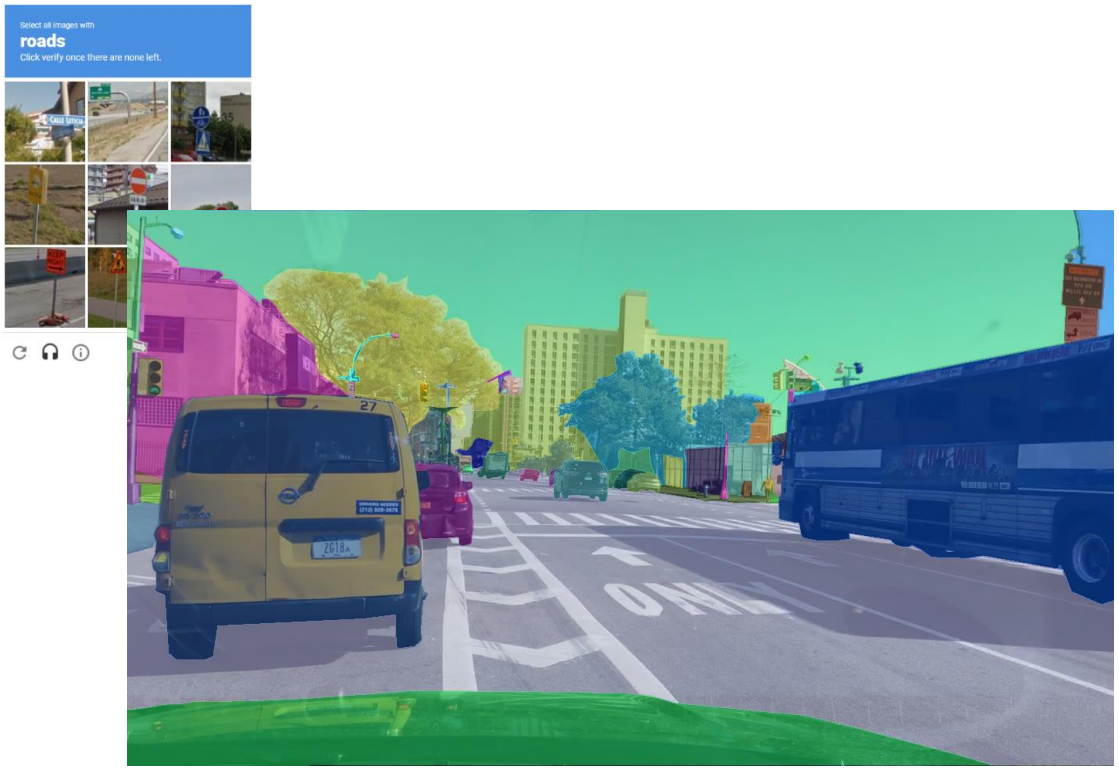




Krijnen, Thomas, and Jakob Beetz. 2017. “An IFC Schema Extension and Binary Serialization Format to Efficiently Integrate Point Cloud Data into Building Models.” *Advanced Engineering Informatics* 33 (Supplement C):473–90. https://doi.org/10.1016/j.aei.2017.03.008.



[Schulz 2019], [Schulz & Beetz]


Select all images with
roads
Click verify once there are none left.

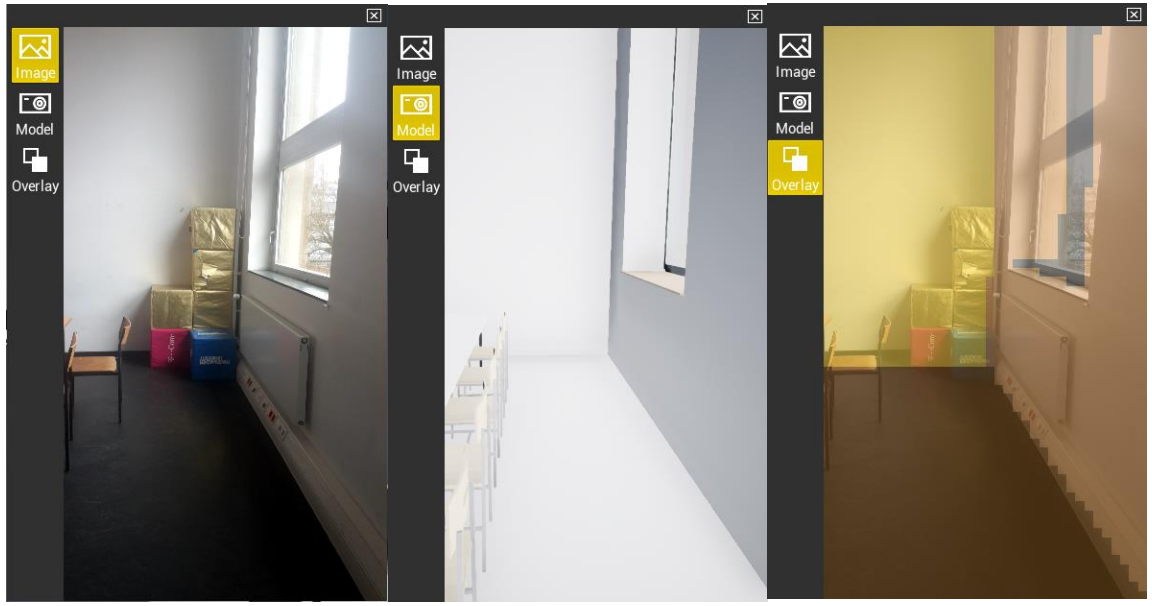
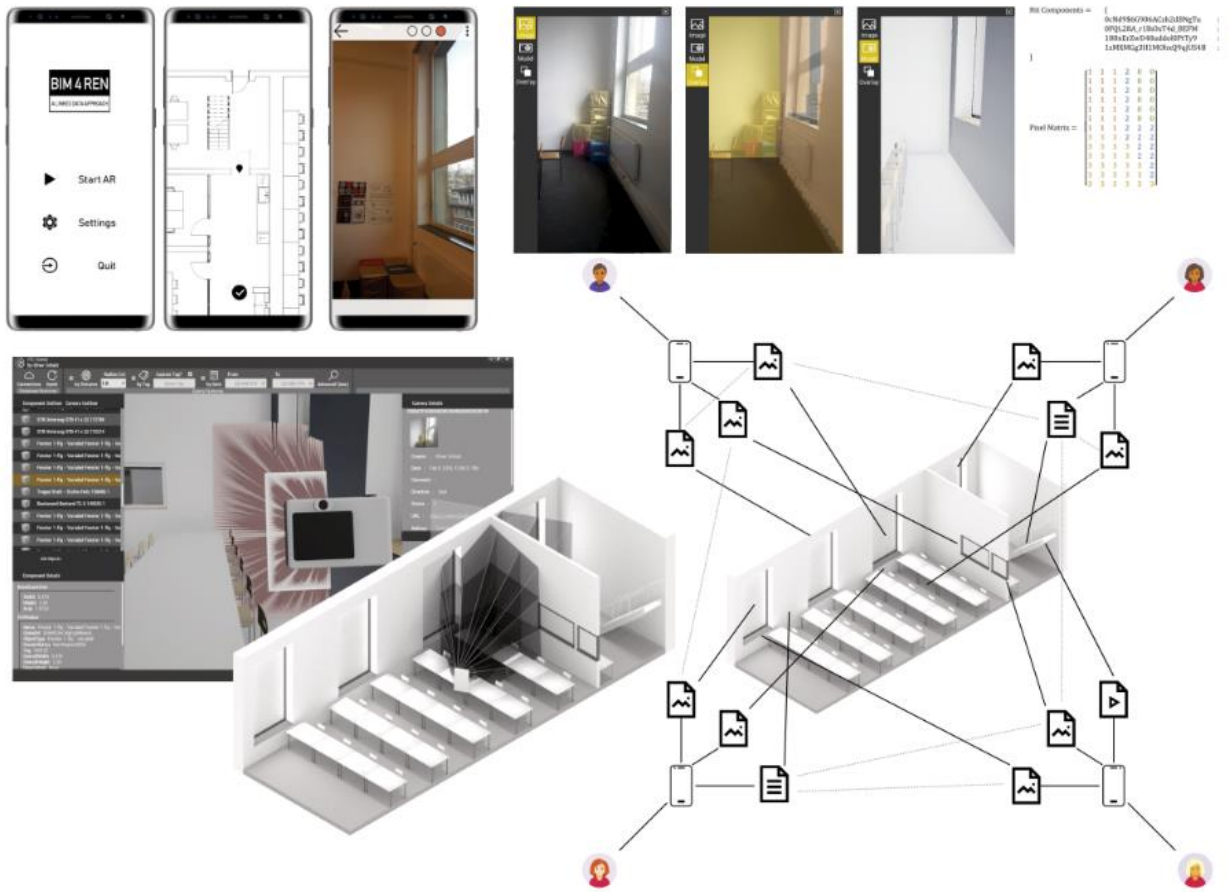


Image
Model
Overlay
Image
Model
Overlay
Image
Model
Overlay

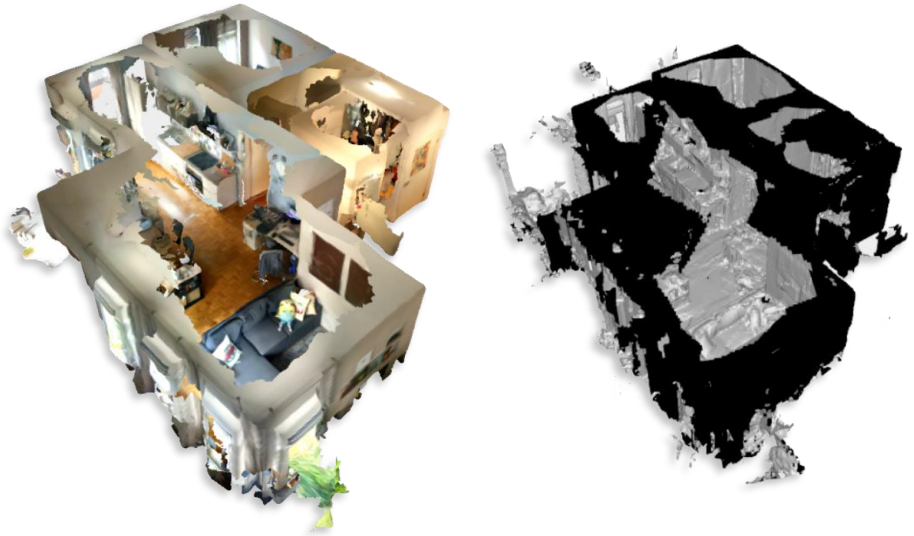
CAIA: Image Aquistion for existing buildings



Schulz, O. & Beetz, J. (2019) *Context-Aware Image Acquisition Approaches for Renovation Building Process Using AR and Linked Data*7th Regional International Symposium on Education and Research in Computer Aided Architectural Design in Europe

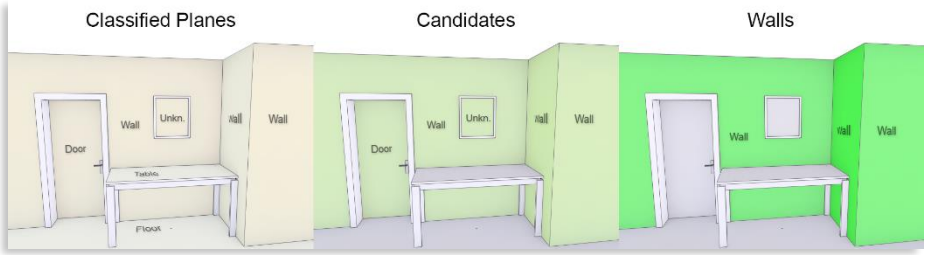
MSc thesis Julian Dorow SoSe 21

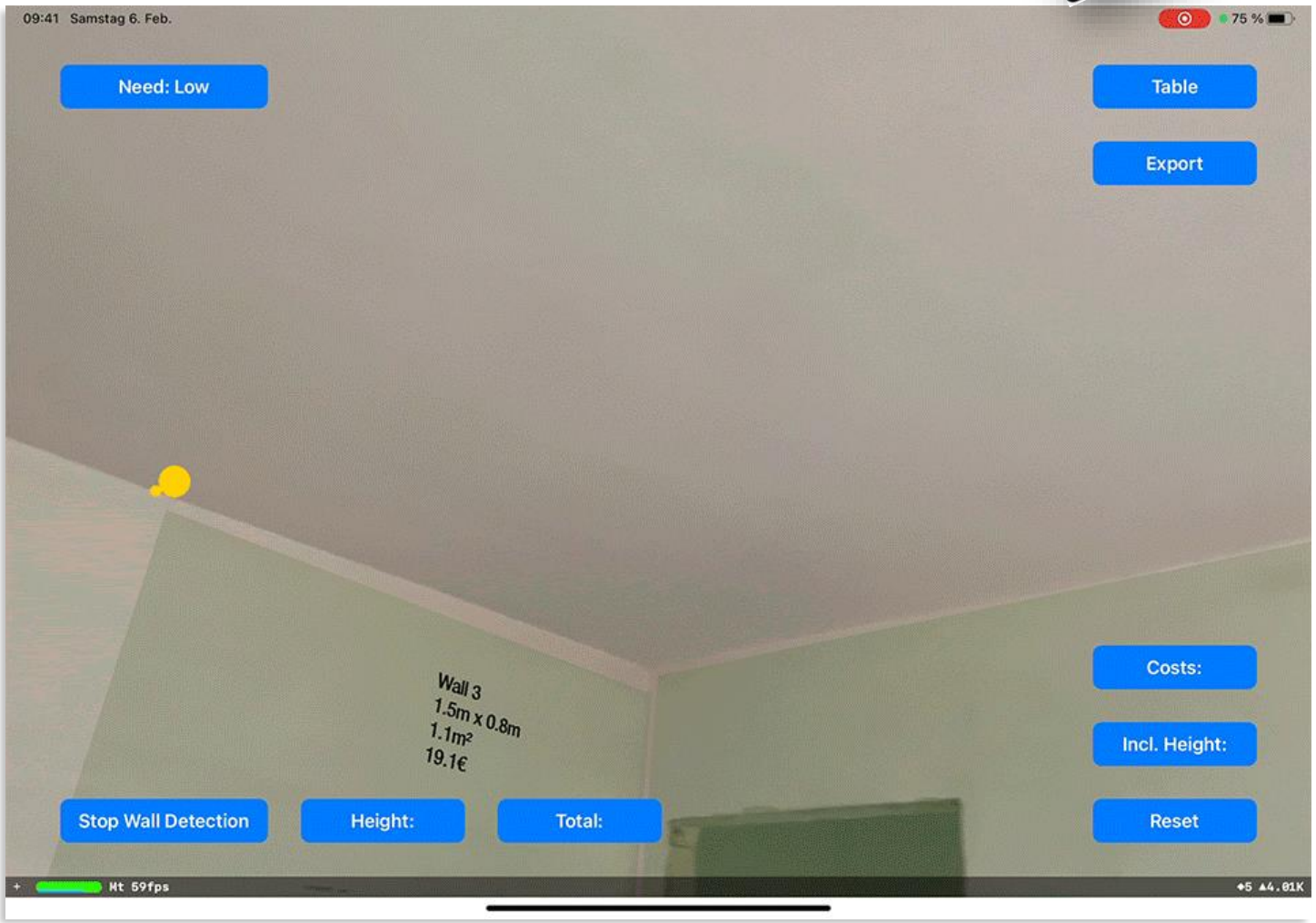
Cost estimation using AR on Tablet



MSc thesis Julian Dorow SoSe 21

Cost estimation using AR on Tablet





MSc Thesis Felix Hüning SoSe 21

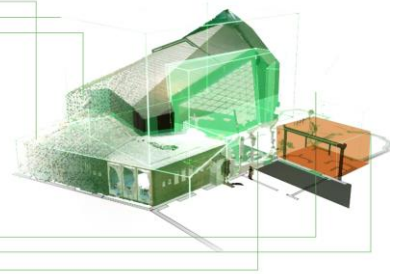
- Integration of existing heritage data structures

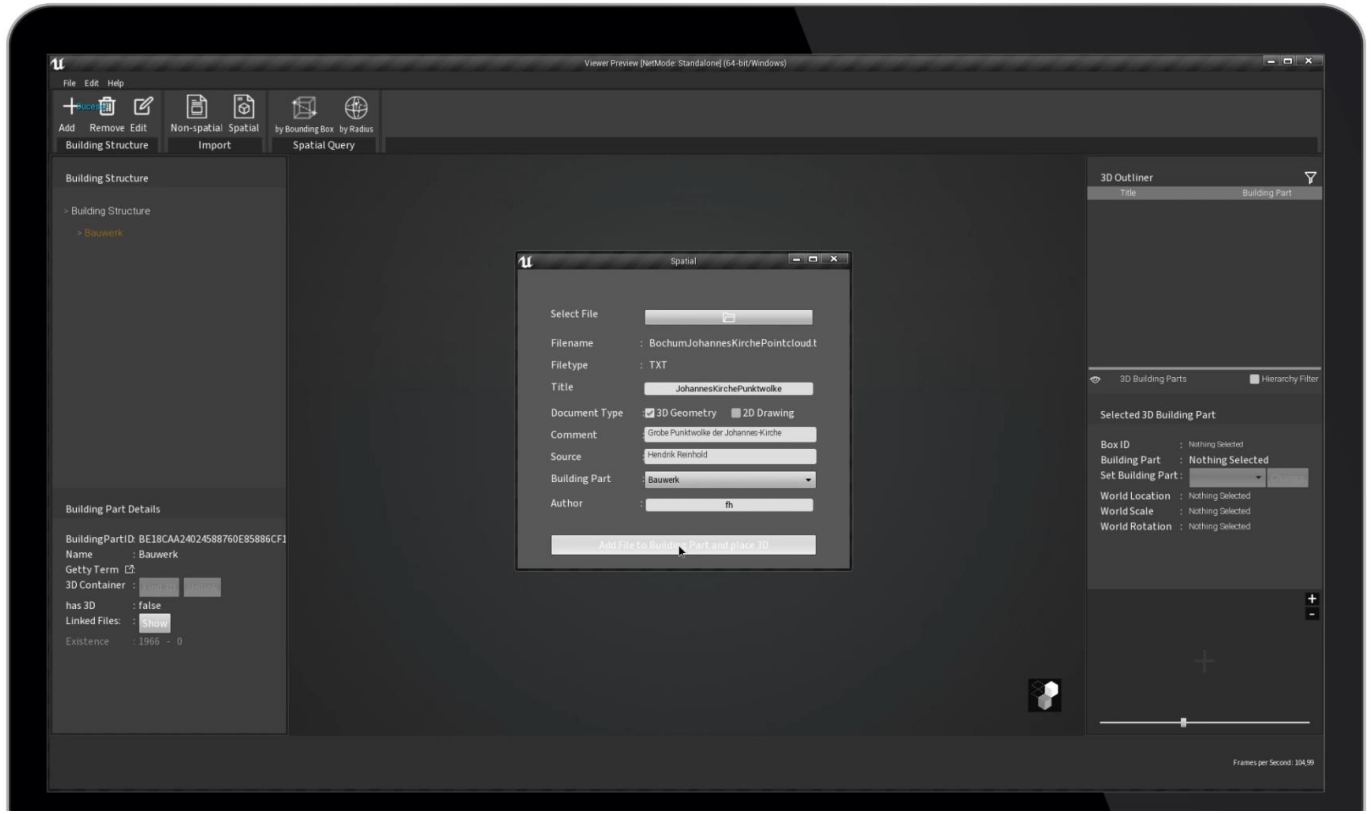
Bauwerksstruktur

```
Areal
    - Johannes-Kirche
    --    Foyer
    --    Großer Saal
    ---     Musikbereich
    ----      Wandfläche 1
    ----      Wandfläche 2
    -----         Fenster
    ----      Wandfläche 3
    -----         Fenster 1
    -----         Fenster 2
    -----         Fenster 3
    -----         Fenster 4
    ---     Altarbereich
    ----      Altar
    ----      Rückwand
    -----         Triptychon

    --    Sakristei
    --    Kapelle
    --    Innenhof
```

Räumliche Repräsentation

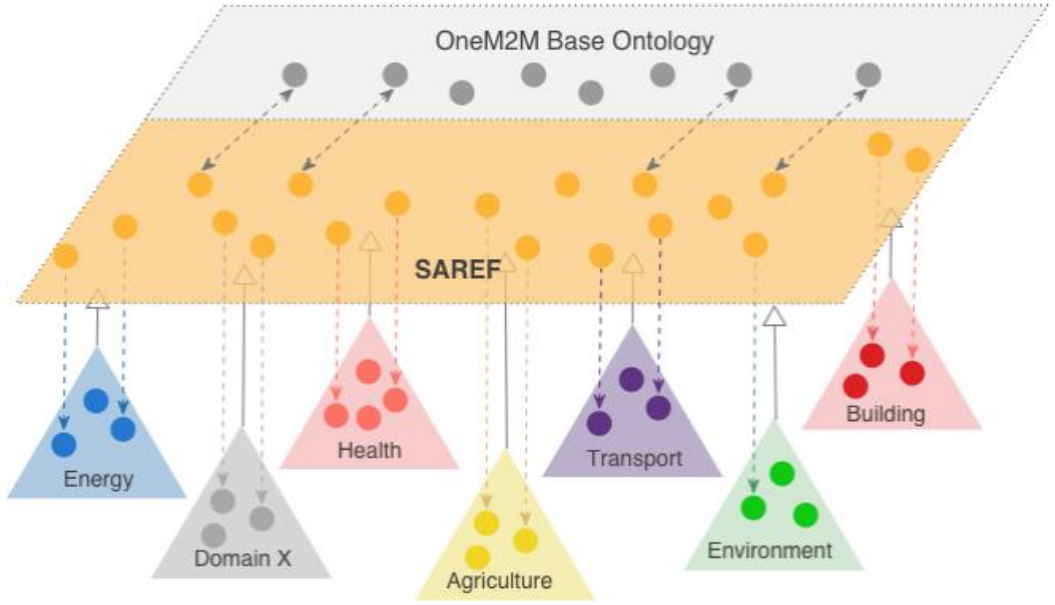


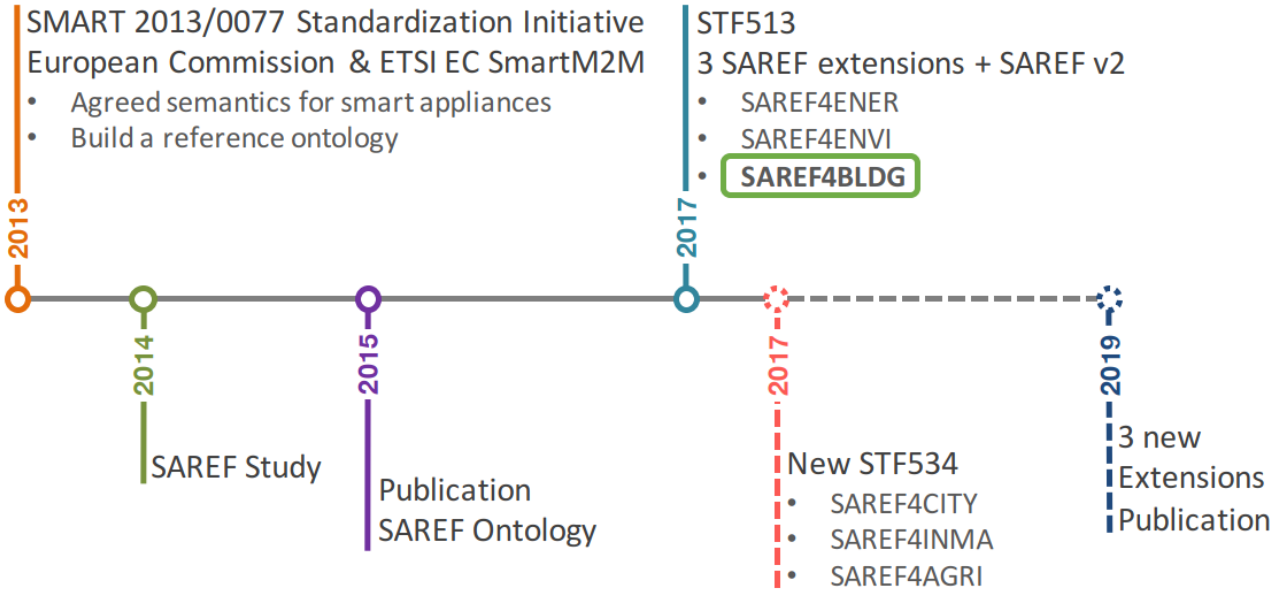


Future: Linked DT Data – SAREF [Poveda 2019]

- Legacy sensor integration
- RDF transformation sensor DB into SAREF
- Interlinking into ifcOWL model SPARQL queries
- [source http://www.oeg-upm.net/]

This material is partially based on “Extending the SAREF ontology for building devices and topology” by María Poveda Villalón and Raúl García Castro”





Future: Linked DT Data – SSN Semantic Sensor Network Ontology

- Semantic Sensor Network Ontology
- W3C Recommendation 19 October 2017
- self-contained core ontology called SOSA (Sensor, Observation, Sample, and Actuator)
- Has PROV-O alignment to capture provenance

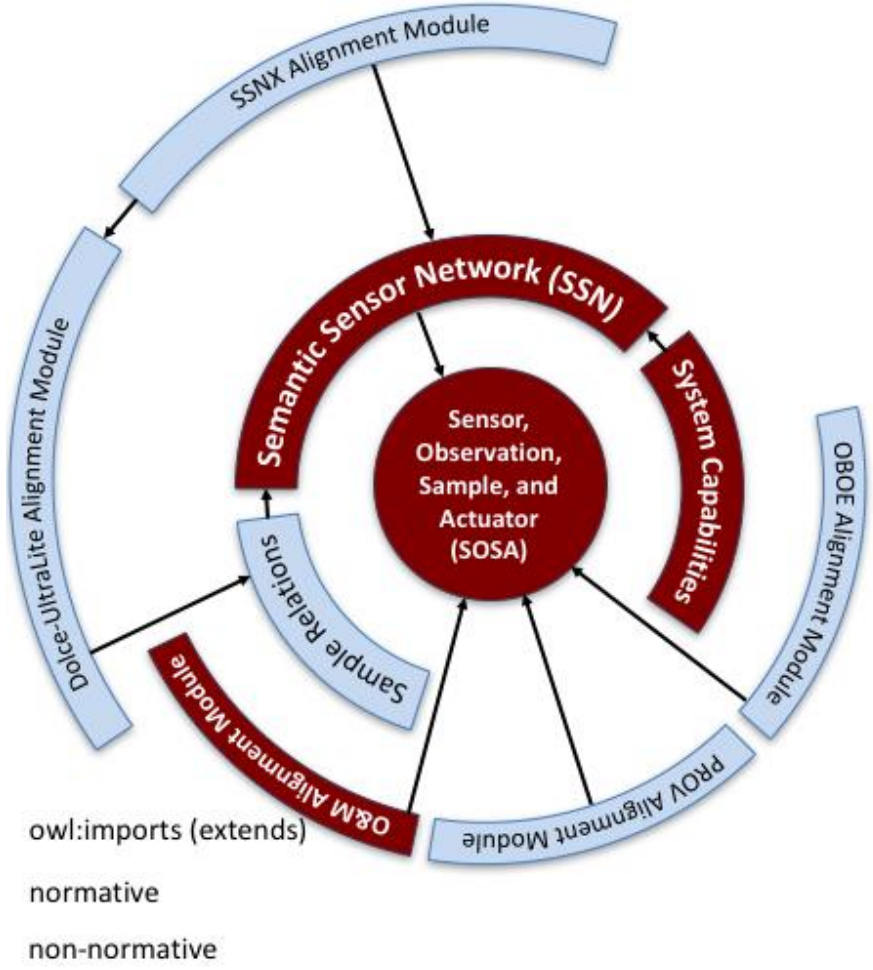
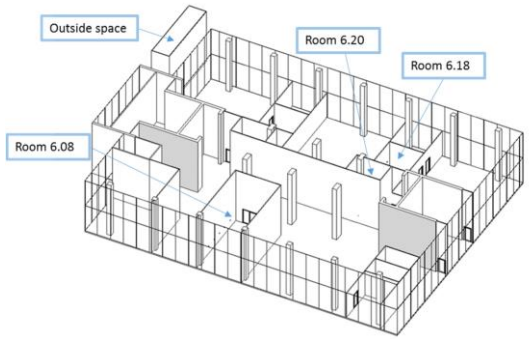


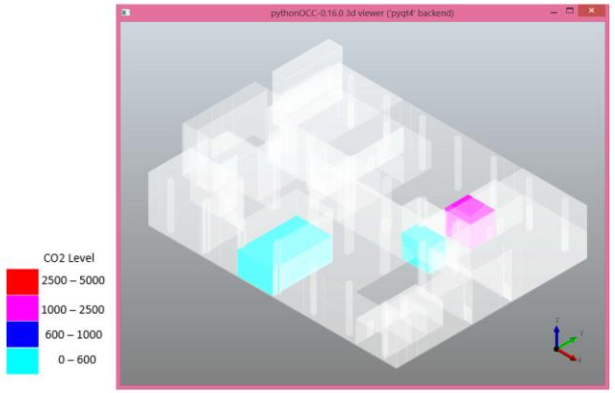
Image source: www.kossmanndejong.nl

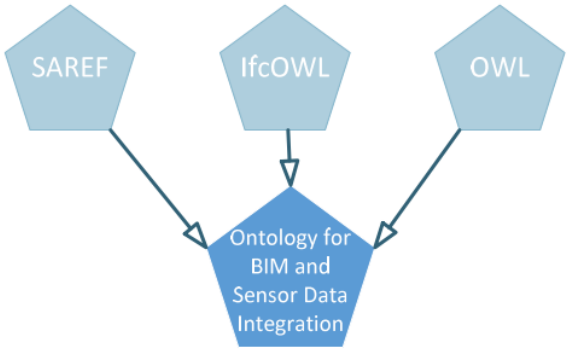
Future: Linked DT Data – SAREF case study [Yu 2016]

- Integration of 48 legacy sensors
- RDF transformation sensor DB into SAREF
- Interlinking into ifcOWL model
- SPARQL queries over many parameters

Sensor Name	Log Interval	Unit	Description	Measurement Range	Location	Height	Log Schedule
DT03	00:00:01	m/s	Air speed at 1.1 m		Room 6.08	1.1m	ComfortStatief
DT06	00:00:01	°C	Air temperature at 1.1 m	-30.0 - 65.0	Room 6.08	1.1m	ComfortStatief
DT07	00:00:01	°C	Temperature black globe at 0.6 m	-30.0 - 65.0	Room 6.08	0.6m	ComfortStatief
DT08	00:00:01	%	Relative Humidity at 0.6 m	0.0 - 100.0	Room 6.08	0.6m	ComfortStatief
M03	00:10:00	ppm	CO2	0 - 5000	Room 6.08		Modbus
M38	00:10:00	°C	Temperature	5 - 45	Room 6.18	0.75m	Modbus
M39	00:10:00	%	Relatieve humidity	0.0 - 100.0	Room 6.18		Modbus
M40	00:10:00	ppm	CO2	0 - 5000	Room 6.18		Modbus
M51	00:10:00	°C	Temperature	-30.0 - 65.0	Room 6.20	0.75m	Modbus
M52	00:10:00	%	Relatieve humidity	0.0 - 100.0	Room 6.20		Modbus
M53	00:10:00	ppm	CO2	0 - 5000	Room 6.20		Modbus
T_amb_avg	00:01:00	°C	Outside temperature		Vertigo roof		DL_SMS_Mete

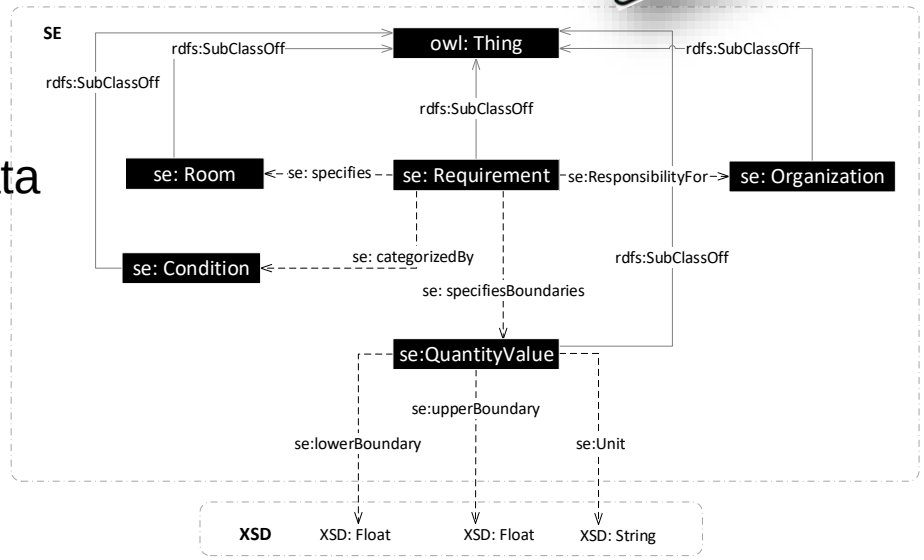


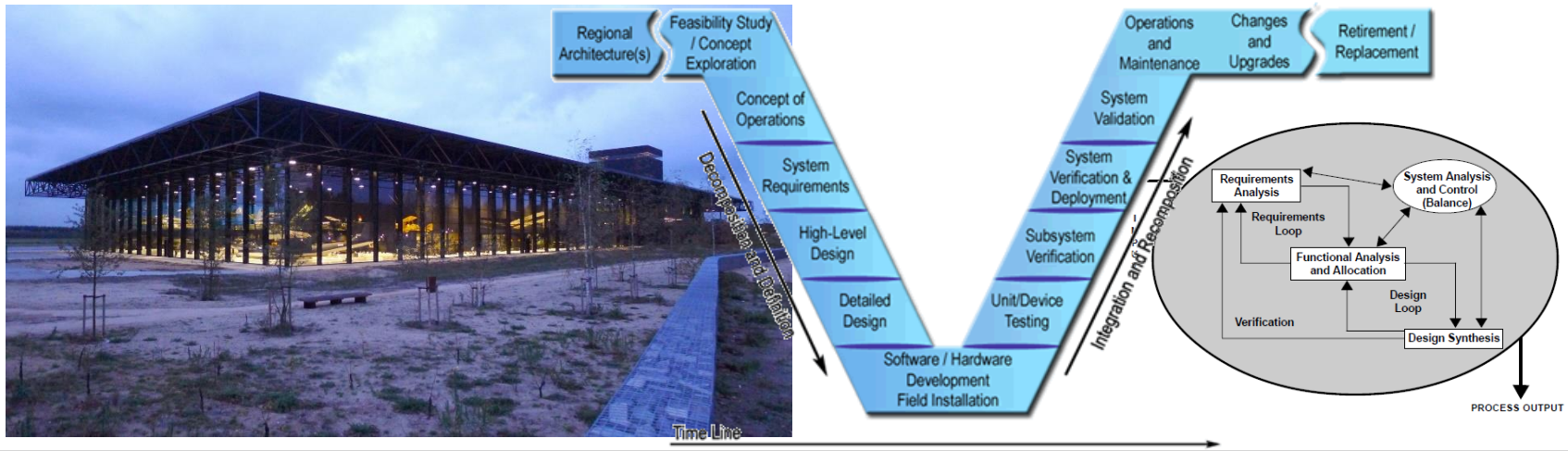




Future: Linked DT Data – SSN case study [Kalpoe 2016]

- Kalpoe, Rakesh (2016): The integration of domain-specific building data using linked data. MSc Thesis (prospective)
- Scheduled compliance checks in performance-based (DBFMO) contracts.
- Example: Room sensor data for National Military Museum, Soest
- Use of **DUL, SSN, QUDT** ontologies augmented with custom Requirements ontology





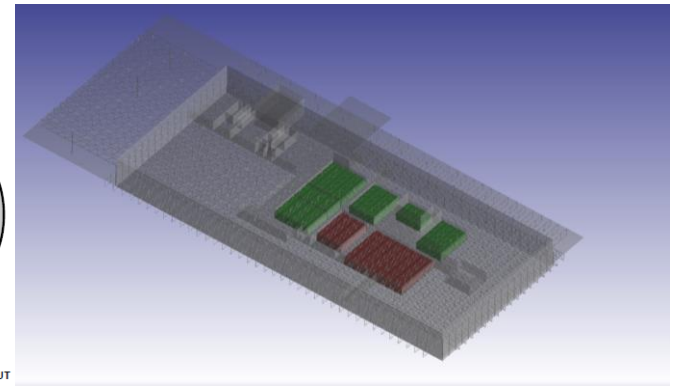


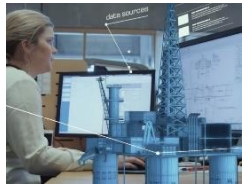
Image source: www.kossmanndejong.nl

The Concept

Edu

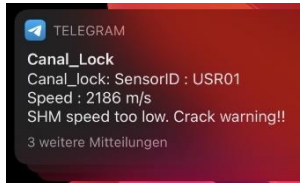
Design Phase **Construction Phase** **Use Phase**

Manual tasks



Plan Sensor Placement

Place Sensors and Receiver



Mobile Device

Monitor

Repair and Maintenance Planning

Programs

Messenger and E-mail

SHM Viewer

Signal Converter

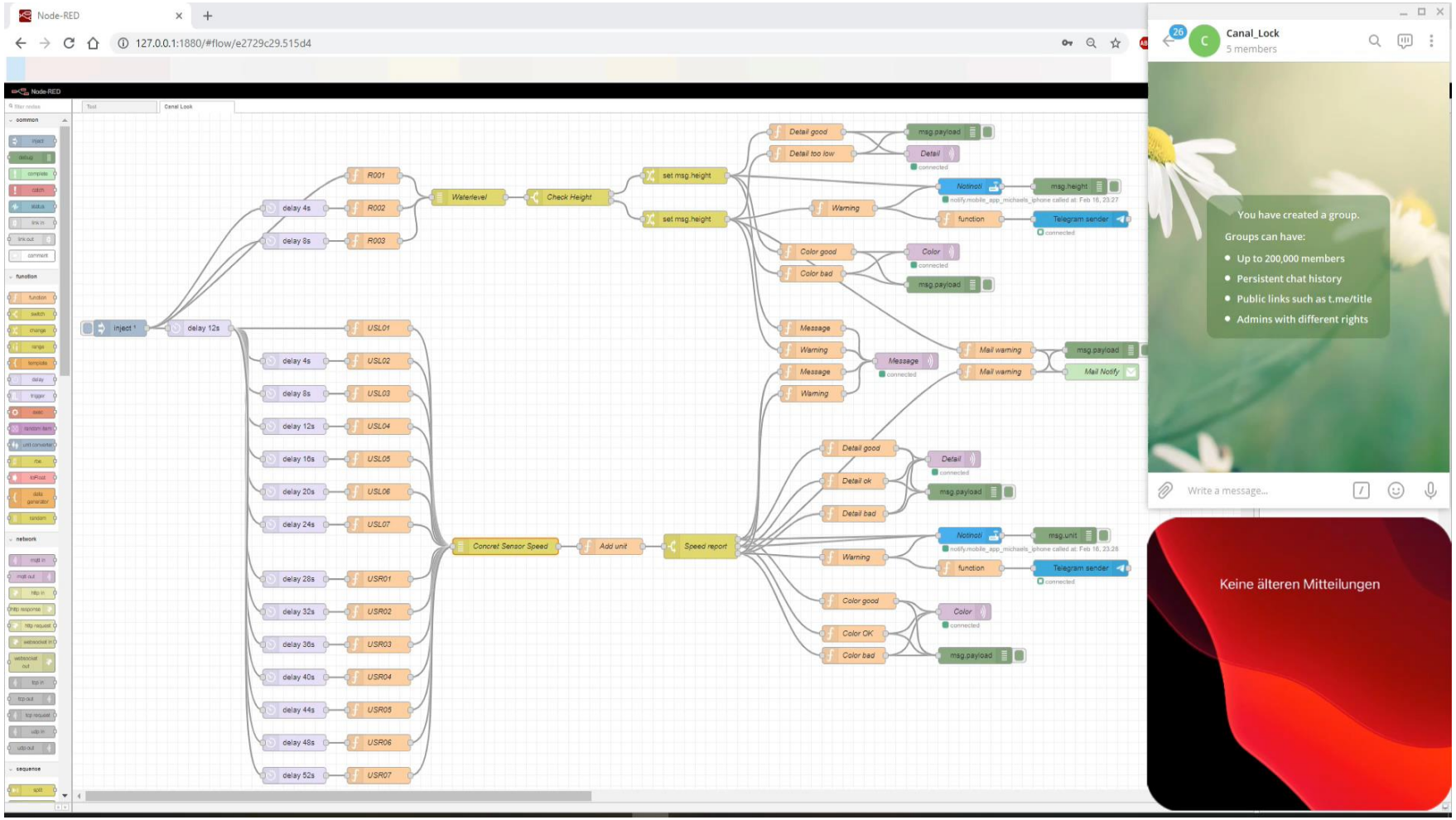
MQTT Broker

SHM Program

Digital Model

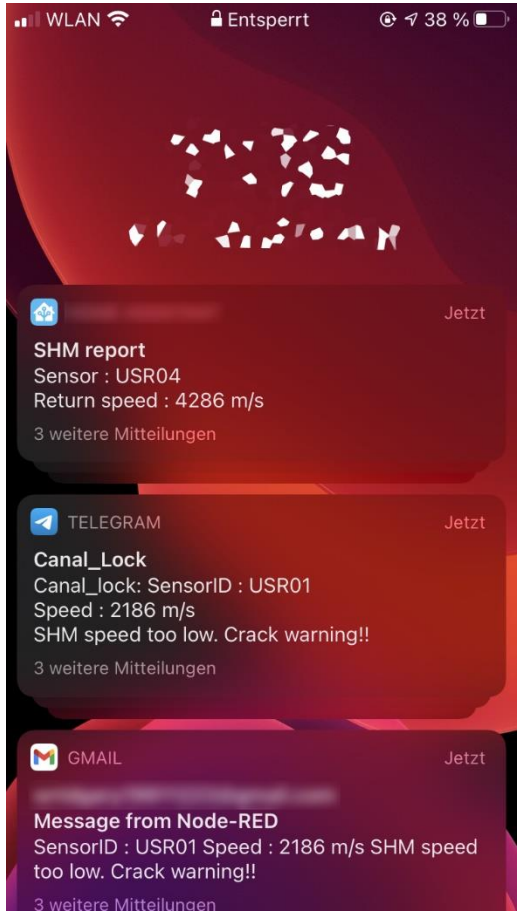
Figures: (in read direction) 5, 6, 7, 8, 9, 10, 11

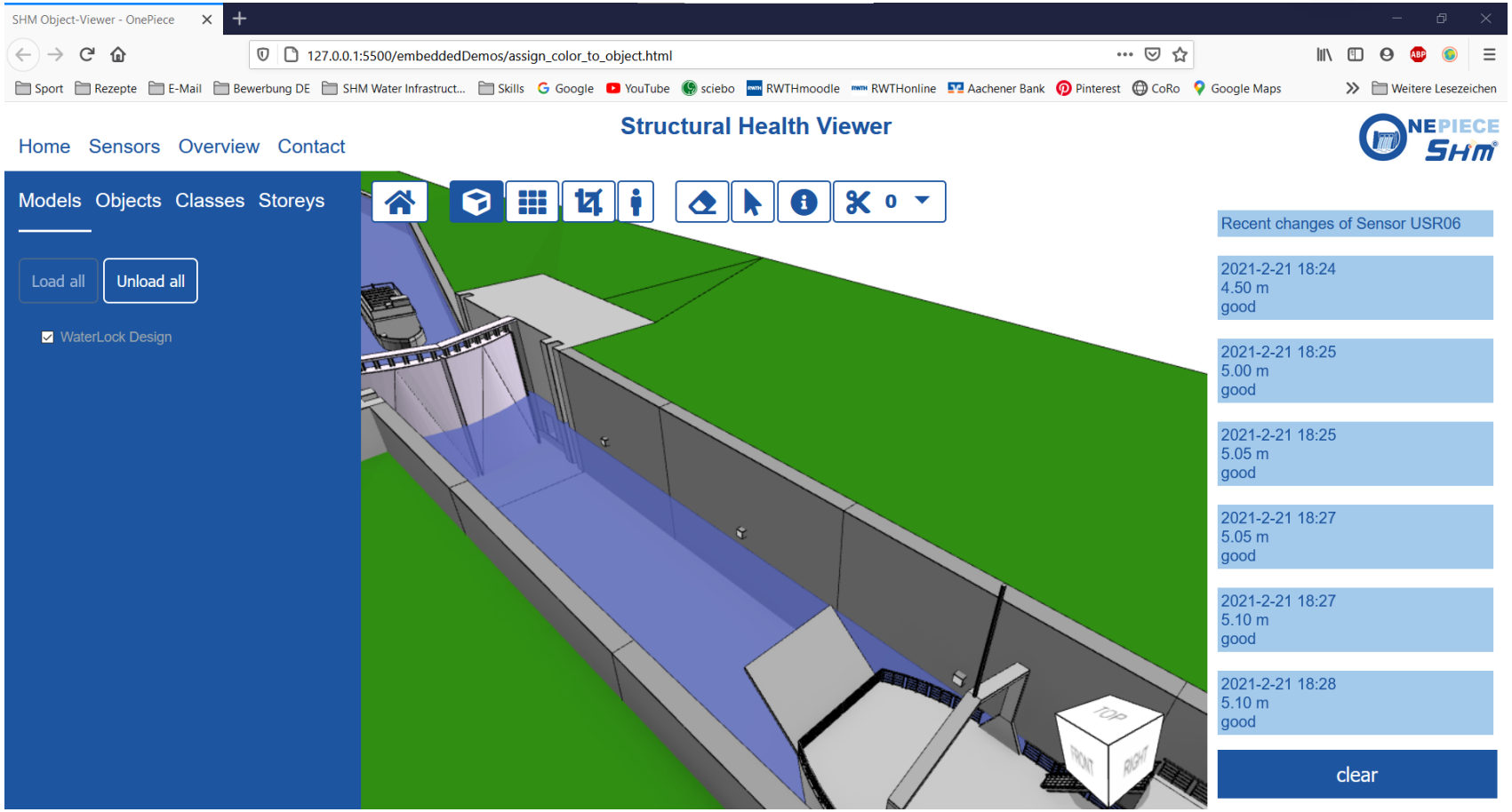
Demonstration



Viewer: https://christine-lappe.github.io/christine-lappe.github.io/embeddedDemos/assign_color_to_object.html

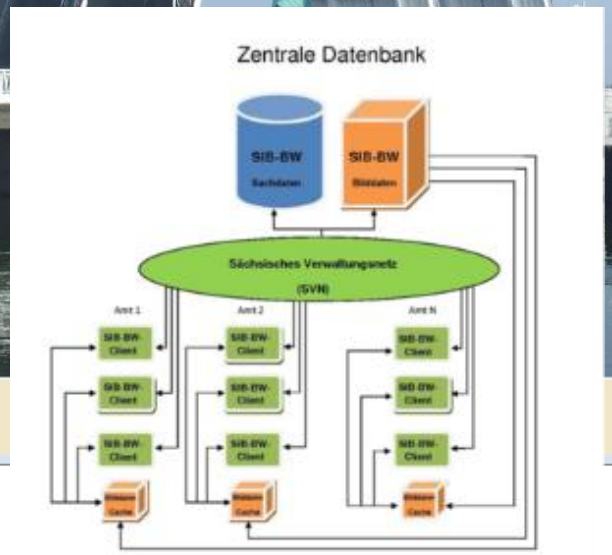
User Surface and Interaction





Use cases: Predictive maintenance

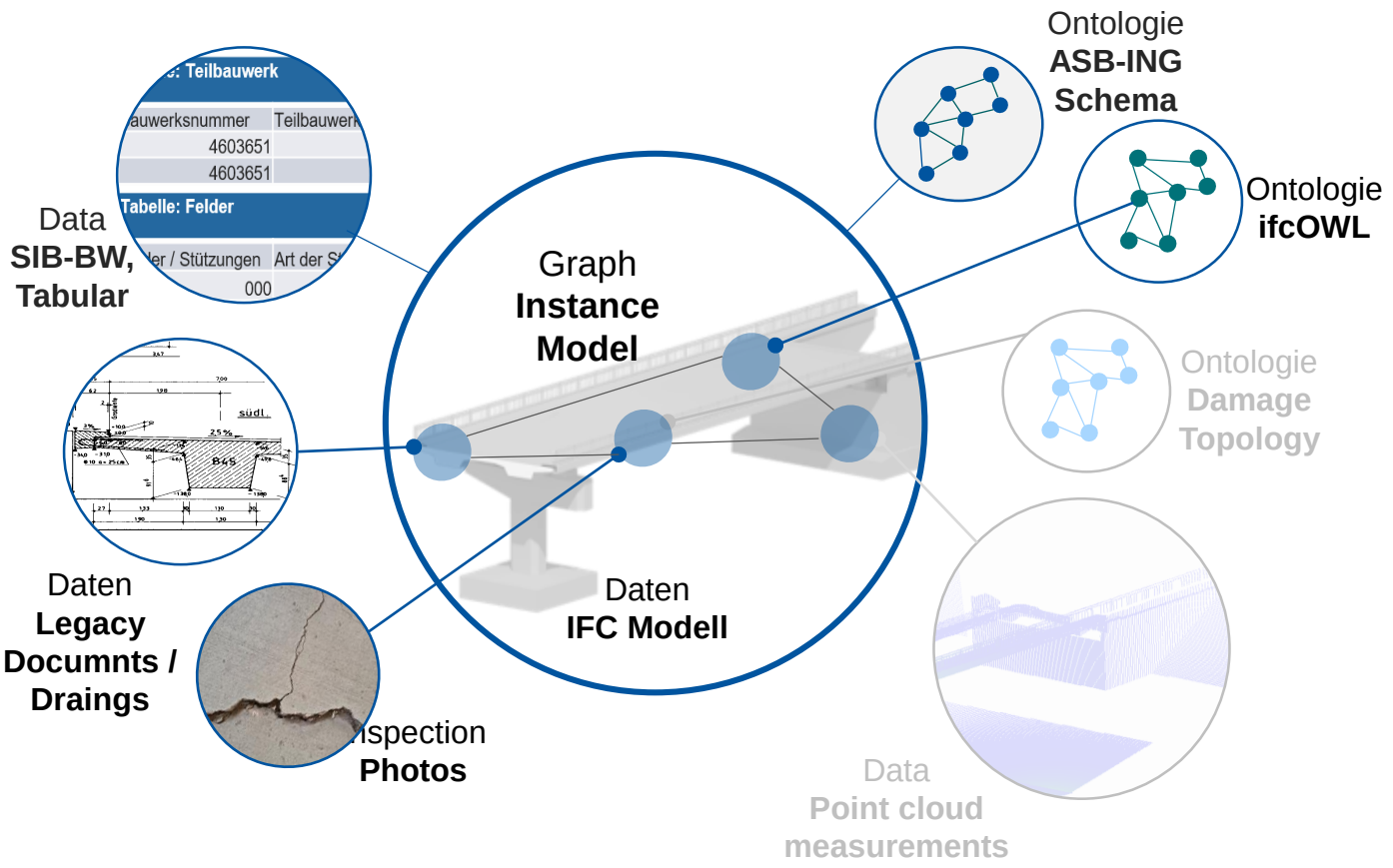
SIB-Bauwerke



Gefördert durch: Bundesministerium für Verkehr und digitale Infrastruktur
ZPP GERMAN ENGINEERING
RUHR UNIVERSITÄT BOCHUM
RUB
RWTH AACHEN UNIVERSITY
Technische Universität München

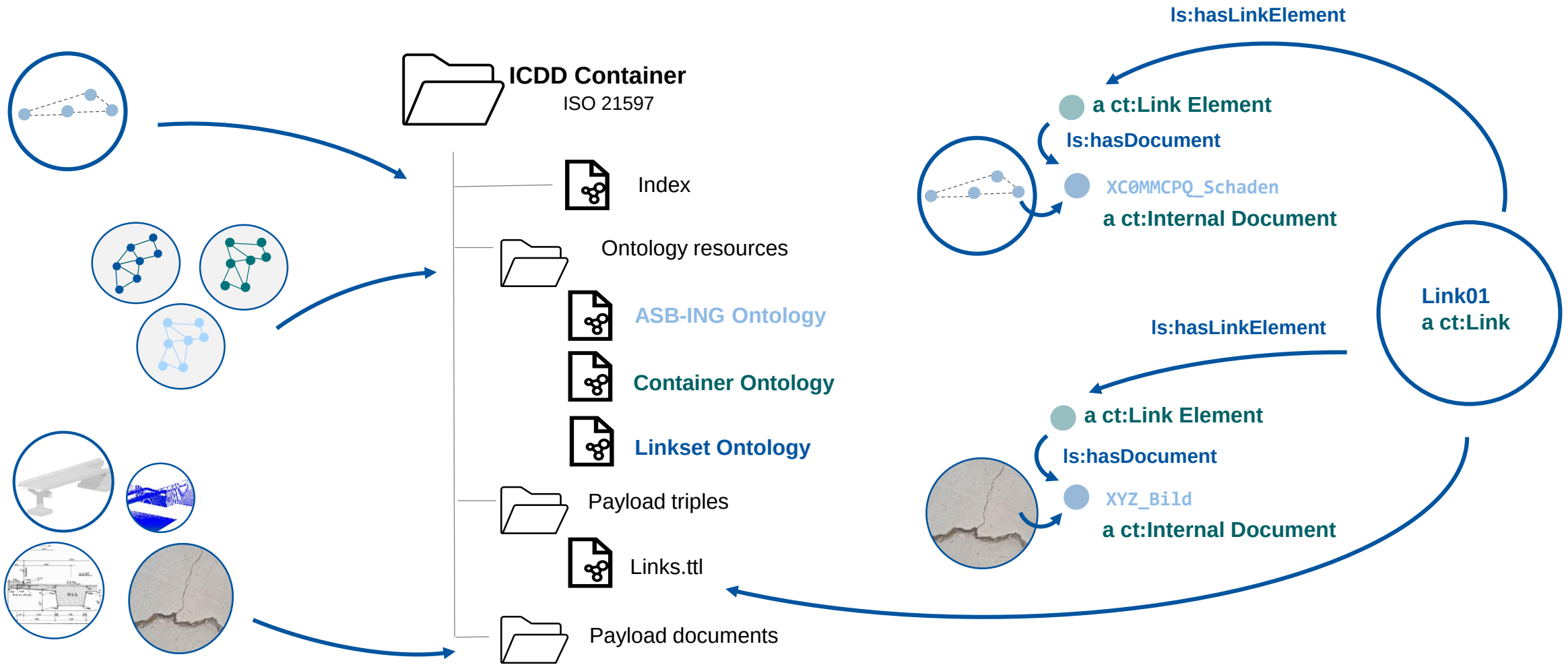
Linking and long-term DT for SIB-BW graph with IFC Model, Pictures, Plans

- Convert IFC Model to LBD Graph (IFC OWL, BOT,…)
- Mapping of IFC (Bridge) Ontology to ASB-ING Ontology
- Linking of building elements intances between SIB-BW and IFC OWL graph
- Creating ICDD Structure for SIB-BW Data, Model, Pictures, Damages..
- Linking Damage Pictures to building elements
- Locate damages in the model, Link between damages and elements



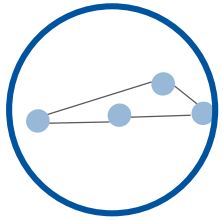
Göbels, Beetz (2021). **Conversion of legacy domain models into ontologies for infrastructure maintenance**. *In Proceedings of the 9th Linked Data in Architecture and Construction Workshop.*

ICDD Container Structur

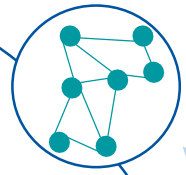


Linking SIB-BW Graph with IFC Model

SIB-BW Graph

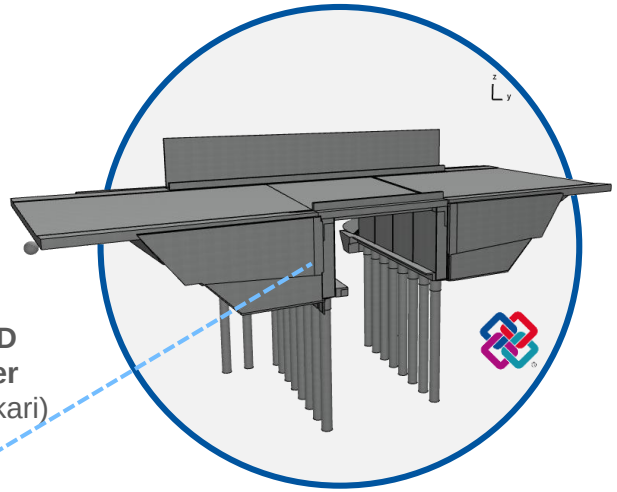


```
inst:wall_4e99b1ef-d1cf-4df6-824b-1b26b5836045
        a                               bot:Element ;
        props:baustoff_simple           "Stahlbeton" ;
        props:bauteilklassifikation_simple
                "N_WDL_SA" ;
        props:betonguete_simple         "C30/37" ;
        props:betonstahl_simple         "B500B" ;
        props:bewehrungsgrad_simple     "149.74"^^xsd:double ;
        props:bezeichnung_simple        "Widerlager" ;
        props:einheit_simple            "m\\X2\\00B3\\X0\\" ;
        props:expositionsklassen_simple
                "XC4 XD2 XF2 WA" ;
        props:globalIdIfcRoot_attribute_simple
                "1EcR7lqSzDze9B6oQrWs15" ;
        props:iFCBauteilklasse_simple   "IfcWall" ;
        props:klassifikation_simple     "Widerlager" ;
        props:lOD_simple                "400."^^xsd:double ;
        props:lebensphase_simple        "Neubau" ;
        props:modellelement_simple      "N_WDL_SA_01" ;
        props:nameIfcRoot_attribute_simple
                "Widerlager" ;
        props:objektname_simple         "Wand" ;
        props:richtzeichnung_simple     "Fl\\X2\\00FC\\X0\\ 1, Bild 1" ;
        props:standardleistungsnummer_simple
                "12.914.2/110 09 08 05 01 TA" ;
        props:volumen_simple            "436.72"^^xsd:double ;
        owl:sameAs                      inst:IfcWall_48304 .
```

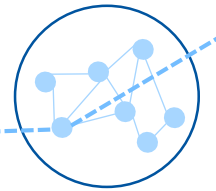


LBD Graph

IFCtoLBD Converter (Jyrki Oraskari)

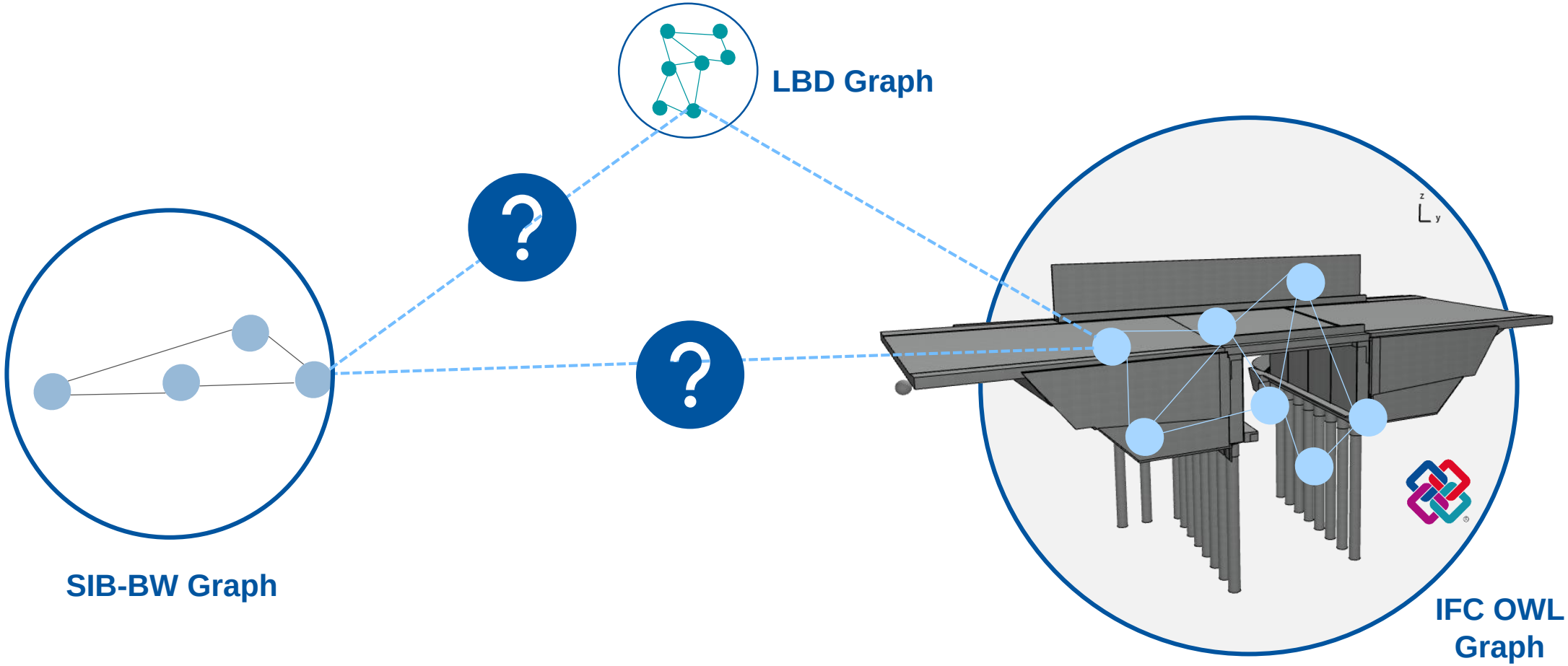


IFC Model

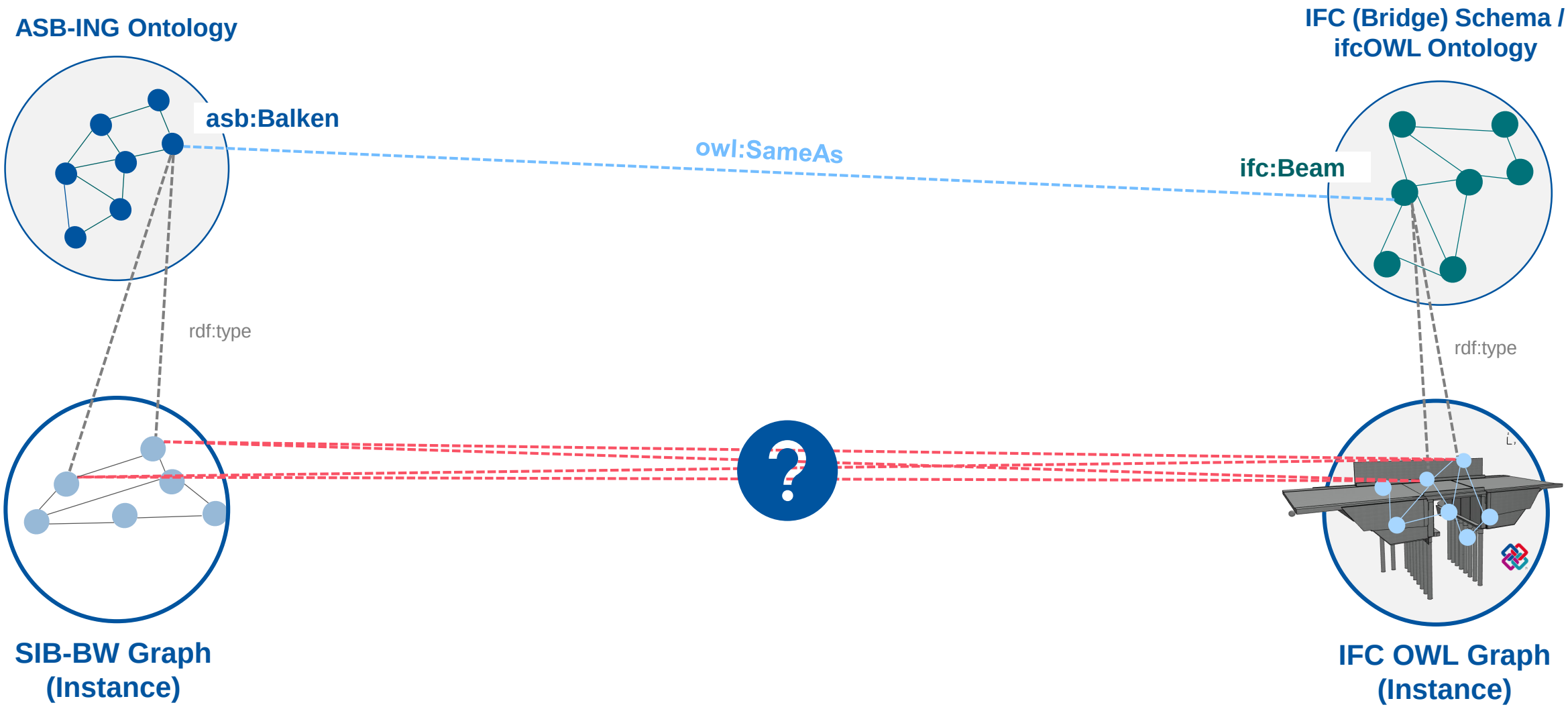


ifcOWL Graph

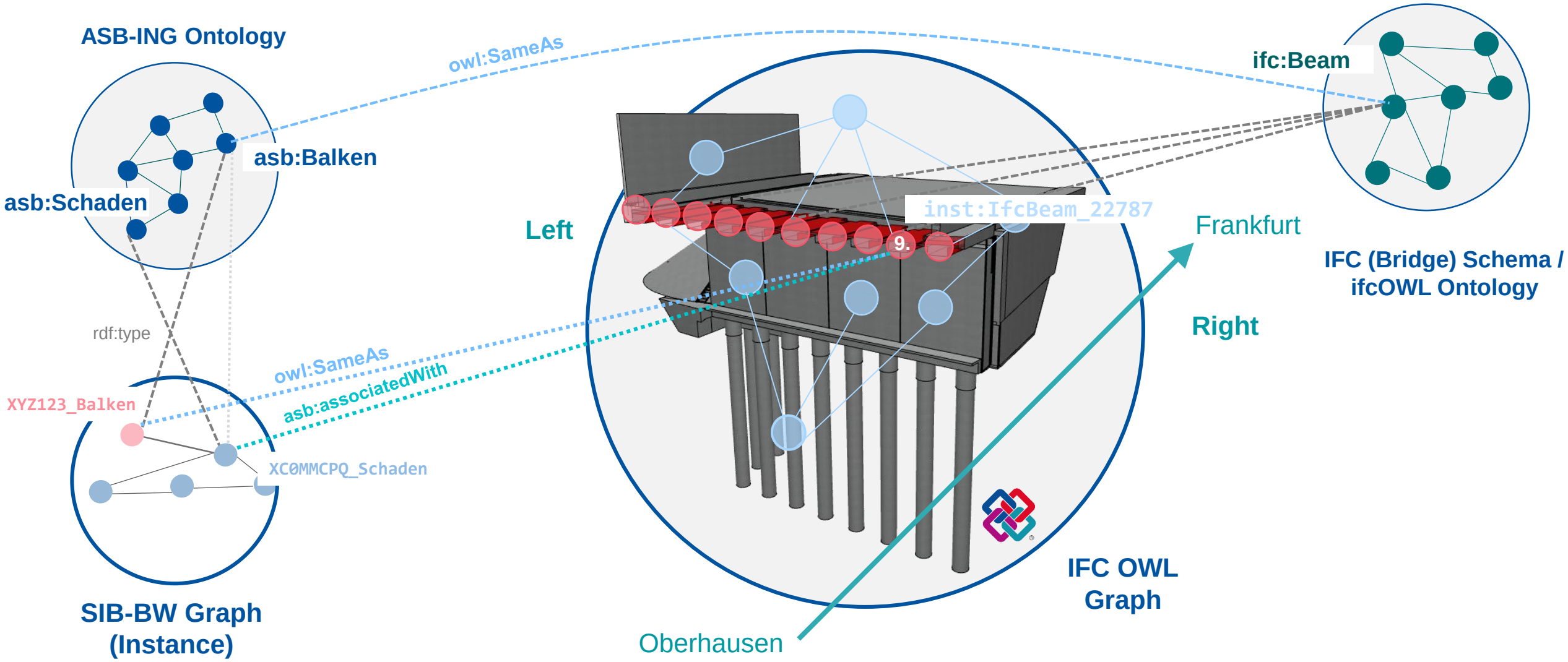
Linking SIB-BW Graph with IFC Model



Linking SIB-BW Graph with IFC Model – Mapping of classes and elements



Linking SIB-BW Graph with IFC Model – Mapping of classes and elements



NL
D
Stiftung
Haus der Geschichte
der Bundesrepublik Deutschland

NL
D
Stiftung
Haus der Geschichte
der Bundesrepublik Deutschland

Use cases: Linked Road information models

Example use cases:

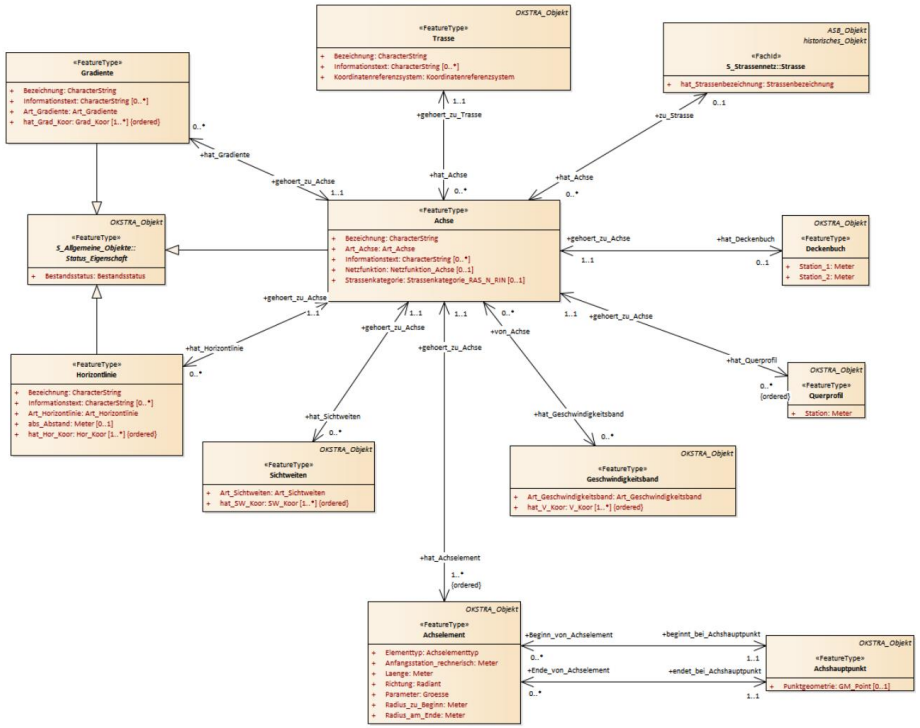
- Find a route for a heavy freight transport **across different countries**
- Query traffic cameras **along international roads** → traffic forecast
- Orchestrate construction and maintenance work **across major transportation axes in Europe**

[Beetz & Borrmann 2018]

OKSTRA → okstraOWL

- German Road Data Model
- Very comprehensive data model
- More than 3,800 entities,
  14,000 attributes
- Covers design, condition, maintenance, equipment, traffic, accidents, etc.
- Mandatory in public projects
- Implemented in commercial products
- Modelled in UML,
  mapped to XML-Schema
- Geometry: GML
- German denominators

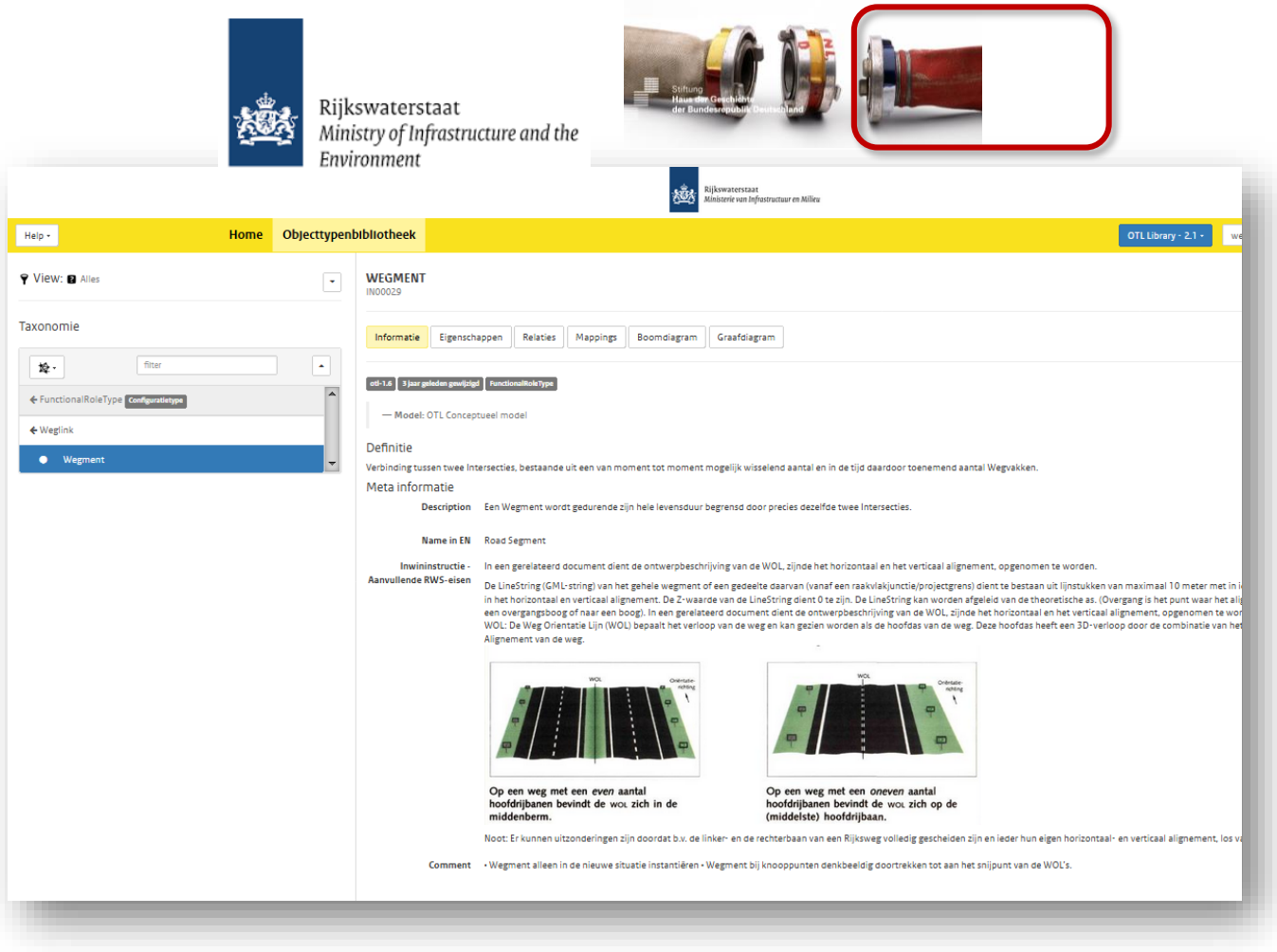
Federal Ministry
of Transport and
Digital Infrastructure



- Paket S_Administration
- Paket S_Allgemeine_Geometrieobjekte
- Paket S_Allgemeine_Mengenberechnung
- Paket S_Allgemeine_Objekte
- Paket S_Arbeitsstelle_an_Strassen
- Paket S_Bauliche_Strasseneigenschaften
- Paket S_Bauwerke
- Paket S_Dynamische_Beschilderung
- Paket S_Dynamische_Verkehrsdaten
- Paket S_Entwurf
- Paket S_Flaechenmodell
- Paket S_Grunderwerb
- Paket S_Hausnummern
- Paket S_Historisierung
- Paket S_Kataster
- Paket S_Kostenmanagement
- Paket S_Kreuzungen
- Paket S_Landschaftsplanung
- Paket S_Lichtsignalanlage
- Paket S_Liegenschaftsverwaltung
- Paket S_Netzaenderungsprotokoll
- Paket S_Oekologie
- Paket S_Organisation
- Paket S_Projektressourcen
- Paket S_Pruefdaten
- Paket S_REB_22013
- Paket S_Schwertransport
- Paket S_Statische_Beschilderung
- Paket S_Strassenausstattungen
- Paket S_Strassennetz
- Paket S_Strassenverzeichnis
- Paket S_Strassenzustandsdaten
- Paket S_Topografie
- Paket S_Umfeldmessstelle
- Paket S_Unfall
- Paket S_Verkehr
- Paket S_Vermessungspunkt

Rijkswaterstaat Object Type Library (RWS-OTL)

- Ontology of the Dutch Ministry of Transport
  - Multiple domains, including roads
- Part of the Dutch BIM for Roads practice
- Defined in OWL
- Describes network, roadway, layers
- Geometry outsourced to common GML format and linked in containers
- Linked to national “upper ontology” Concept Library CB-NL

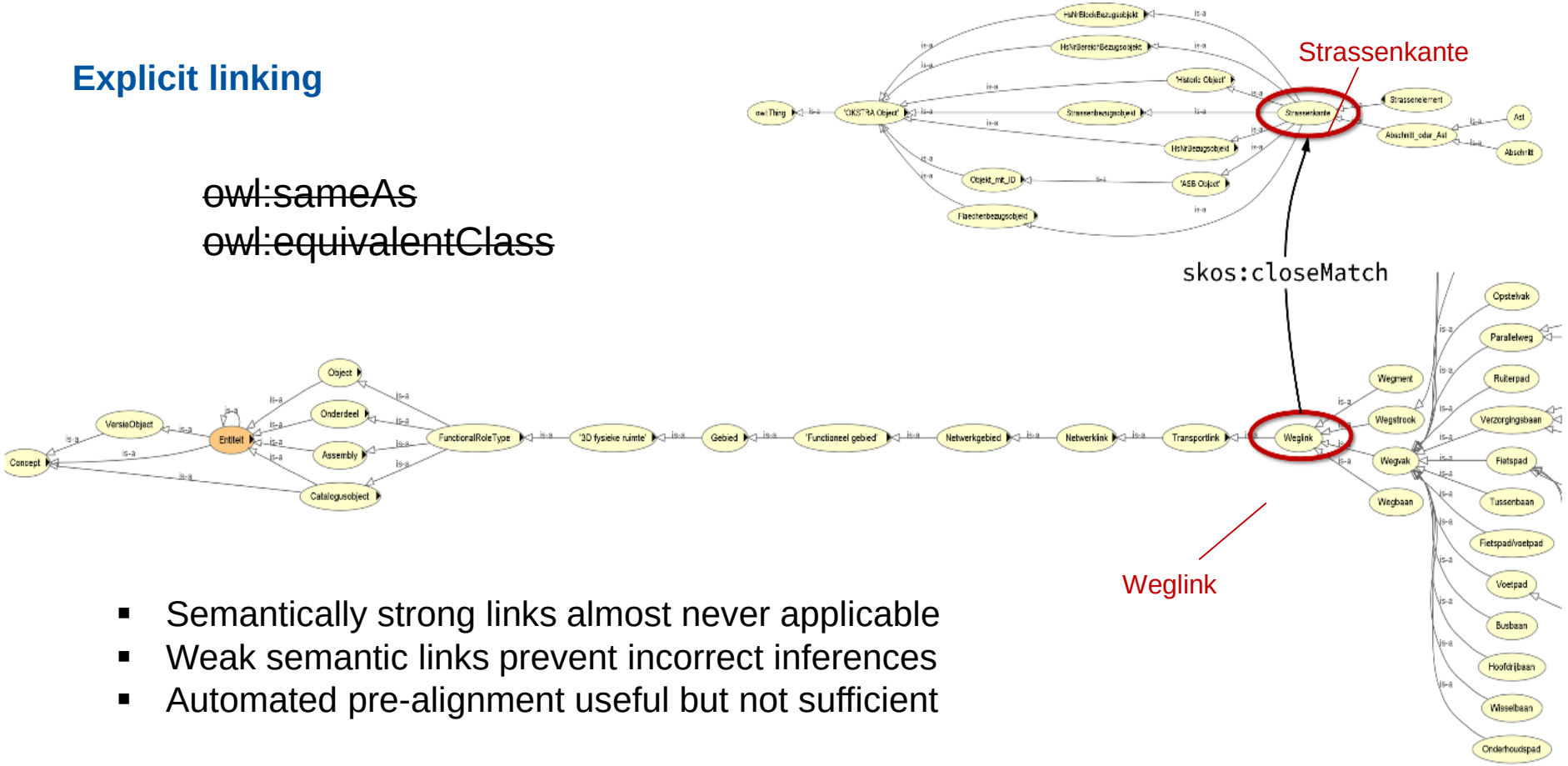


source: https://otl.rws.nl/publicatieomgeving/#/

Linking okstraOWL and RWS-OTL

Explicit linking

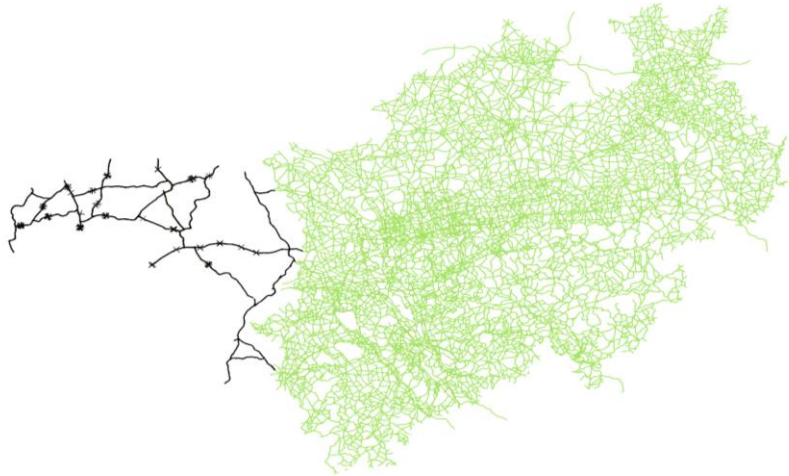
~~owl:sameAs~~
~~owl:equivalentClass~~

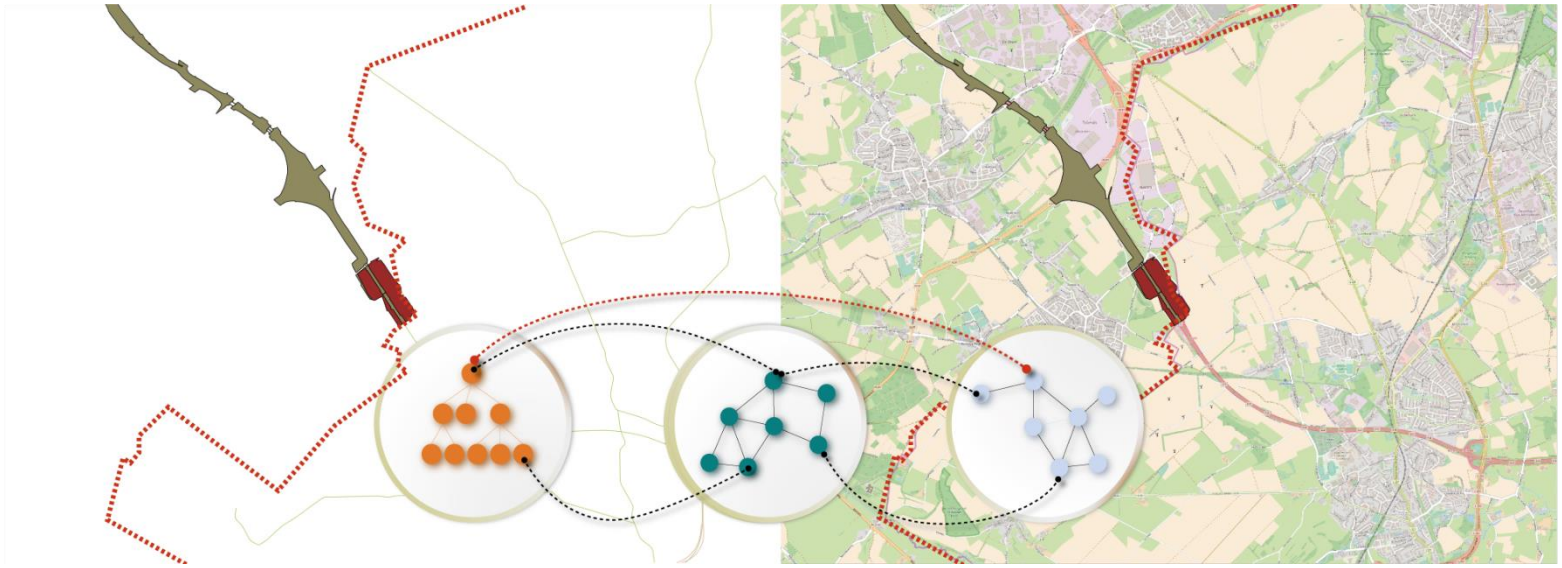


- Semantically strong links almost never applicable
- Weak semantic links prevent incorrect inferences
- Automated pre-alignment useful but not sufficient

Linked Data in Road Construction: Scenario 1: Explicit mapping of RWS-OTL and OKSTRA data sets

- okstraOWL and CB-NL instance data
- Additional classifications of road sections through schema mappings and SPARQL rules
- Graphs of > 140 Mio triples
- Queries across (physically distributed) graphs

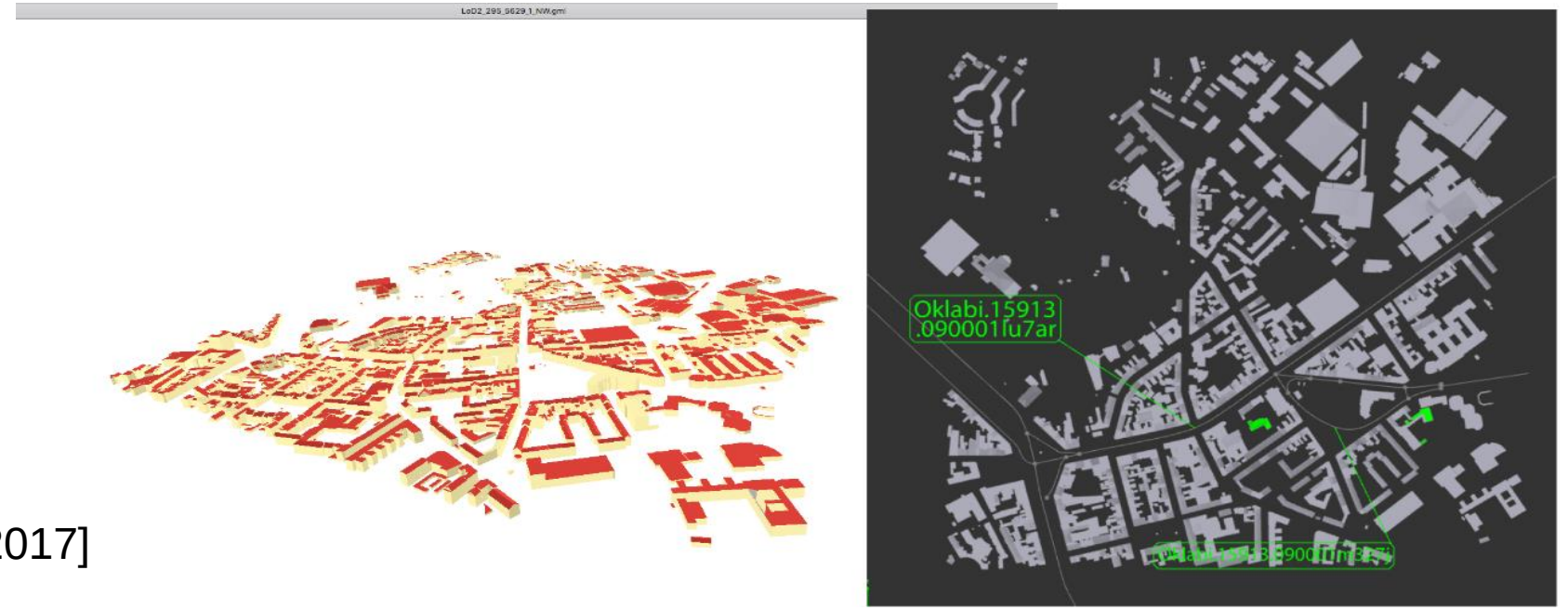




[Beetz & Borrmann 2018]

Scenario 2:
Implicit mapping OKSTRA with CityGML

- Integration of LOD2 CityGML data sets
  (Open Geo Data NRW federal state)
- Intensive use of GeoSPARQL functionalities
- “Retrieve all kindergardens with a distance < 100m to highways“



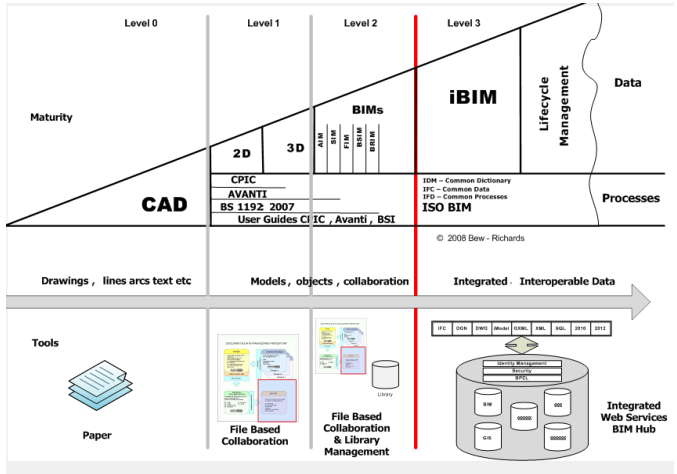
[Beetz & Borrmann 2018] [Zheng 2017]

Design Computation Curriculum in Arch. B.A.

Kontext im Curriculum des Bachelor Architektur

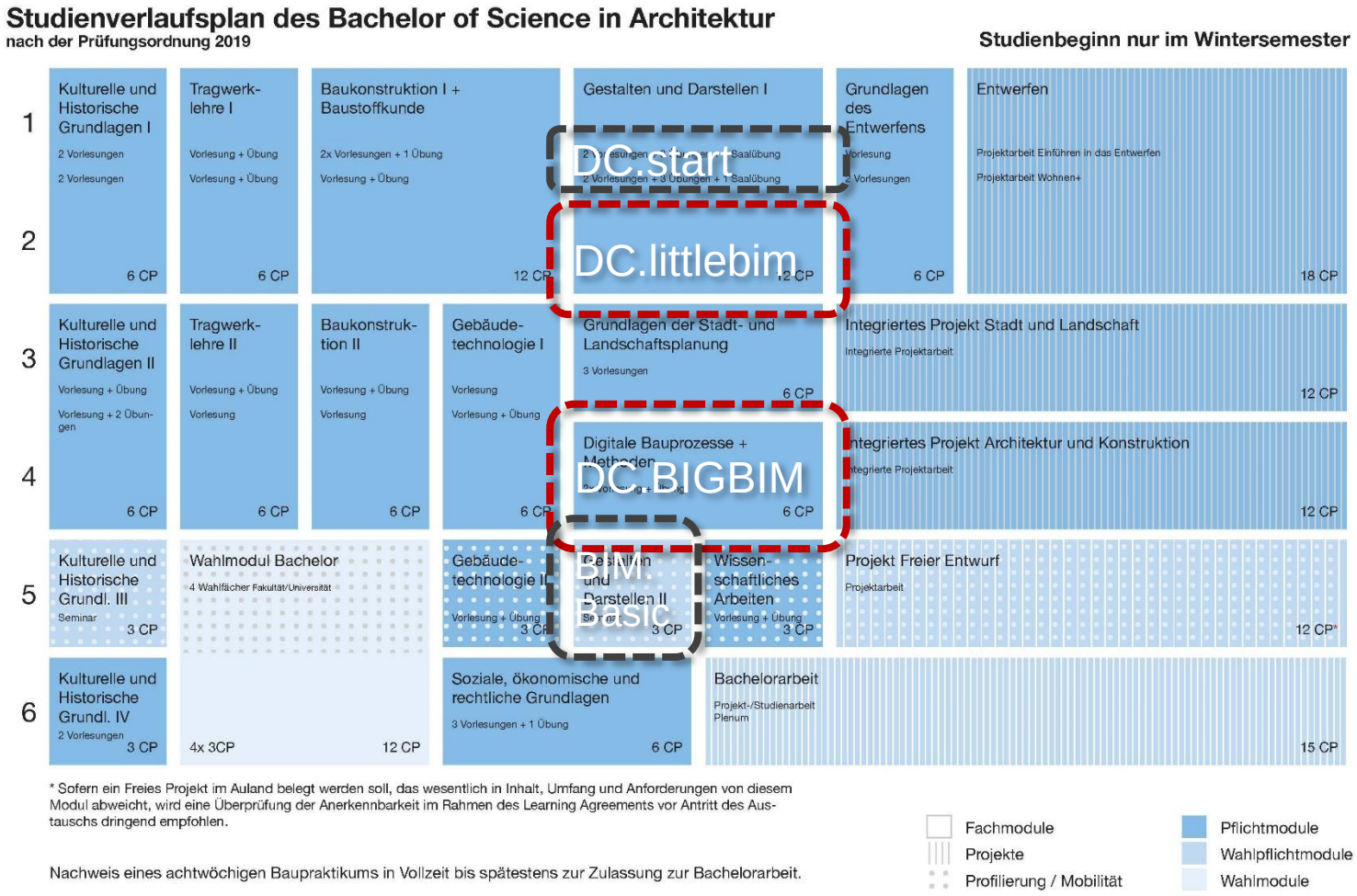
DC.start
DC.littlebim
DC.BIGBIM
DC.B
DC.4 M1, M2, M3

Level 0	Level 1	Level 2	Level 3	
	2D 3D	Federated BIMs	Integrated BIM	
CAD	Proprietary Formats	Proprietary formats + COBie	ISO standards	Exchange Formats
Drawings	Geometric models	Coordinated Discipline specific BIM models	Integrated, interoperable Building Information Models for the entire life-cycle	Depth of information
Paper	File-based collaboration	Central manage-ment of files (Common Data Environment), Shared libraries	Cloud-based model management (BIM Hub)	Coordination and Collaboration



- [Borrmann König, Koch, Beetz 2015] auf Bew & Richards basiert

Design Computation Curriculum | Bachelor



Lectures

Excercises

Design Computation Curriculum | Master

Lectures

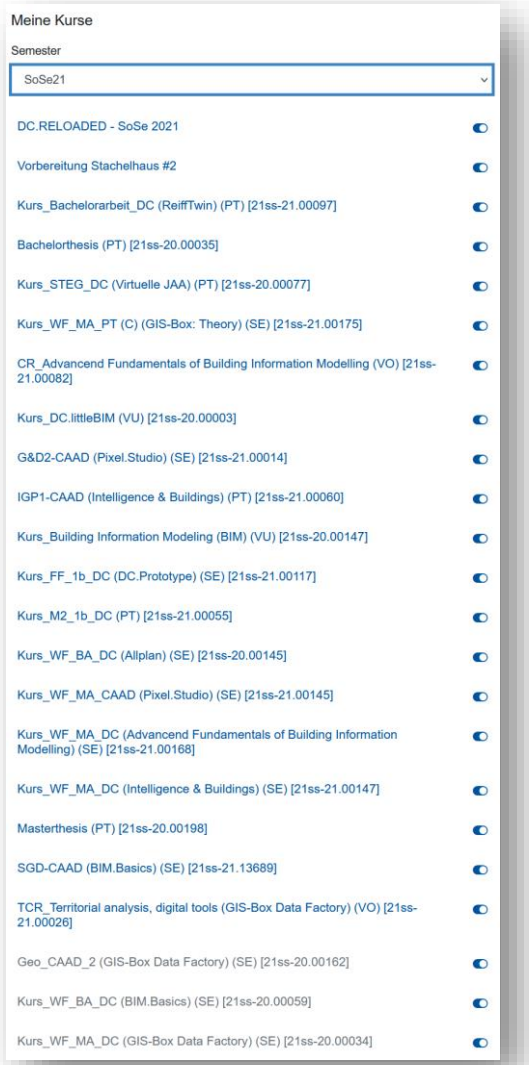
- Advanced Fundamentals of Building Information Modelling
- GIS-Box: DataFactory (Blended Learning)

Projects

- Design Driven Project (Construction & Robotics)
- TCR Design Project (Transforming City Regions)
- DC.Prototype, Intelligence & Buildings,
- M1, M2, M3
- Short infos: RingFrei, Virtuelle JAA, Fahrradparkaus

excercies

- BIM.Basic (Auflage), PixelStudio, Allplan….



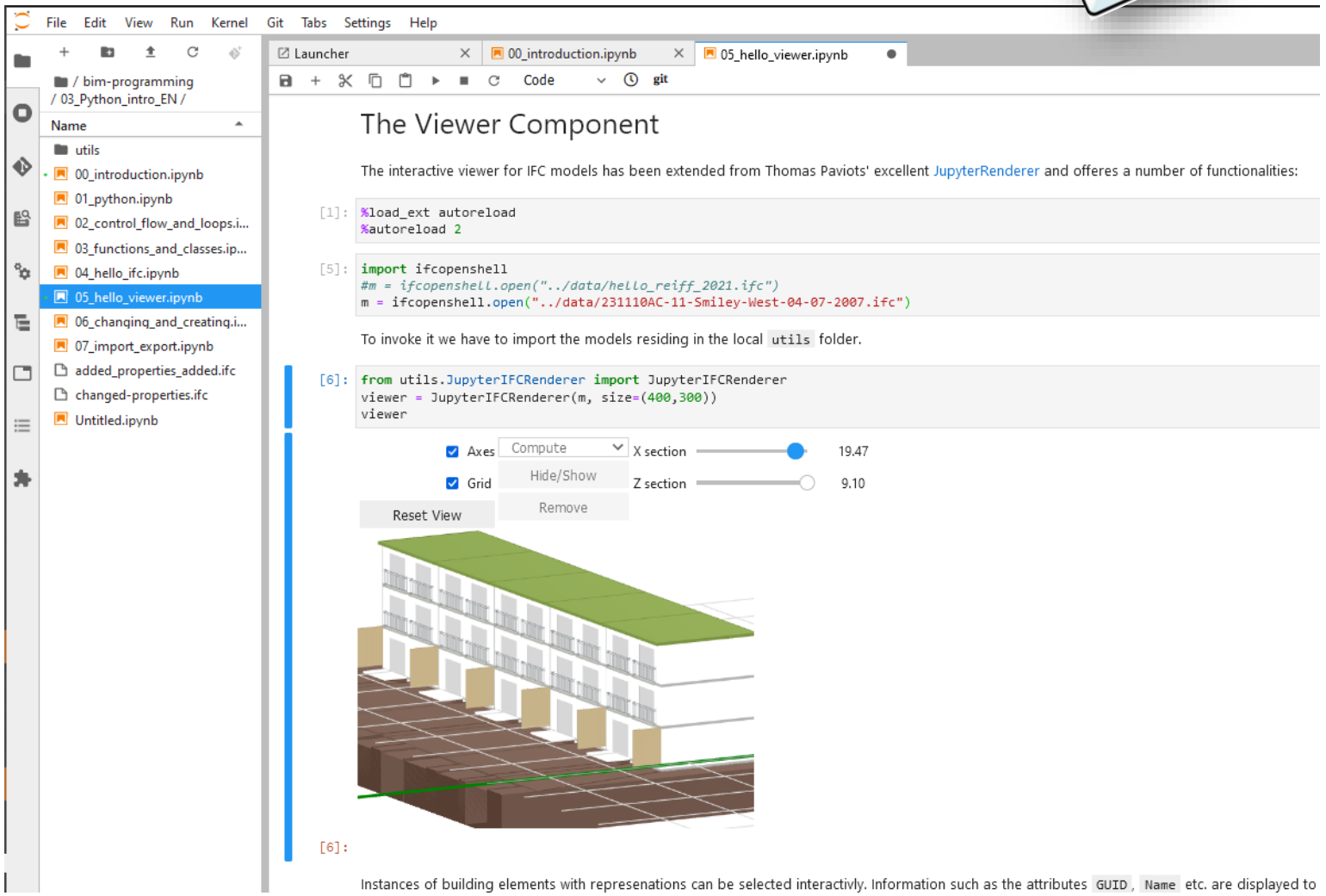
IfcOpenShell Programming in Jupyter Notebooks

https://github.com/jakob-beetz/ifcopenshell-notebooks

Open Educational Resources

DOI 10.5281/zenodo.5733973

launch binder



IfcOpenShell Programming in Jupyter Notebooks

Display documentation on IFC Model parts

Importing and using the helper class `utils.IfcHelp` allows you to load the official IFC documentati
`IfcHelp3(Enitity)` and `IfcHelp4(Enitity)` .

```
1]: import utils.IfcHelp as IfcHelp
    IfcHelp.getHelp4("ifcdoor")
```

1]:

6.1.3.16 IfcDoor

Natural language names

DE	Tür
EN	Door
FR	Porte

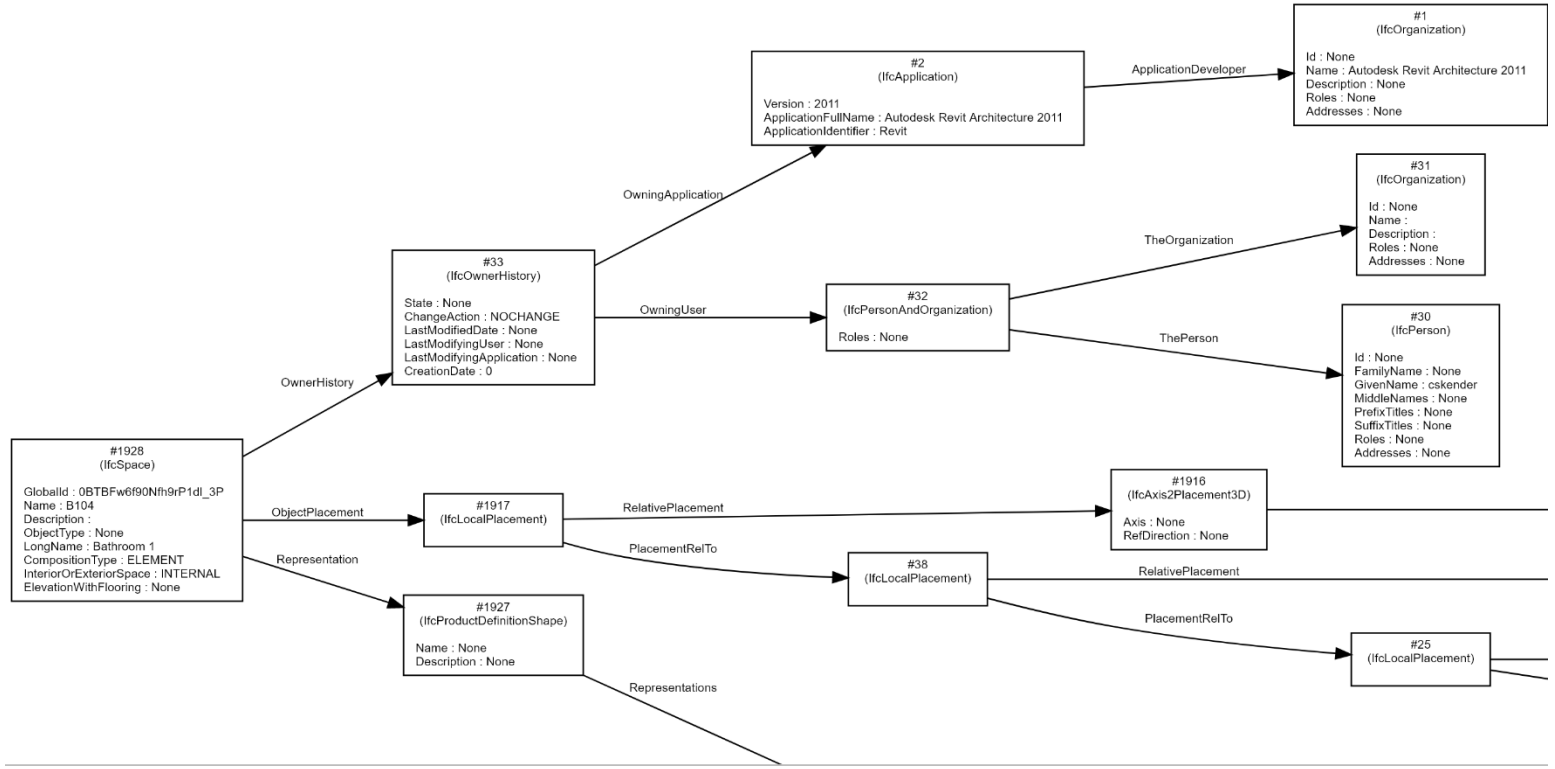
Change log

Item	SPF	XML	Change	Description
4.0.0.0				
IfcDoor				
OwnerHistory			MODIFIED	Instantiation changed to *OPTIONAL*.
PredefinedType			ADDED	
OperationType			ADDED	
UserDefinedOperationType			ADDED	

6.1.3.16.1 Semantic definitions at the entity

Entity definition

```
1 from utils import IfcGraphViz
2 #graph = IfcGraphViz.IfcGraphViz().plot_graph(m, r)
3 graph = IfcGraphViz.IfcGraphViz().plot_graph(m, r)
4 graph
```



IfcOpenShell Programming in Jupyter Notebooks

Walk through all keys an values of a dictionary with `.items()`

```
]: for layer, thickness in layers.items():
       print (f"{layer} \t: {thickness}" )
```

Excercise: Calculate the U-value of the wall

Thermal resistance R_{si} = 0.13

Thermal resistance R_{se} = 0.04

$$R_{construciton} = \frac{d_1}{\lambda_{R1}} + \frac{d_2}{\lambda_{R2}} + \ldots + \frac{d_n}{\lambda_{Rn}}$$

$$\text{U-value} = \frac{1}{R_{si}+R_{construction}+R_{se}}$$

Material	thermal transmittance λ in W/(m*K)
lime brick	0.99
mineral wool	0.04
air layer 1 cm	0.15

```
]: lambdas = {"KS": 0.99, "Mineral Wool": 0.04, "Air 1 cm" : 0.15}
   r_total = 0
   for layer, thickness in layers.items():
       l = 0
       if layer.find("KS") > -1:
           l = lambdas["KS"]
       elif layer.find("Mineral Wool") > -1:
```

Alle Properties in einen Pandas DataFrame

(nur für Interessierte und Fortgeschrittene=

```
[30]: import pandas as pd
elements = m.by_type("IfcElement")
df = pd.DataFrame()
#df = pd.DataFrame({"element_id":[],"pset":[], "name":[], "value":[]})


for elem in elements:
    psets = ifcopenshell.util.element.get_psets(elem)
    for psetname, props in psets.items():
        for name, value in props.items():

            data = {"element_id":elem.id(),"elem-name":elem.Name, "type":elem.is_a(), "pset":psetname, "r

            df = df.append(data, ignore_index=True)
df = df.astype({"element_id":"int32"})
```

```
[31]: df.tail()
```

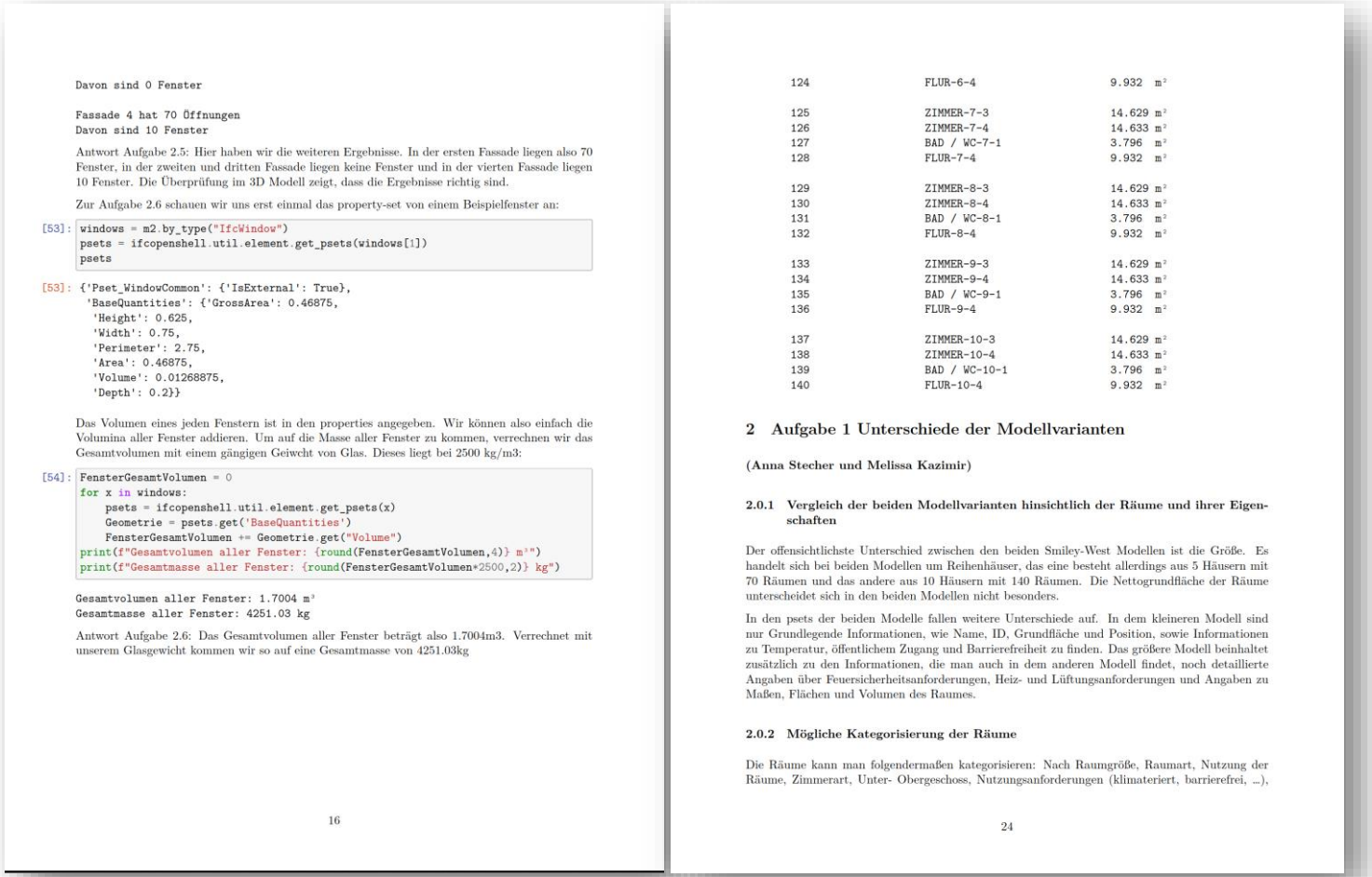
[31]:

	elem-name	element_id	name	pset	type	value
8731	Dach-4	157012	Perimeter	BaseQuantities	IfcSlab	29.666
8732	Dach-4	157012	GrossArea	BaseQuantities	IfcSlab	54.99664
8733	Dach-4	157012	NetArea	BaseQuantities	IfcSlab	54.99664
8734	Dach-4	157012	GrossVolume	BaseQuantities	IfcSlab	10.999328
8735	Dach-4	157012	NetVolume	BaseQuantities	IfcSlab	10.999328

```
[28]: df.info()
```

IfcOpenShell Programming in Jupyter Notebooks

Student Reports



Davon sind 0 Fenster

Fassade 4 hat 70 Öffnungen
Davon sind 10 Fenster

Antwort Aufgabe 2.5: Hier haben wir die weiteren Ergebnisse. In der ersten Fassade liegen also 70 Fenster, in der zweiten und dritten Fassade liegen keine Fenster und in der vierten Fassade liegen 10 Fenster. Die Überprüfung im 3D Modell zeigt, dass die Ergebnisse richtig sind.

Zur Aufgabe 2.6 schauen wir uns erst einmal das property-set von einem Beispielfenster an:

[53]:
```
windows = m2.by_type("IfcWindow")
psets = ifcopenshell.util.element.get_psets(windows[1])
psets
```

[53]:
```
{'Pset_WindowCommon': {'IsExternal': True},
 'BaseQuantities': {'GrossArea': 0.46875,
  'Height': 0.625,
  'Width': 0.75,
  'Perimeter': 2.75,
  'Area': 0.46875,
  'Volume': 0.01268875,
  'Depth': 0.2}}
```

Das Volumen eines jeden Fenstern ist in den properties angegeben. Wir können also einfach die Volumina aller Fenster addieren. Um auf die Masse aller Fenster zu kommen, verrechnen wir das Gesamtvolumen mit einem gängigen Geiwcht von Glas. Dieses liegt bei 2500 kg/m3:

[54]:
```
FensterGesamtVolumen = 0
for x in windows:
    psets = ifcopenshell.util.element.get_psets(x)
    Geometrie = psets.get('BaseQuantities')
    FensterGesamtVolumen += Geometrie.get("Volume")
print(f"Gesamtvolumen aller Fenster: {round(FensterGesamtVolumen,4)} m³")
print(f"Gesamtmasse aller Fenster: {round(FensterGesamtVolumen*2500,2)} kg")
```

```
Gesamtvolumen aller Fenster: 1.7004 m³
Gesamtmasse aller Fenster: 4251.03 kg
```

Antwort Aufgabe 2.6: Das Gesamtvolumen aller Fenster beträgt also 1.7004m3. Verrechnet mit unserem Glasgewicht kommen wir so auf eine Gesamtmasse von 4251.03kg

16

124	FLUR-6-4	9.932 m²
125	ZIMMER-7-3	14.629 m²
126	ZIMMER-7-4	14.633 m²
127	BAD / WC-7-1	3.796 m²
128	FLUR-7-4	9.932 m²
129	ZIMMER-8-3	14.629 m²
130	ZIMMER-8-4	14.633 m²
131	BAD / WC-8-1	3.796 m²
132	FLUR-8-4	9.932 m²
133	ZIMMER-9-3	14.629 m²
134	ZIMMER-9-4	14.633 m²
135	BAD / WC-9-1	3.796 m²
136	FLUR-9-4	9.932 m²
137	ZIMMER-10-3	14.629 m²
138	ZIMMER-10-4	14.633 m²
139	BAD / WC-10-1	3.796 m²
140	FLUR-10-4	9.932 m²

2 Aufgabe 1 Unterschiede der Modellvarianten

(Anna Stecher und Melissa Kazimir)

2.0.1 Vergleich der beiden Modellvarianten hinsichtlich der Räume und ihrer Eigenschaften

Der offensichtlichste Unterschied zwischen den beiden Smiley-West Modellen ist die Größe. Es handelt sich bei beiden Modellen um Reihenhäuser, das eine besteht allerdings aus 5 Häusern mit 70 Räumen und das andere aus 10 Häusern mit 140 Räumen. Die Nettogrundfläche der Räume unterscheidet sich in den beiden Modellen nicht besonders.

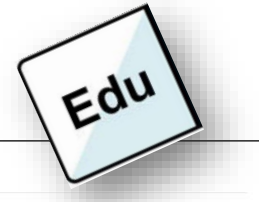
In den psets der beiden Modelle fallen weitere Unterschiede auf. In dem kleineren Modell sind nur Grundlegende Informationen, wie Name, ID, Grundfläche und Position, sowie Informationen zu Temperatur, öffentlichem Zugang und Barrierefreiheit zu finden. Das größere Modell beinhaltet zusätzlich zu den Informationen, die man auch in dem anderen Modell findet, noch detaillierte Angaben über Feuersicherheitsanforderungen, Heiz- und Lüftungsanforderungen und Angaben zu Maßen, Flächen und Volumen des Raumes.

2.0.2 Mögliche Kategorisierung der Räume

Die Räume kann man folgendermaßen kategorisieren: Nach Raumgröße, Raumart, Nutzung der Räume, Zimmerart, Unter- Obergeschoss, Nutzungsanforderungen (klimateriert, barrierefrei, ...),

24

Linked Data BIM / DT Programming



Basics of

- **RDF(S), Linked Data**
- **SPARQL**
- **RDFLib (Python), Jena(Java)**
- **Node Red**

https://github.com/linkedbuildingdata/SummerSchoolOfLDAC/

README.md

Summer School of LDAC

This repository contains the documentation and source of the coding challenge of the Summer School of Linked Data in Architecture and Construction held 17 - 18 June in Lisbon, Portugal. The summer school precedes the 7th Workshop on Linked Data in Architecture and Construction (LDAC).

Getting Started

Please move to Index to start working with the material of the 2019 edition of the Summer School of LDAC. You can also launch the content by opening it in Binder or Colab:

launch binder Open in Colab

For the Java Notebooks in the multiKernel branch, you can use the following binder: launch binder

Usage and Tools

The content of this summer school are distributed using Jupyter notebooks. The notebooks can be statically examined in Github by simply clicking on it. To execute the scripts they can be either locally executed or the project can be opened using Binder [1]. For the local usage a iPyhton installation is required. We suggest using a python distribution such as Anaconda to work locally.

If you are not familiar to iPython/ Jupyter etc. please refer to the introductory content by Jake VanderPlas

Authors

A couple of persons contributed to the content of this repository (Sorted alphabetically):

- **Jakob Beetz**, RG
- **Matthias Bonduel**. RG

Contributors 10

Languages

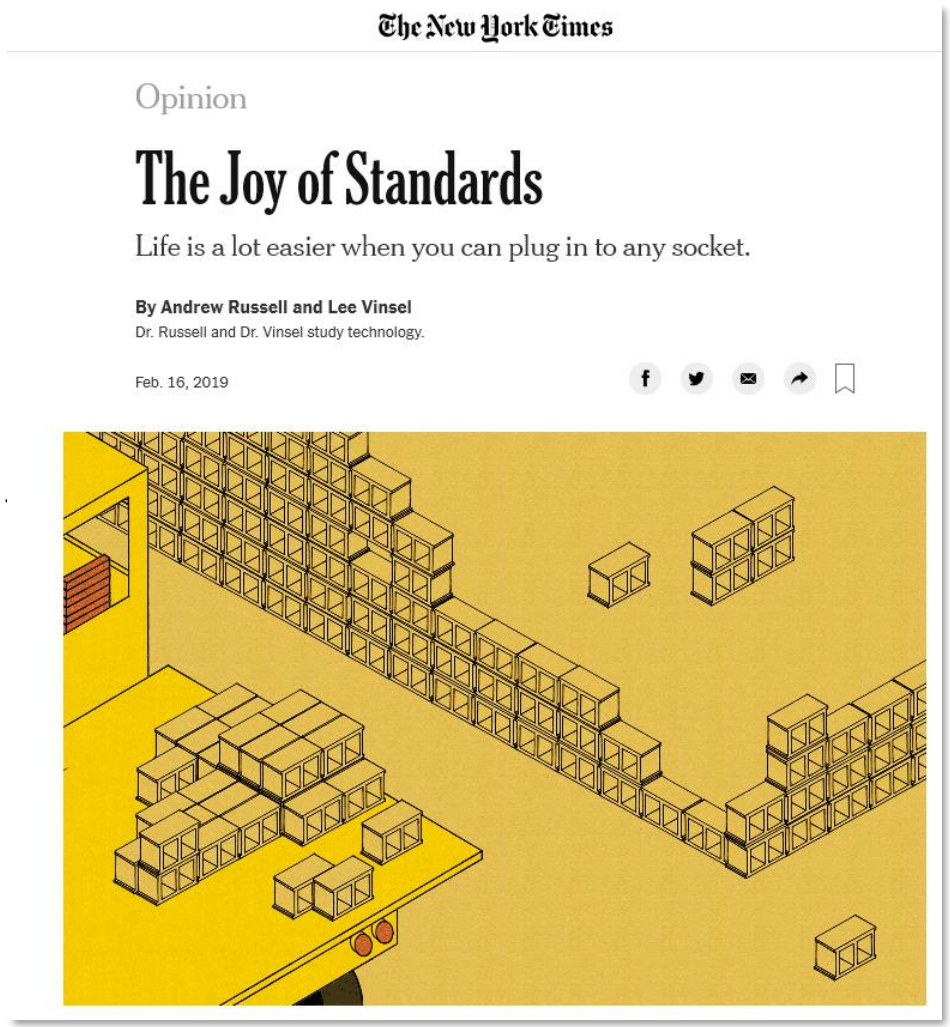
Jupyter Notebook 95.7% HTML 4.3%

Why standards matter

- Imagine if bricks formats would be reinvented over and over
- Your laptop contains 250+ standards
  - 44 % by consortia
  - 36 % by formal standards organization
  - 20 % by single companies

  - 75 % Reasonable and non-discriminatory (RAND) terms, also known as reasonable, and non-discriminatory (FRAND)
  - 22 % royality free
  - 3 % patented

Biddle, Brad and White, Andrew and Woods, Sean, How Many Standards in a Laptop? (And Other Empirical Questions) (September 10, 2010). Available at SSRN: https://ssrn.com/abstract=1619440 or http://dx.doi.org/10.2139/ssrn.1619440



The New York Times

Opinion

The Joy of Standards

Life is a lot easier when you can plug in to any socket.

By Andrew Russell and Lee Vinsel

Dr. Russell and Dr. Vinsel study technology.

Feb. 16, 2019

Semantic DTs for the Built Environment: Overview

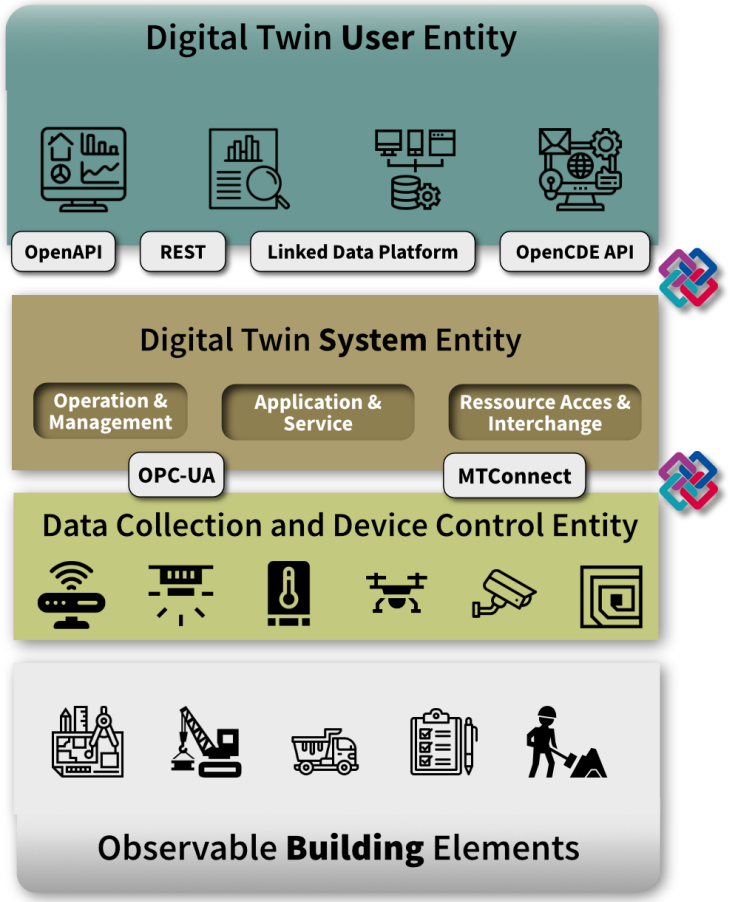
- **Standardized static DT (BIM)**
  - Industry Foundation Classes **ISO 16739-1:2018**
  - buildingSMART Data Dictionary bSDD **ISO 12006-3**
  - Properties and QA for bSDD – PPBIM **ISO 23386**
  - HVAC **VDI 3805**
- **Augmenting DT with standardized dynamic data**
  - Data Protocols for building-specific IoT
    - BPS, BAS
      - BACNet (**ISO 16484**, ASHRAE SSPC 135)
      - MVD for BACNet
      - KNX **ISO/IEC 14543-3**
      - Simulation interoperability **Annex 60**, **FMI 2.0**
    - SHM
      - **OASIS** MQTT and Geo MQTT
    - Products
      - Product Catalogues **ISO 16757**

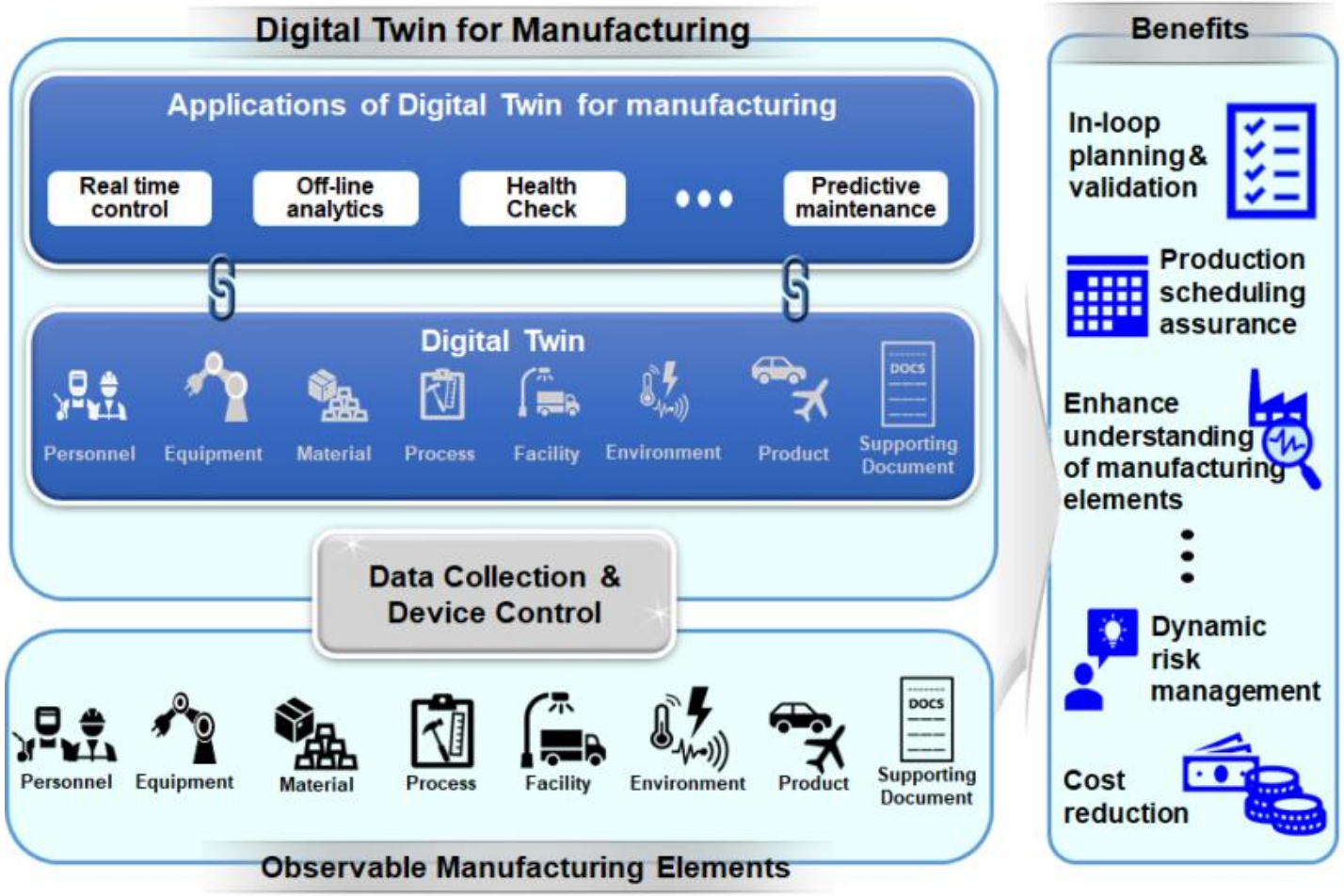
- **Semantic Enrichment and Organization and integration of heterogeneous DT data**
  - OpenCDE API **DIN SPEC 91391**
  - IDM **ISO 29481-2:2012**
  - Multimodal Multi-models and ICDD **ISO 21597-1:2019**
  - **W3C SSN**
  - SAREF
  - Linked Data, data silos and the long run: **W3C RDF, OWL, SPARQL, JSON-LD, XML**
  - Solid

- **Long term access to DT data**
  - Long Term preservation and the OAIS **ISO 14721:2012**
  - Blockchain, Interplanetary File System IPFS

ISO DIS 23247-2:2019 Automation systems and integration — Digital Twin framework for manufacturing

Digital Twin for the Built Environment
based on the ISO 23247 framework





How should Semantic Digital Twins for the Built Environment, such that …

… standardised yet extensible?

- Make compatibility with agreed upon **OPEN standards** part of **contracting** (manufacturers, home automation, Facility Mangers, construction companies, HVAC engineering).
- Create common, reusable reference **IDMs** (UCs, ER, EIR/MVD …) , for common use cases (Energy use in buildings, Structural Health Monitoring of infrastructure assets, construction logistics monitoring etc.
- **Extend** in separate models, standards, descriptions **only where necessary**
- Agree on **common** decomposition and aspect model views (e.g. building, storey, space)
- **Simplicity**, reduction of complexity, transparency
- **Privacy** for personal data – home automation highly dependent on user behavior patterns
- include **provenance** information (data stemming from which sensors? measured how? date of last calibration? tolerances, margins of error?
- Move to **collaborative**, **open source development** (Git etc.)
- **Release early, release often**

How should Semantic Digital Twins for the Built Environment, such that they are…

… able to address key use cases directly and specialty use cases with extensions?

- **reuse** and **integrate** existing standards
  - Alignments and mappings of existing
    - AEC/FM standards (IFC, gbXML, CityGML, BACnet ISO 16484-5, KNXm, LOD),
    - **IoT** protocols (HTTP, WebSockets, CoAP, MQTT, XMPP and WebRTC), modelling of sensor meaning SensorML, SSN ect.) and
    - Information **Archival** Strategies (ISO 14721:2012, OAIS)

- agree on **common mappings**, best practices and usage patterns

- publish **reference data sets**,

- specify quality standards, **certification** and testing

How should Semantic Digital Twins for the Built Environment, such that they are…

… cloud and computationally friendly?

- Look at what is proven, simplify, embrace bottom up developments: e.g. **JSON**, **JSON-LD, REST**
- Specify simple, domain-specific **API**s
- move **out of proprietary silos**, use simple representations at least as derived
- **stick strictly to protocols**
- secure and **encrypt** with authentication layers (OAuth etc.)

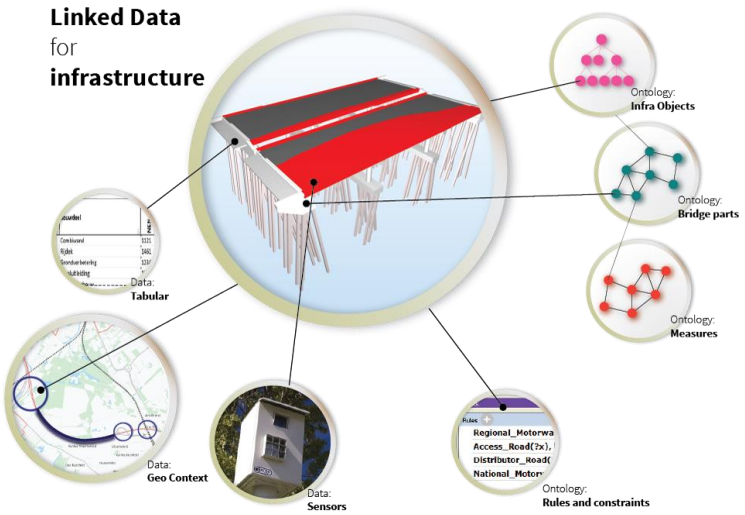
How should Semantic Digital Twins for the Built Environment, such that they are…

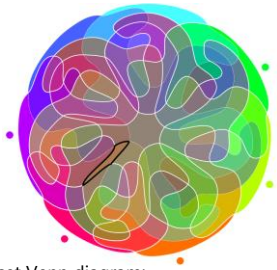
… scalable and verifiable?

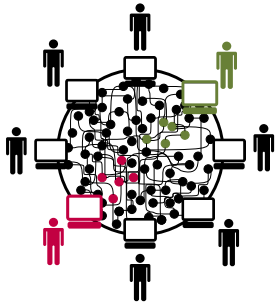
- **Decentralize**
- Look at what is proven, simplify, embrace bottom up and community developments and best practices: e.g. **JSON**, **JSON-LD, REST, GraphQL**
- **Test-driven** development
- Do not rely only on low-level technologies only (sharding etc.)
- create common **references**
- include **provenance** information
- checkums/fingerprints in **aggregators** for authenticity

Thank you

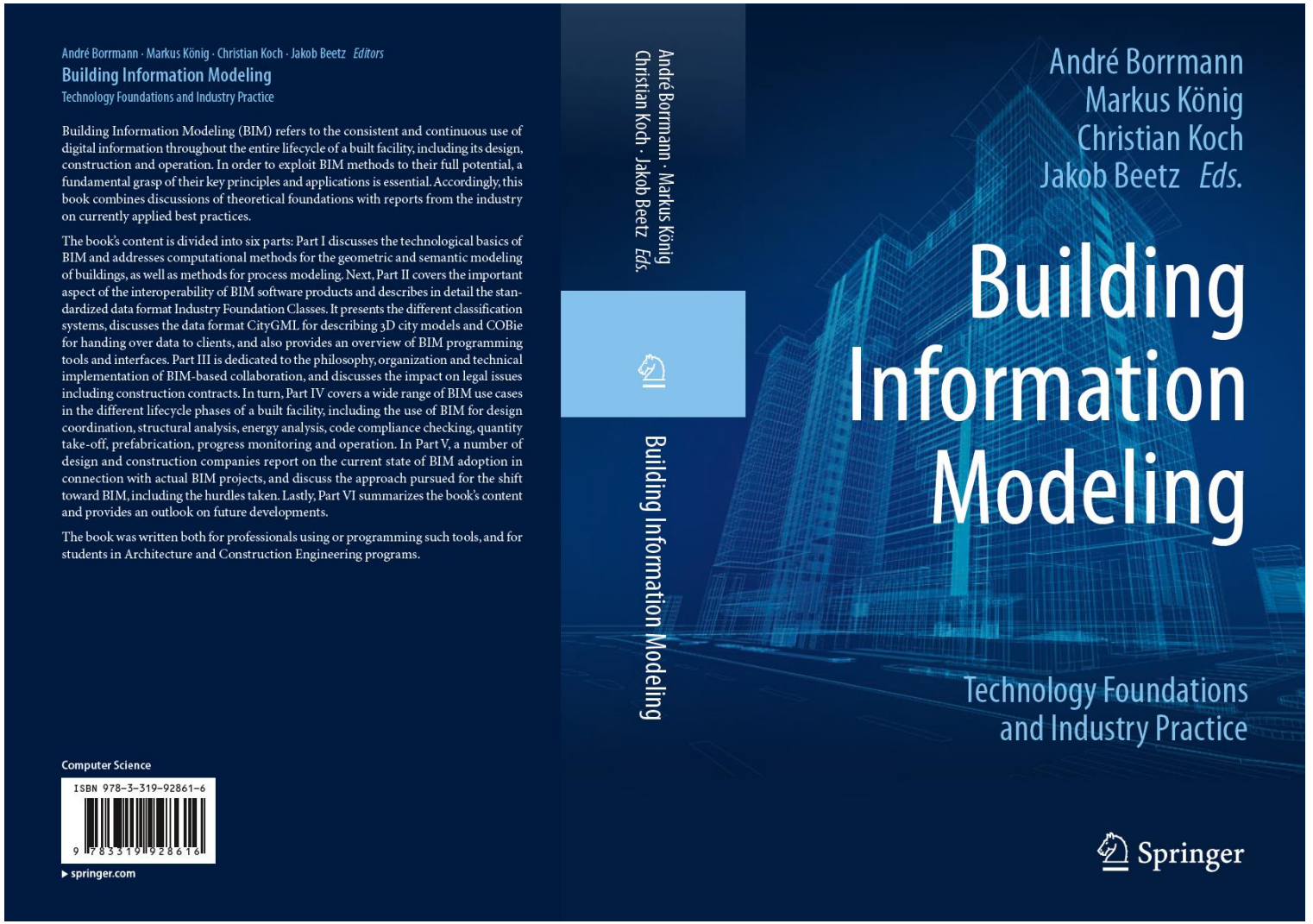
j.beetz@caad.arch.rwth-aachen.de



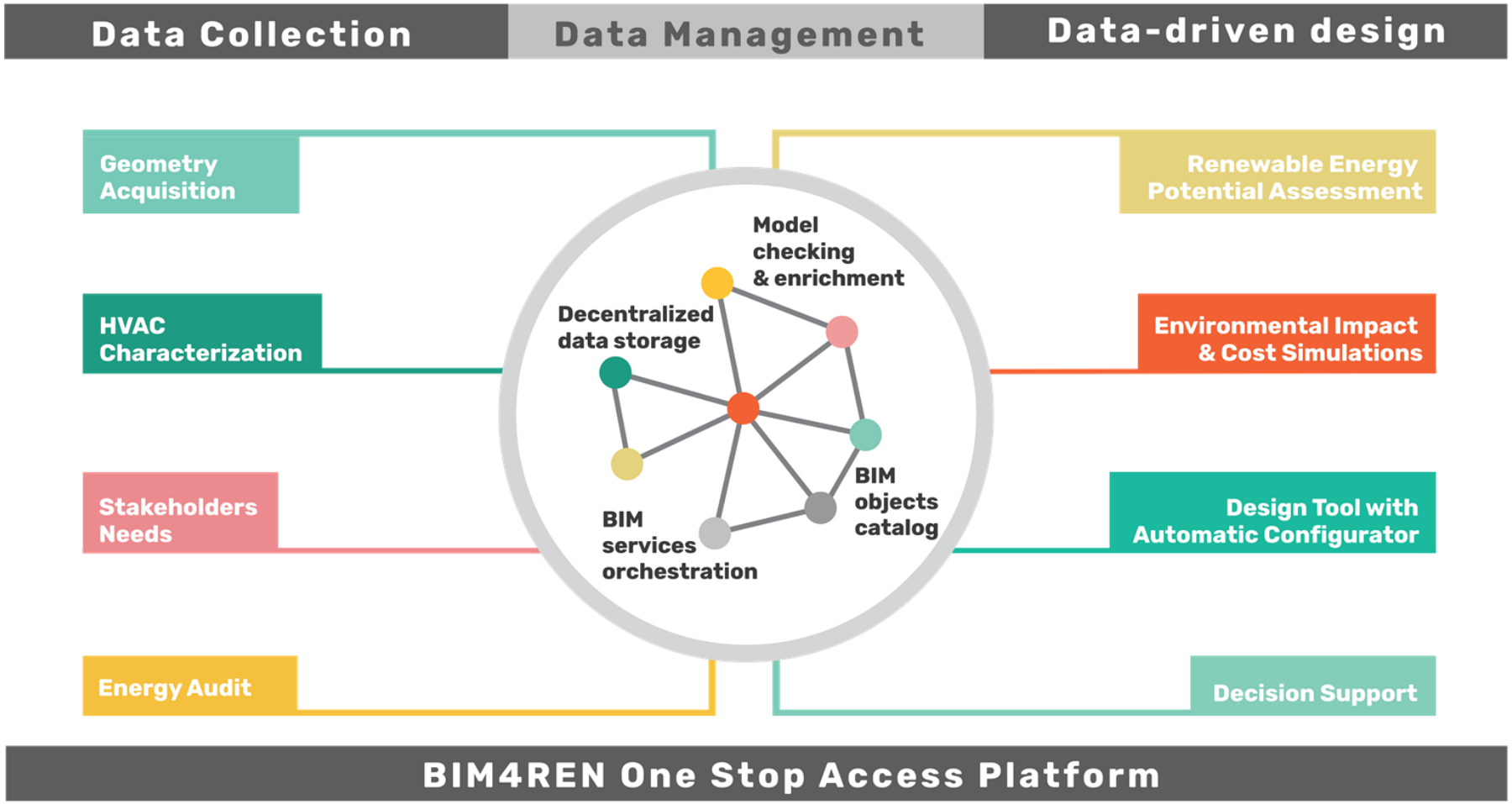




source 7-set Venn diagram:
[Ortiz 2013]



Semantic Digital Twins on the Building level : BIM4Ren



Semantic Digital Twins on the Building level : BIM4Ren (1

Project : 2018-2022

Easy-to-use BIM tools and workflows for collaborative and energy-efficient renovation of residential buildings

Consortium: 23 partners from 10 European countries

Coordinator: Nobatek/INEF4

Duration: 48 months

Start: 1st Oct 2018

Budget: 7M€

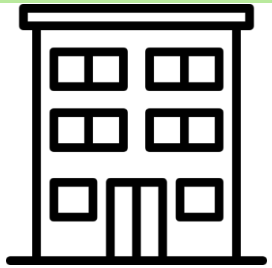
H2020 G.A. 820773

BIM4Ren CONCEPT

Data Management

Data collection

WHAT IS THE EXISTING DATA ?



- Year?
- Local regulation?
- Cost € ?
- Energy performance?
- Geometry?
- Stakeholders expectations?
- Type of occupants ?
- Renovation potential ?
- State of the existing infrastructure ?

H2020 G.A. 820773

Data- driven design

Stakeholders involved in the renovation

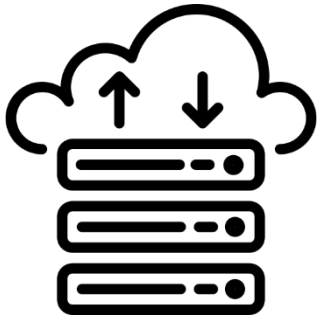
BIM4Ren CONCEPT

Digital inputs

Data collection

WHAT IS THE EXISTING DATA ?

Data Management



H2020 G.A. 820773

1. To create the BIM model
2. To organize, consolidate, secure
3. To exploit the BIM model

Data- driven design

Stakeholders involved in the renovation

BIM4Ren CONCEPT

Digital inputs

Data Management

Exploit BIM

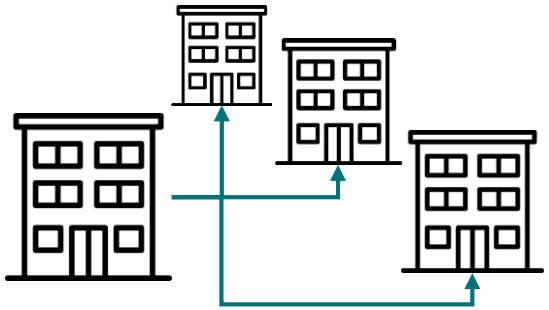
Data collection

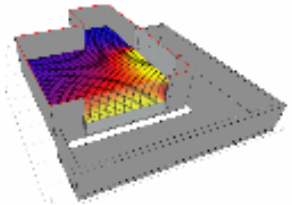
Data- driven design

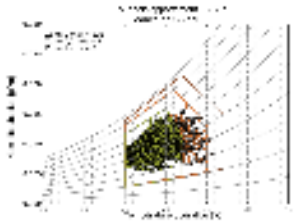
WHAT IS THE EXISTING DATA ?

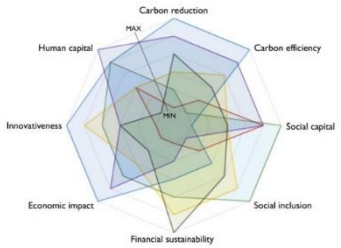
H2020 G.A. 820773

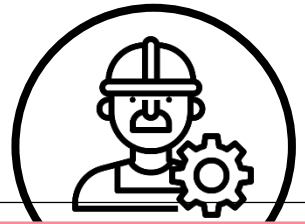
1. To create the BIM model
2. To organize, consolidate, secure
3. To exploit the BIM model











Stakeholders involved in the renovation

BIM4Ren CONCEPT

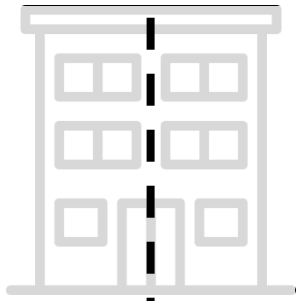
Data Management

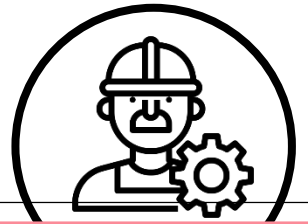
Data collection

Data- driven design

H2020 G.A. 820773

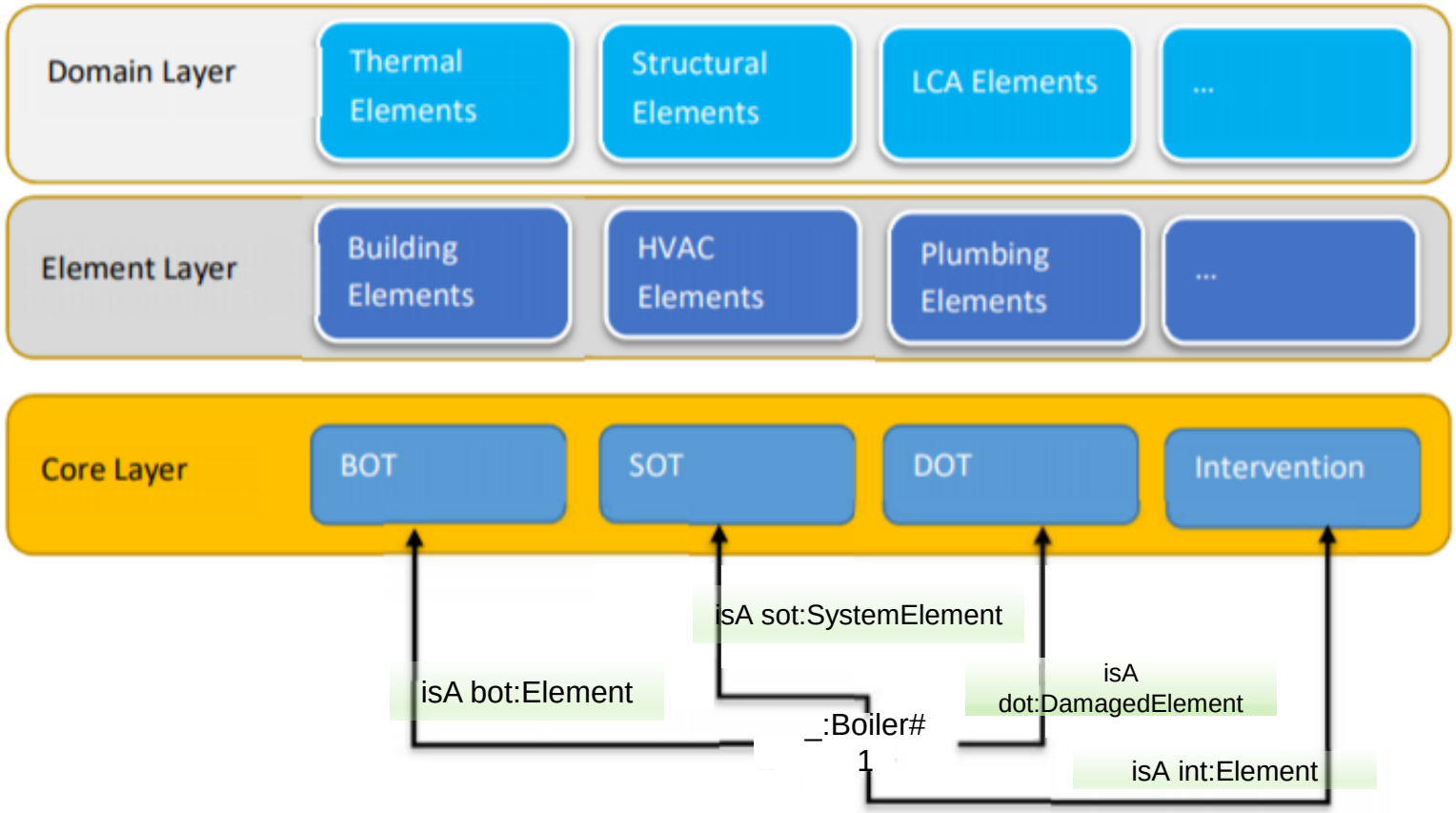
BIM4REN ONE STOP ACCESS PLATFORM



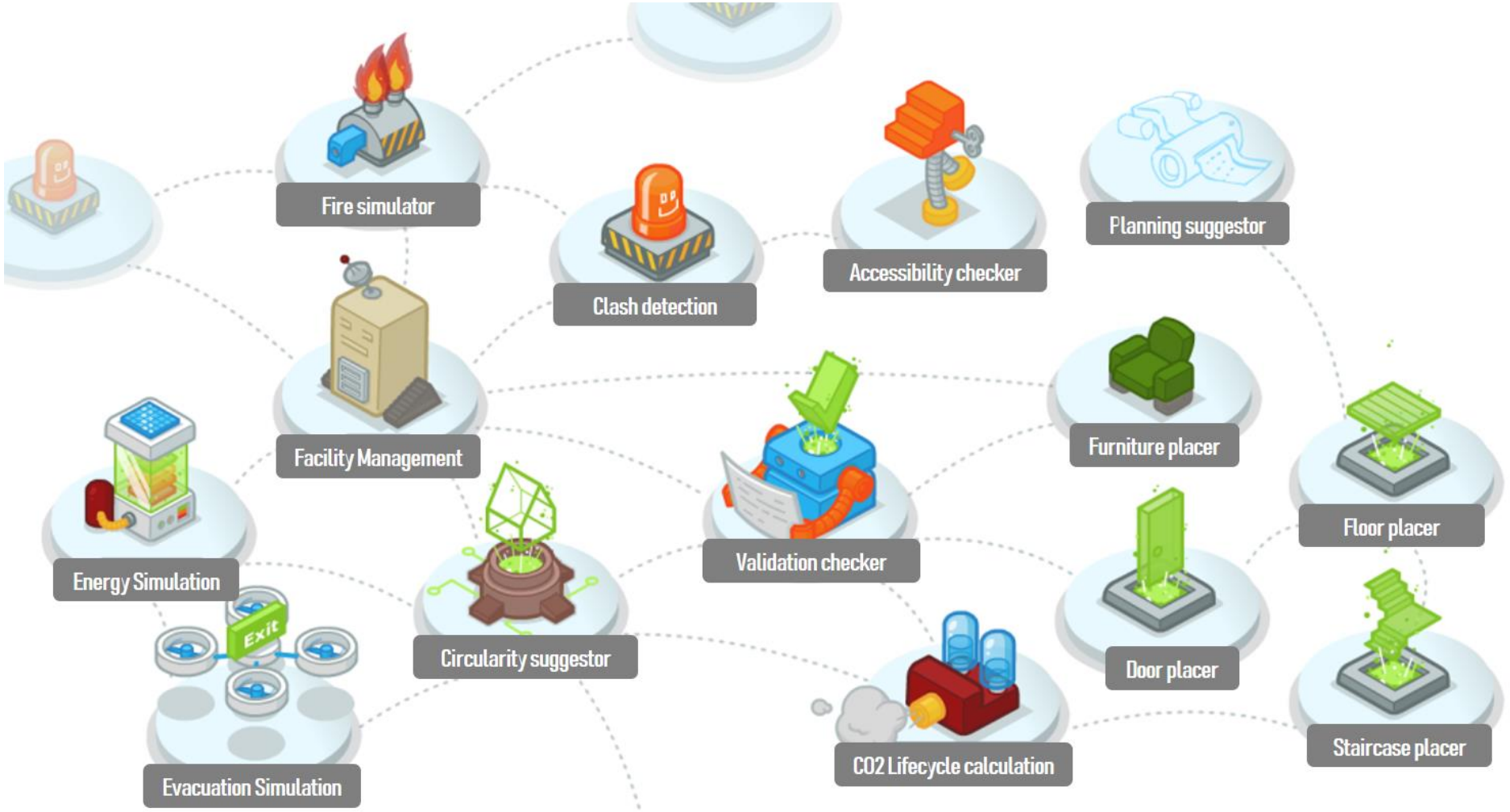


Stakeholders involved in the renovation

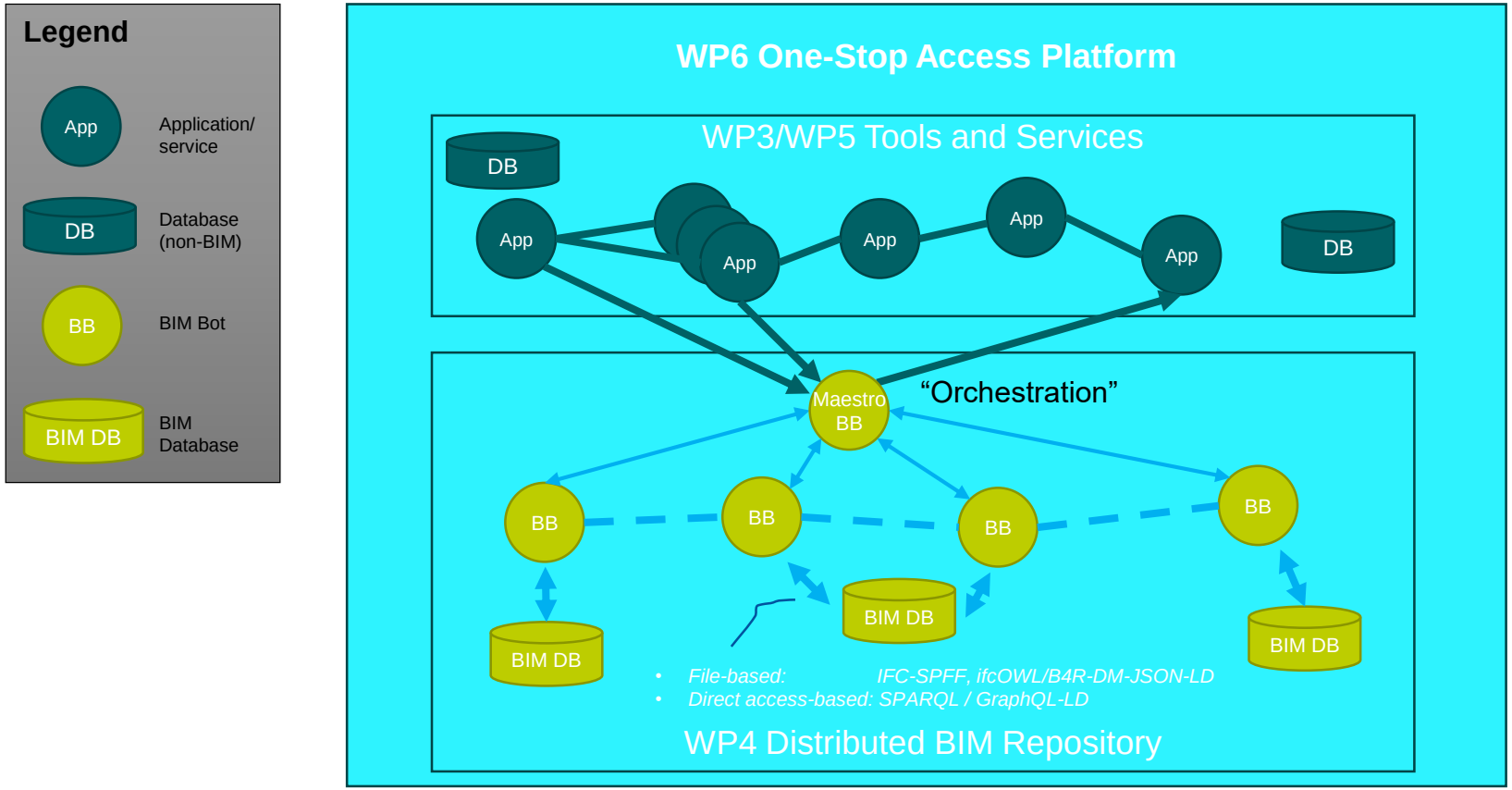
Proposed BIM4Ren Data Model



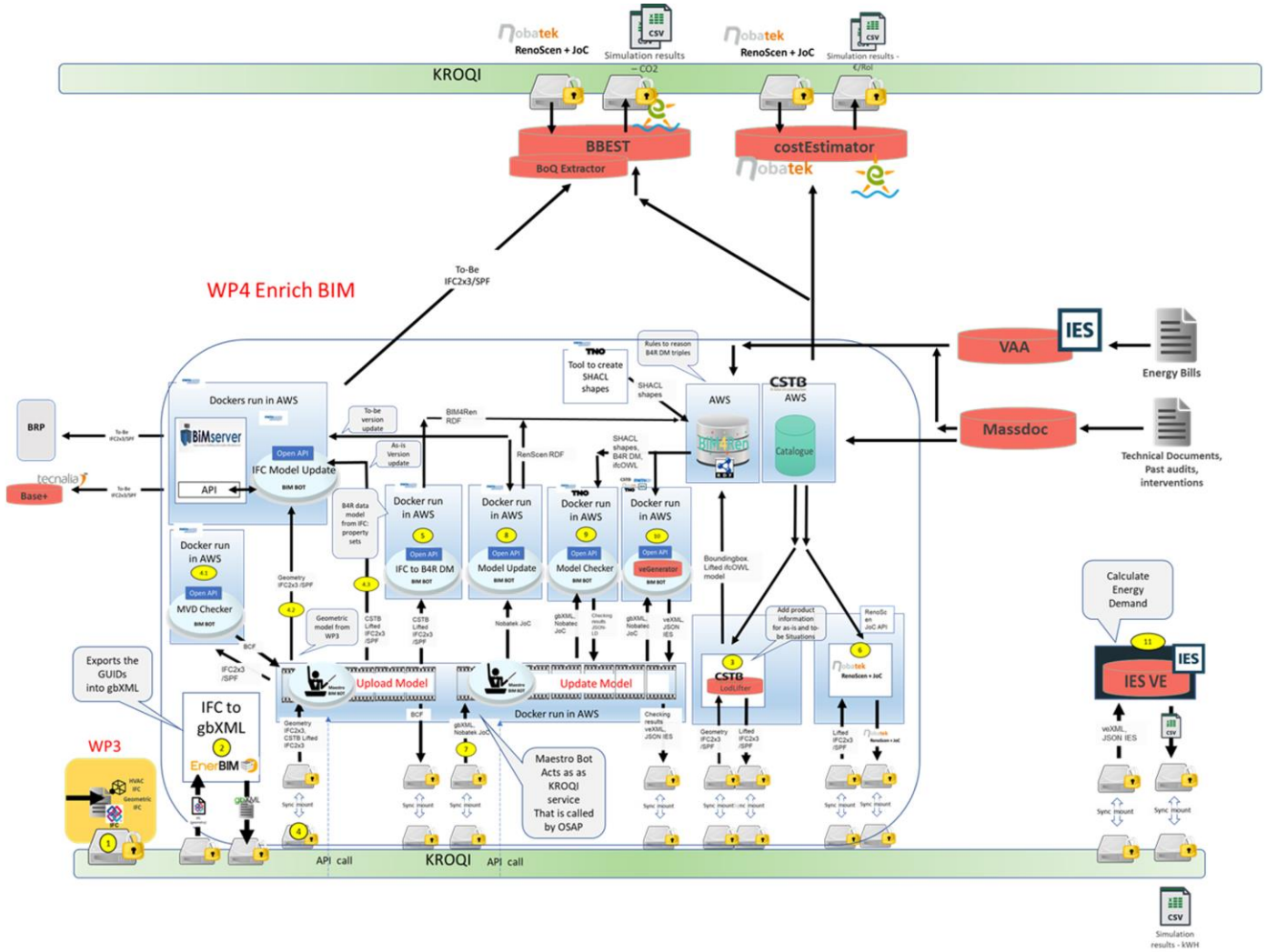
BIM4Ren Architecture



BIM4Ren Architecture



Applications/services & BIM Bots

- implemented as “OpenAPI micro services”
- deployed in Amazon Web Services (AWS) & CSTB KROQI cloud platforms

BIM4Ren Architecture