Linked data for the life cycle assessment of built assets

Calin Boje*, Tomas Navarrete, Sylvain Kubicki, Thomas Beach

R&T Associate
calin.boje@list.lu

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Why develop an LCA ontology for the built environment?

01 Increased **interoperability** between LCA and built environment tools

02 Means for increased **automation** on LCA

03 More “**explainable**” **impacts** assessments given complex contexts and hybrid data sources

Ontology development process – Steps 1, 2 & 3

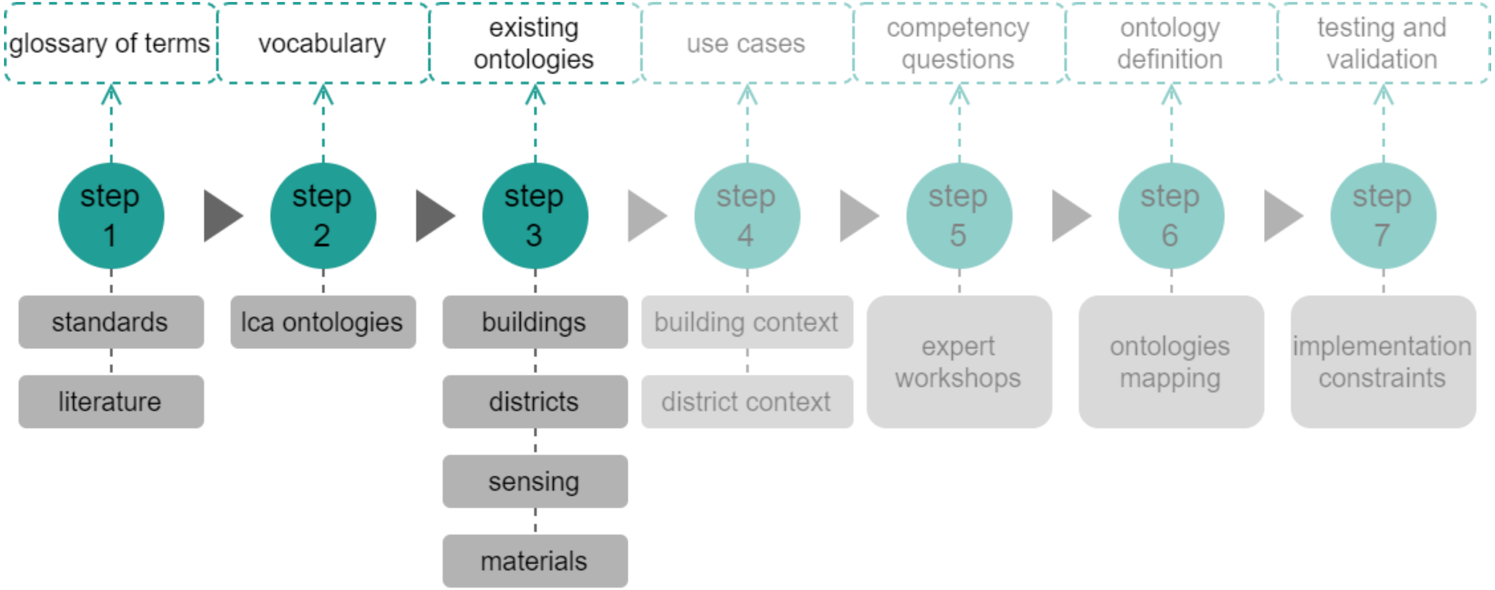

Table 1
Relevant tools with concepts related to Semantic LCA domains

Ontology/Schema	Type	Domain	Concepts of interest
BONSAI	ontology	LCA	activities, flows, properties
LCA Commons[13]	library	LCA	flows, mappings
OpenLCA Schema[14]	schema		methods, processes, results, impact categories
Brightway2[15]	Library	LCA	toolkits for calculation
IfcOwl[16]	ontology	Building	elements, materials, properties, aggregations, hierarchies, types, spatial constructs, sensors
BOT[17]	ontology	Building	spatial constructs, elements
OPM[18]	ontology	Building	properties
RealEstateCore[19]	ontology	Building	building systems, elements, spatial constructs, sensors and controls
Building Product Ontology[20]	ontology	Building	elements, aggregations, properties
SSN-SOSA[21]	ontology	Sensing	sensors, observations, results
SAREF[22]	ontology	Sensing Integration	devices, appliances, energy, gas
Freeclass ontology[23]	ontology & classification	Building	hierarchies, building products, processes, properties
DCMI[24]	ontology	Metadata	annotations
SKOS[25]	ontology	Metadata	semantic associations
XKOS[26]	ontology	Metadata	associations of classifications
OWL-time[27]	ontology	Scenario & State	time spans, start, end times

BONSAI dedicated to LCA activities alone

No dedicated ontologies for describing built assets construction and usage exist

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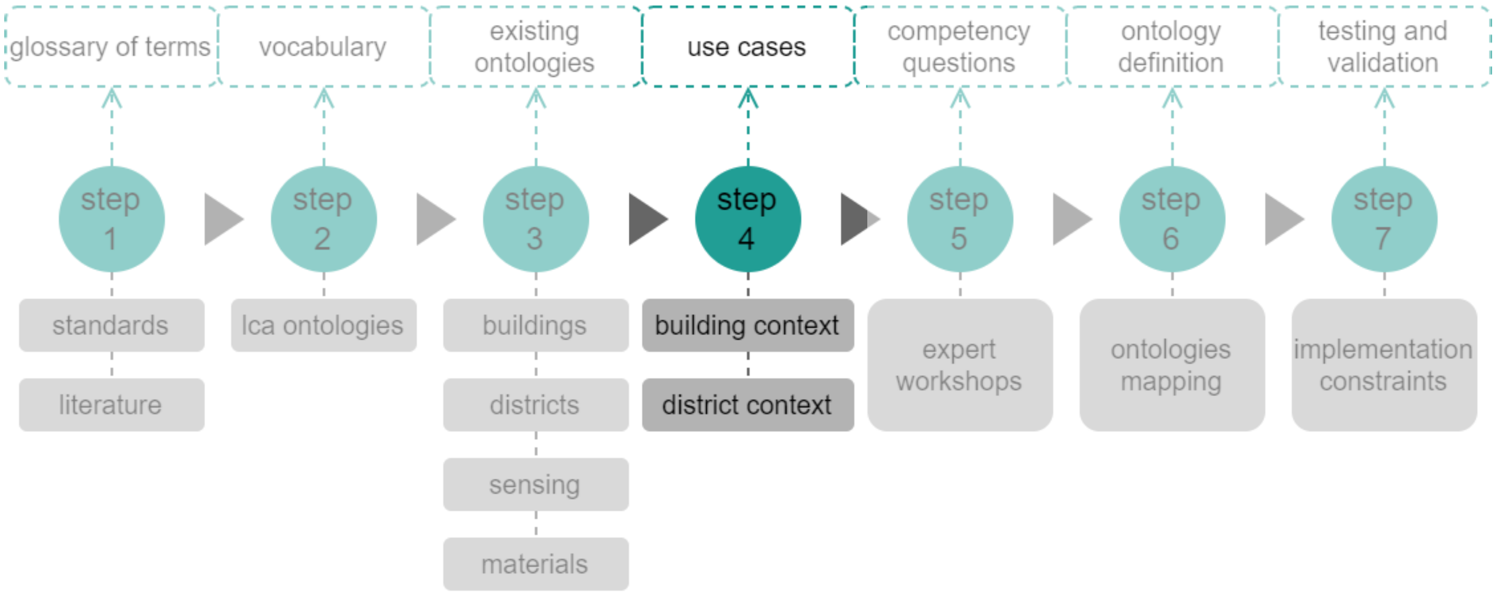
Ontology development process – step 4



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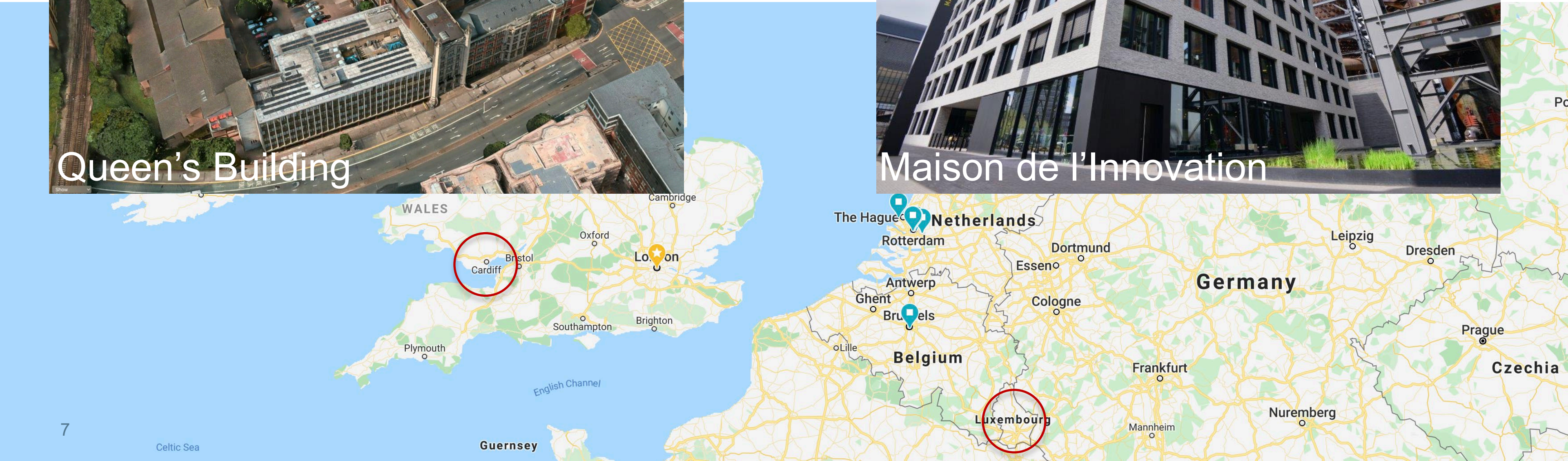
Use cases

no	Name	Scope
1	BIM to LCA	BIM elements, materials, products
2	Operational trade-offs	Energy consumption, air quality, human toxicity
3	Building energy optimisation	Energy modelling, simulation, optimisation algorithms
4	District energy	Energy consumption prediction
5	District building's extensions	Extended buildings, materials
6	Weighting/Scoring	Weighting factors, single scores

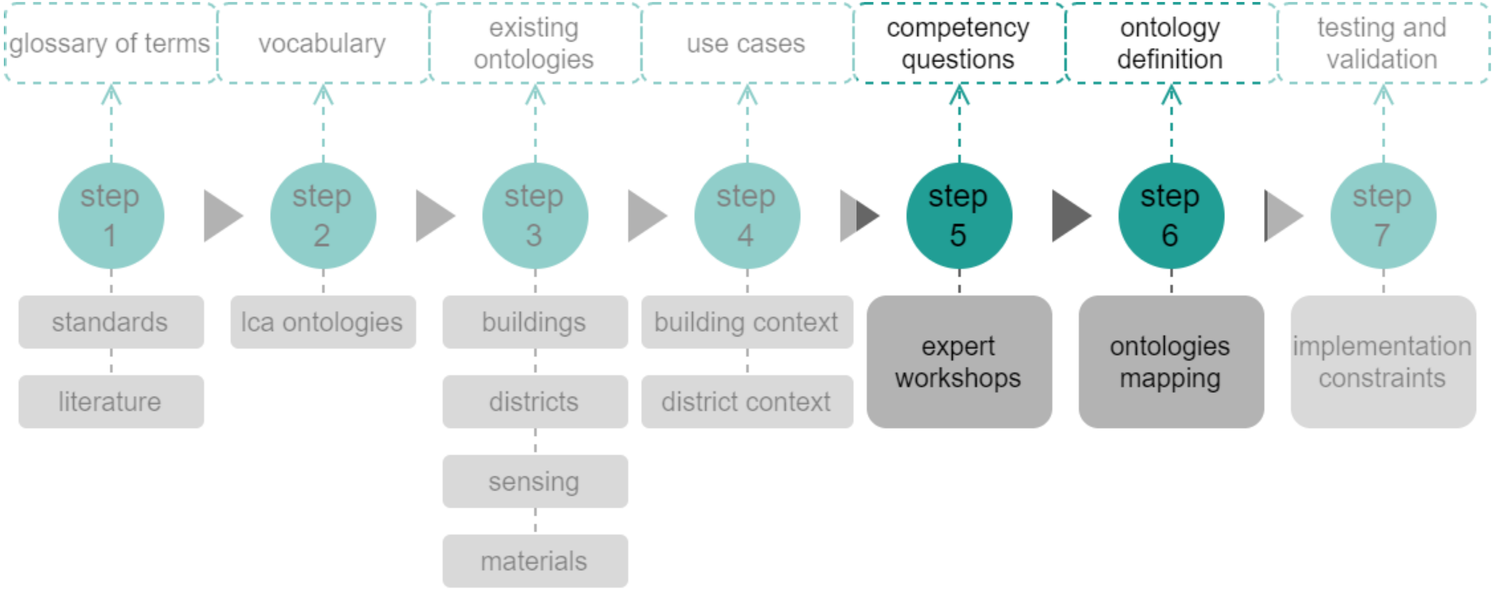
Semantic LCA Pilots


Queen's Building


Maison de l'Innovation



Ontology development process – steps 5 & 6



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Competency questions

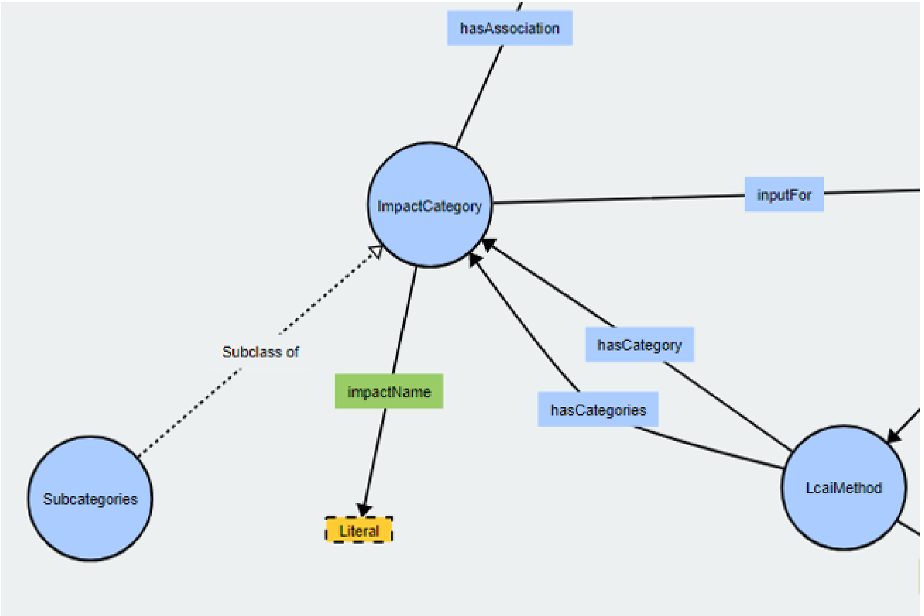
A total of 145 competency questions were identified (duplicates excluded)

LCA examples:

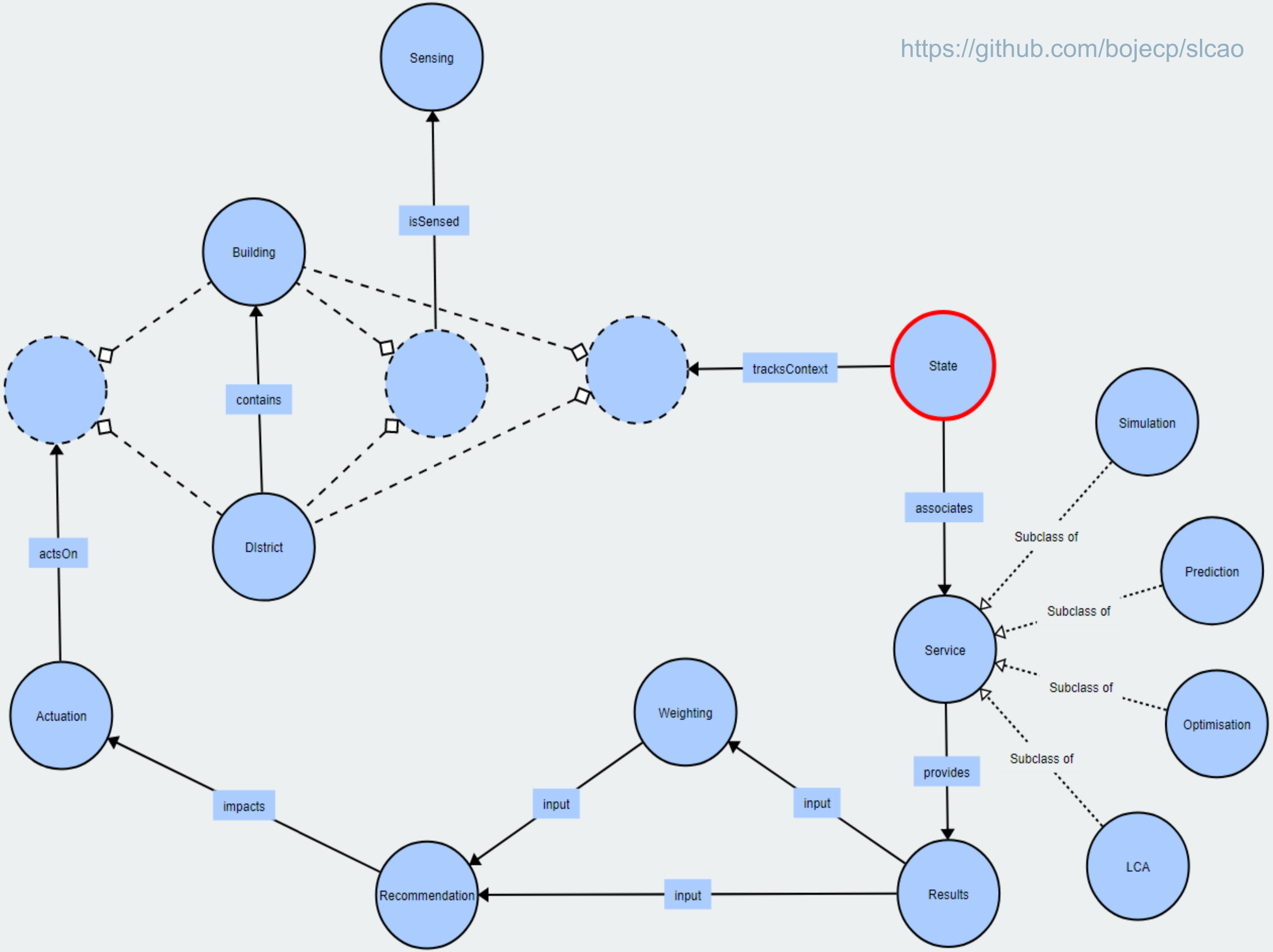
What are the available LCA impact categories?

What are the LCA impact categories considered for calculation?

Which Life Cycle Impact Assessment (LCIA) method is used for the calculation?



https://github.com/bojecp/slcao/blob/main/CompetencyQuestions.md https://github.com/bojecp/slcao



SLCAO – work in progress

Not all data properties were modelled/specified

Aimed to fit into a software system as a data integration schema, with minimal reasoning

Challenging to fit multiple very different use cases -> a modular mapping

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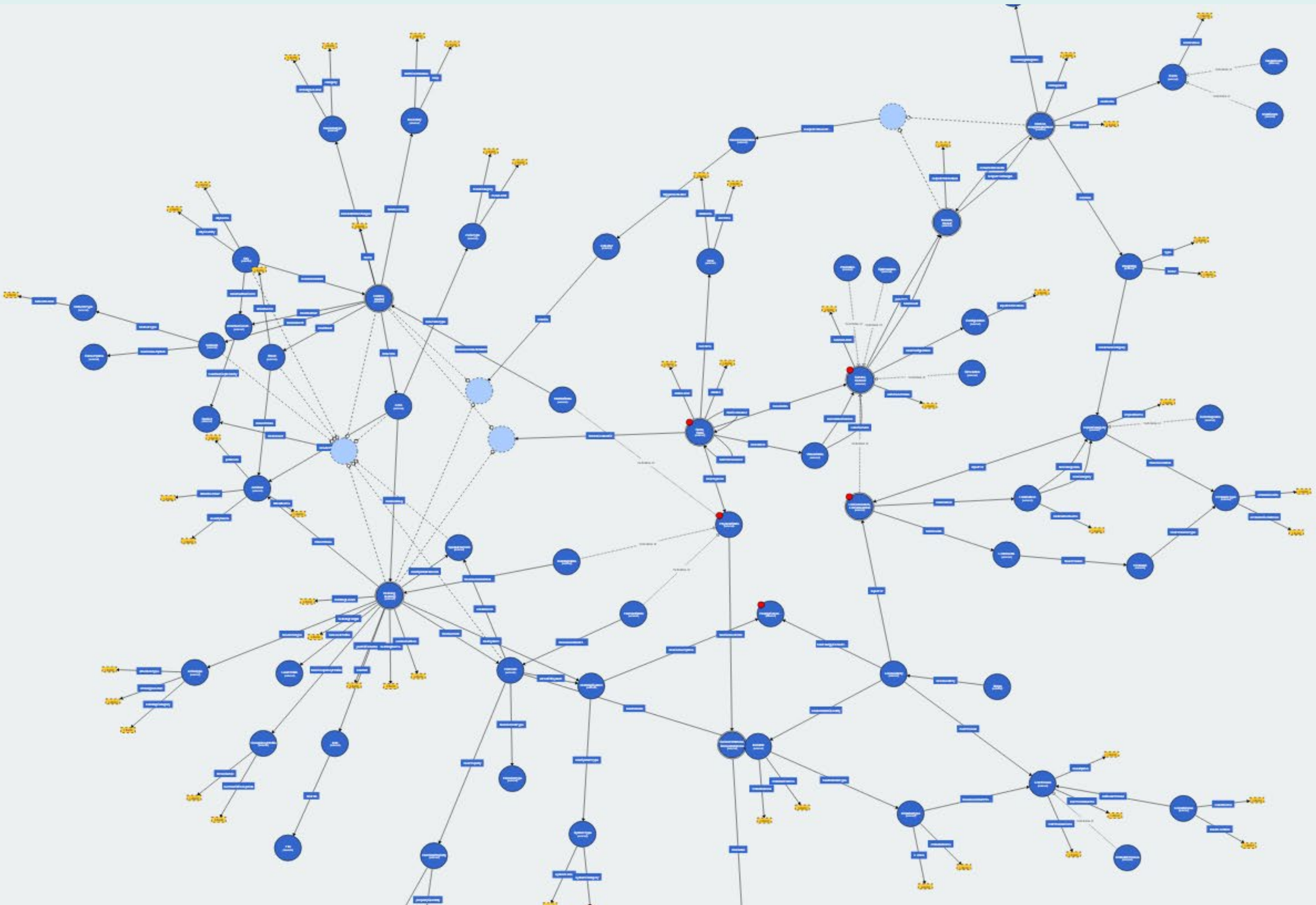
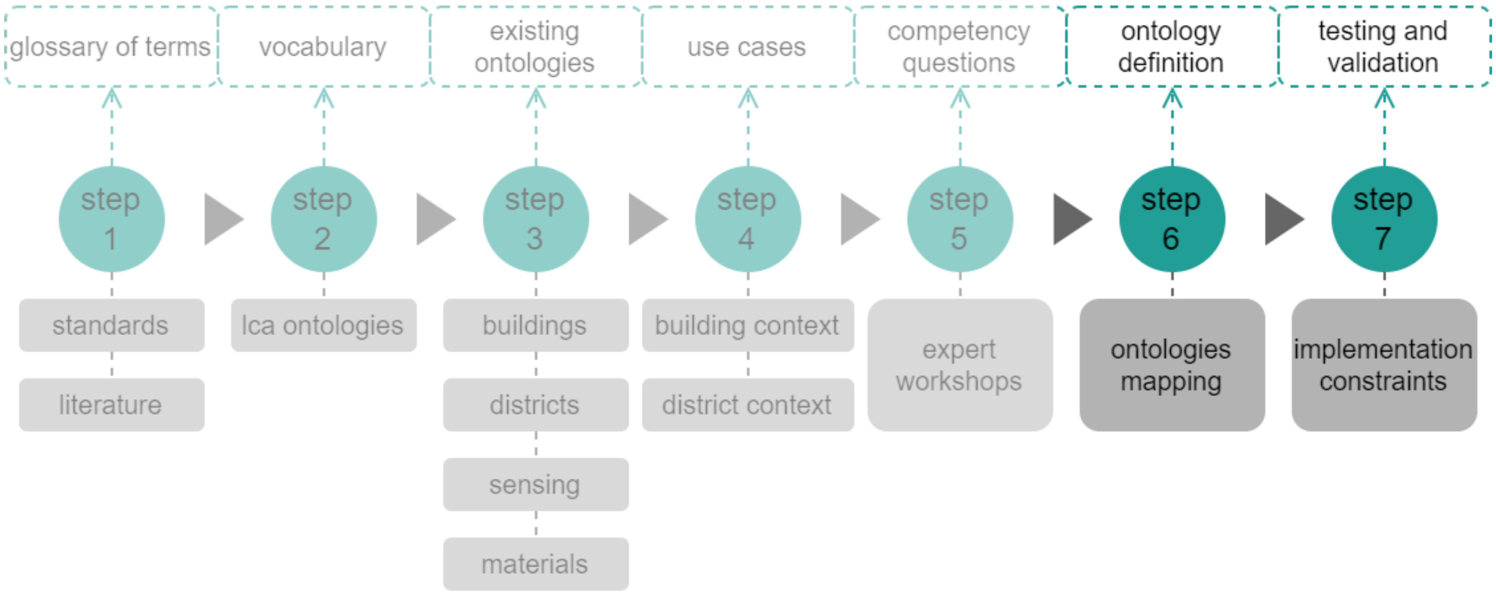


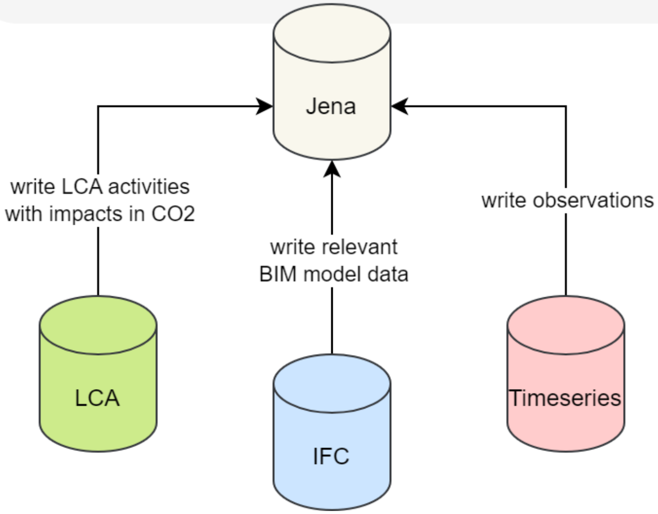
Ontology development process – steps 6 & 7



Case study on building data

4 step process

1. Map relevant ontologies (TBox)
2. Write instance data in triples (ABox)
3. Match LCA processes/activities with BIM or other measured data
4. Calculate impacts (CO2)



1. Explicitly state mappings of internal modules & external ontologies

2. Converted to triples relevant LCA/BIM data

3. Match LCA processes (with impacts in CO2) to relevant material quantities or measurements (energy/water/gas, etc.)

(using SWRL rules, SPARQL, or just SPARQL)

4. Calculate the impacts (using SPARQL)

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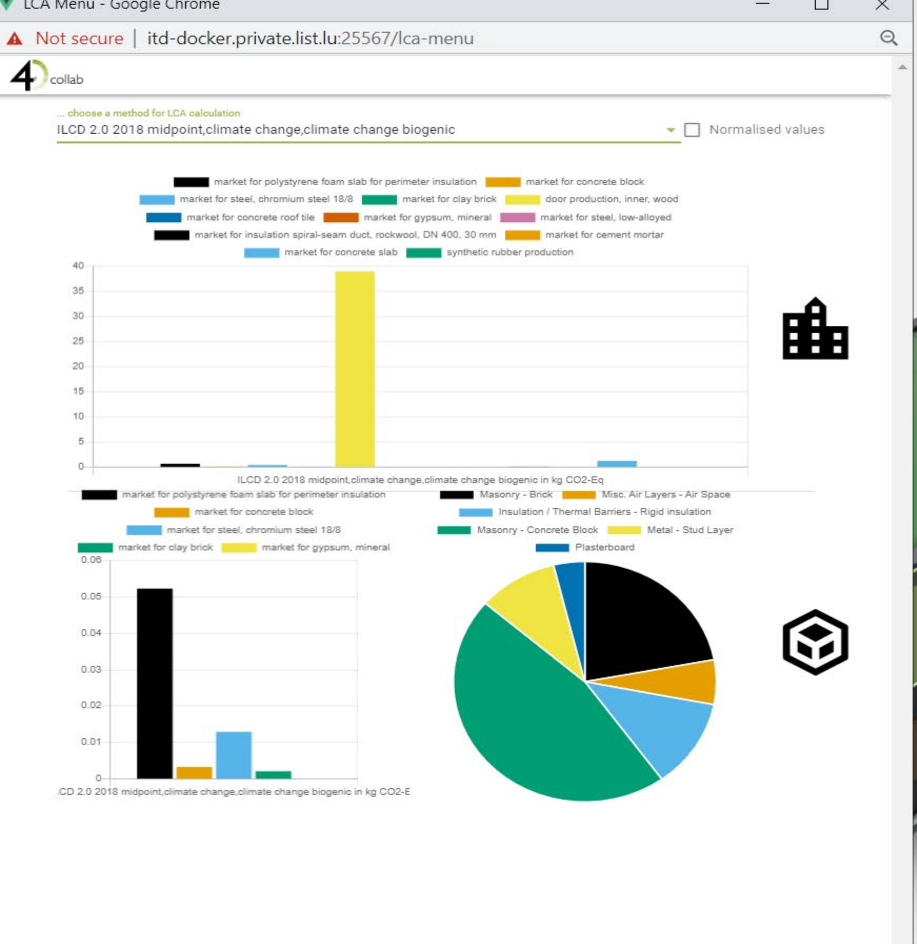

We initially integrated a Brightway2 service to conduct LCA on specific BIM models.

Challenges:

- no semantic models/ontologies on LCA side
- - materials had to be mapped to Ecoinvent at 1:1 basis

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Step 1 – mapping ontologies (Tbox)

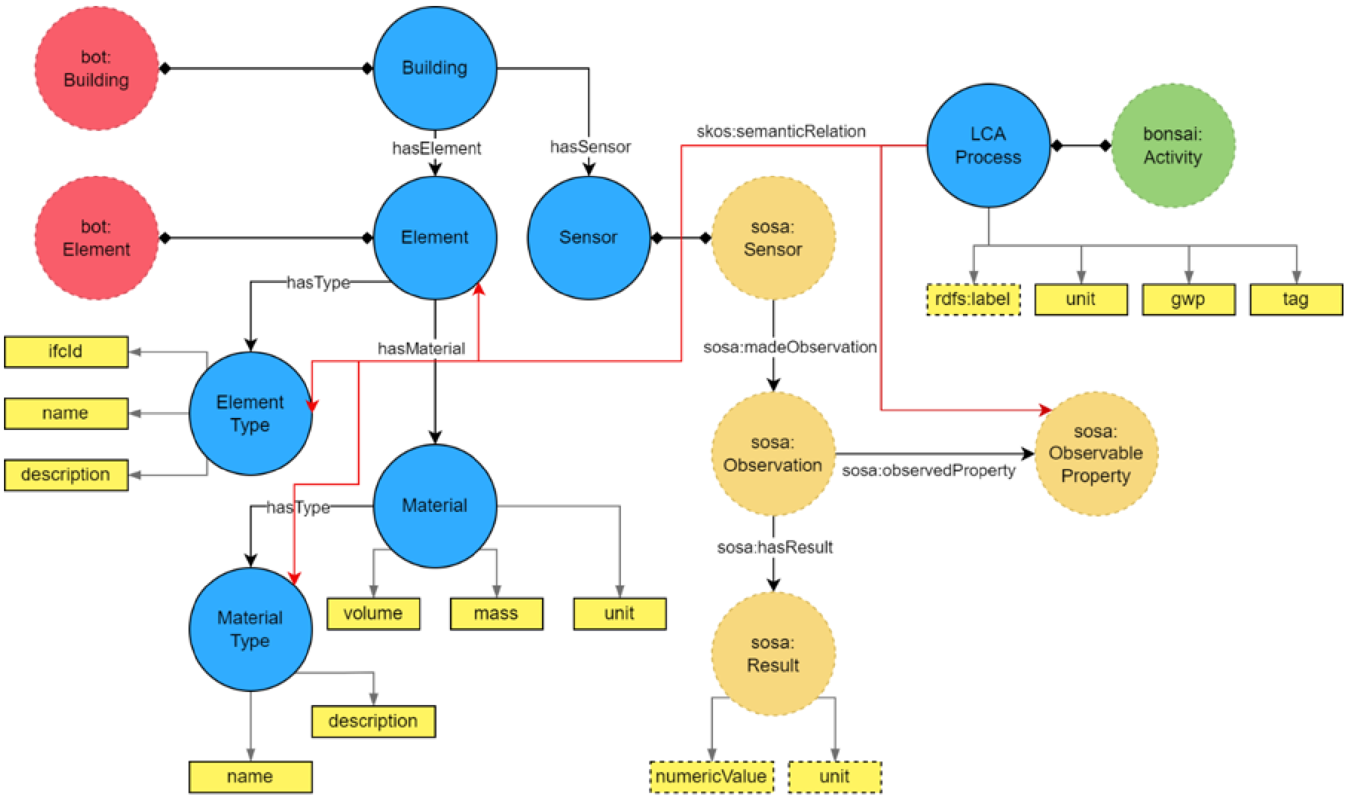

Figure 3: Schema level representation of Tbox assertions, with imported concepts from nearby domain ontologies.

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STEP 3 - matching LCA and building instance data

Limitations:

- bim data is low quality

- enriched BIM data (materials + NLSfB) is too vague for LCA

- lca data is very specific, depending on markets/locations

See results in Table 3

We defined 3 tiers of matching:

- Tier III – related data; a broad match, with many potential results;
- Tier II – relevant data; a close match; high possibility of exact concepts with several results;
- Tier I – exact data; an identical match; 1 specific result.

We implemented several rules for tier III and II, using SWRL rules, but SPARQL is also possible

Table 2
Example rules for matching LCA processes with building material types using SKOS relationships

no	Tier	Body	Head
1	III	lca:tag(?p, ?tag) ^ building:elementName(?e, ?name) ^ swrlb:matches(?name, ?tag)	-> skos:relatedMatch(?e, ?p)
3	III	lca:tag(?p, ?tag) ^ building:materialTypeName(?m, ?name) ^ swrlb:matches(?name, ?tag)	-> skos:relatedMatch(?m, ?p)
4	II	building:Element(?e) ^ skos:relatedMatch(?e, ?p) ^ building:MaterialType(?m) ^ skos:relatedMatch(?m, ?p)	-> skos:closeMatch(?m, ?p)

Case study – step 2: Calculating LCA impacts

Impacts of 1 selected element in GWP

```
PREFIX lca: <http://slca.org/slca/lca/>
PREFIX building: <http://slca.org/slca/building/>
PREFIX skos: <http://www.w3.org/2008/05/skos#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX bw2ont:<http://ontology.brightway.dev/>

SELECT DISTINCT ?materialName ?lcaName ?mass ?gwp (ABS(?gwp * ?mass) as ?calculatedGwp)
WHERE {
  ?element building:hasMaterial ?material .
  ?material building:materialMass ?mass .
  ?material building:hasMaterialType ?materialType .
  ?materialType building:materialTypeName ?materialName .
  ?materialType skos:closeMatch ?lcaProcess .
  ?lcaProcess rdfs:label ?lcaName .
  ?lcaProcess bw2ont:gwp ?gwp .
}
```

	materialName	lcaName	mass	gwp	calculatedGwp
1	"Masonry - Brick"	"market for clay brick"	"2504"^^xsd:double	"0.318174743118504"^^xsd:decimal	"796.709556768734e0"^^xsd:double
2	"Plasterboard"	"market for gypsum, mineral"	"174.16"^^xsd:double	"0.0648311513957918"^^xsd:decimal	"11.290993327088902e0"^^xsd:double
3	"Metal - Stud Layer"	"market for steel, low-alloyed"	"30"^^xsd:double	"1.9957075713862387"^^xsd:decimal	"59.87122714158716e0"^^xsd:double
4	"Insulation / Thermal Barriers - Rigid insulation"	"market for stone wool"	"24.5"^^xsd:double	"1.3369904608859726"^^xsd:decimal	"32.7562662917063e0"^^xsd:double
5	"Masonry - Concrete Block"	"market for concrete block"	"5135"^^xsd:double	"0.07056324260584888"^^xsd:decimal	"362.342250781034e0"^^xsd:double

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Case study – step 2: Calculating LCA impacts

Impacts of 1 selected material type in GWP, across the BIM

```
PREFIX building: <http://slca.org/slca/building/>
PREFIX skos: <http://www.w3.org/2008/05/skos#>
PREFIX bw2ont:<http://ontology.brightway.dev/>

SELECT ?materialName  ?totalVolume (ABS(?gwp * ?totalVolume) as ?totalGwp)
WHERE {
  ?materialType building:materialTypeName ?materialName .
  ?materialType skos:closeMatch ?lcaProcess .
  ?lcaProcess bw2ont:gwp ?gwp .
  {
    SELECT ?materialType (SUM(?vol) as ?totalVolume)
    WHERE {
      ?material building:materialVolume ?vol .
      ?material building:hasMaterialType ?materialType .
    } GROUP BY ?materialType
  }
  FILTER STRSTARTS(?materialName, "Concrete")
}
```

	materialName	totalVolume	totalGwp
1	"Concrete"	"48.761477286999956e0"^^xsd:double	"14301.174376684177e0"^^xsd:double

Case study – step 2: Calculating LCA impacts

Impacts of 1 selected measurement type in GWP (energy consumption)

```
PREFIX sense: <http://slca.org/slca/sense/>
PREFIX skos: <http://www.w3.org/2008/05/skos#>
PREFIX bw2ont:<http://ontology.brightway.dev/>
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX qudt-1-1: <http://qudt.org/1.1/schema/qudt#>

SELECT ?observableProperty ?unit ?value  ?gwp (ABS(?gwp * ?value) as ?calculatedGwp)
WHERE {
  ?building sense:hasSensor ?sensor .
  ?sensor sosa:observes ?observableProperty .
  ?observableProperty skos:exactMatch ?lcaProcess .
  ?lcaProcess bw2ont:gwp ?gwp .
  ?sensor sosa:madeObservation ?observation .
  ?observation sosa:hasResult ?result .
  ?result qudt-1-1:numericValue ?value .
  ?result qudt-1-1:unit ?unit .
}
```

	observableProperty	unit	value	gwp	calculatedGwp
1	<http://example.org/data/Appartment/134/electricConsumption>	<http://qudt.org/1.1/vocab/unit#Kilowatthour>	"22.4"^^xsd:double	"0.3496524295499448"^^xsd:decimal	"7.832214421918763e0"^^xsd:double

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conclusions

The SemanticLCA ontology is useful because it models practical applications of applying LCA to buildings (materials and energy use)

Mapping BIM and LCA domains is challenging and limited due to different scopes, but could be more automated.

Semantic web technologies can bridge the interoperability gap between LCA and built assets, allowing more explainable impacts of building elements and energy usage.

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