

Representing Modelica models as knowledge graphs using the MoOnt ontology

W3C Linked Building Data Community Group, online, 2022-11-16

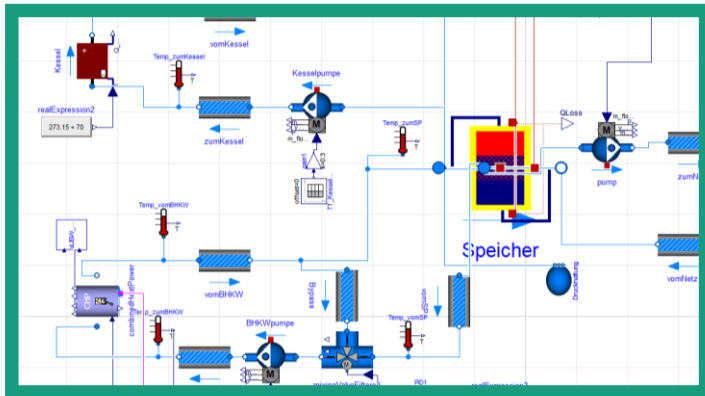
Elisabeth Eckstädt

Motivation

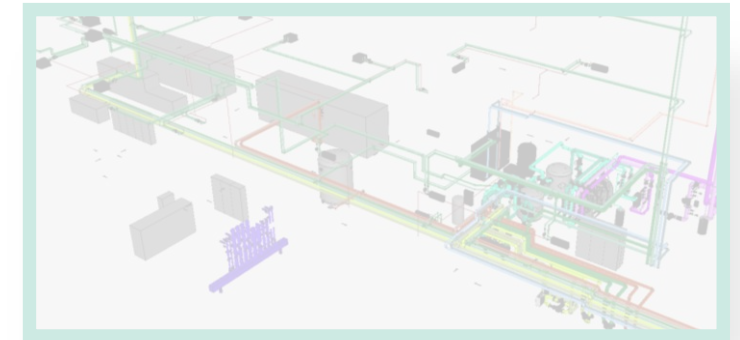
Modelica Models should be part of the Digital Twin

Building Information
Management

Digital Twin



OpenBIM IFC (Building
Information Model)



- Knowledge Graph
- W3C Standards: RDF, RDFS, OWL

Agenda

45 minutes to introduce you to my ideas

	Motivation
	Previous Works
	<u>Knowledge Engineering Methodology</u>
	1. Specification <ul style="list-style-type: none">▪ Modelica Basics▪ Design Decisions
	2.-4. Conceptualisation, Formalisation & Implementation – MoOnt
	5. Maintenance & Evaluation
	Populating the Knowledge Graph <ul style="list-style-type: none">▪ Modelica Transcriptor▪ Ontologies for Libraries▪ KG for instance model
	Answering Competency Questions
	Outlook

Previous Works

Pop, Adrian / Fritzson, Peter @Whitepaper 2004

- THE MODELICA STANDARD LIBRARY AS AN ONTOLOGY FOR MODELING AND SIMULATION OF PHYSICAL SYSTEMS

Delgoshaei, Parastoo / Heidarinejad, Mohammad / Austin, Mark A. @“Procedia Engineering” 2017

- „Semantic Inference-Based Control Strategies for Building HVAC Systems Using Modelica-Based Physical Models”

Sprint Project 2014-2017

- Uri Shani: „Can ontologies prevent MBSE models from becoming obsolete?” @IEEE SYSCON 2017
- “Modelica Ontology” @ <http://www.sprint-iot.eu/Wolfram-Modelica-ontology.zip> 2014

Zeb, Akhtar / Kortelainen, Juha @Whitepaper 2017

- “Web Ontology Language data modelling of Modelica simulation models”

Roxin, Ana / Dundee, Vishak / Vukovic, Vladimir @LDAC 2021

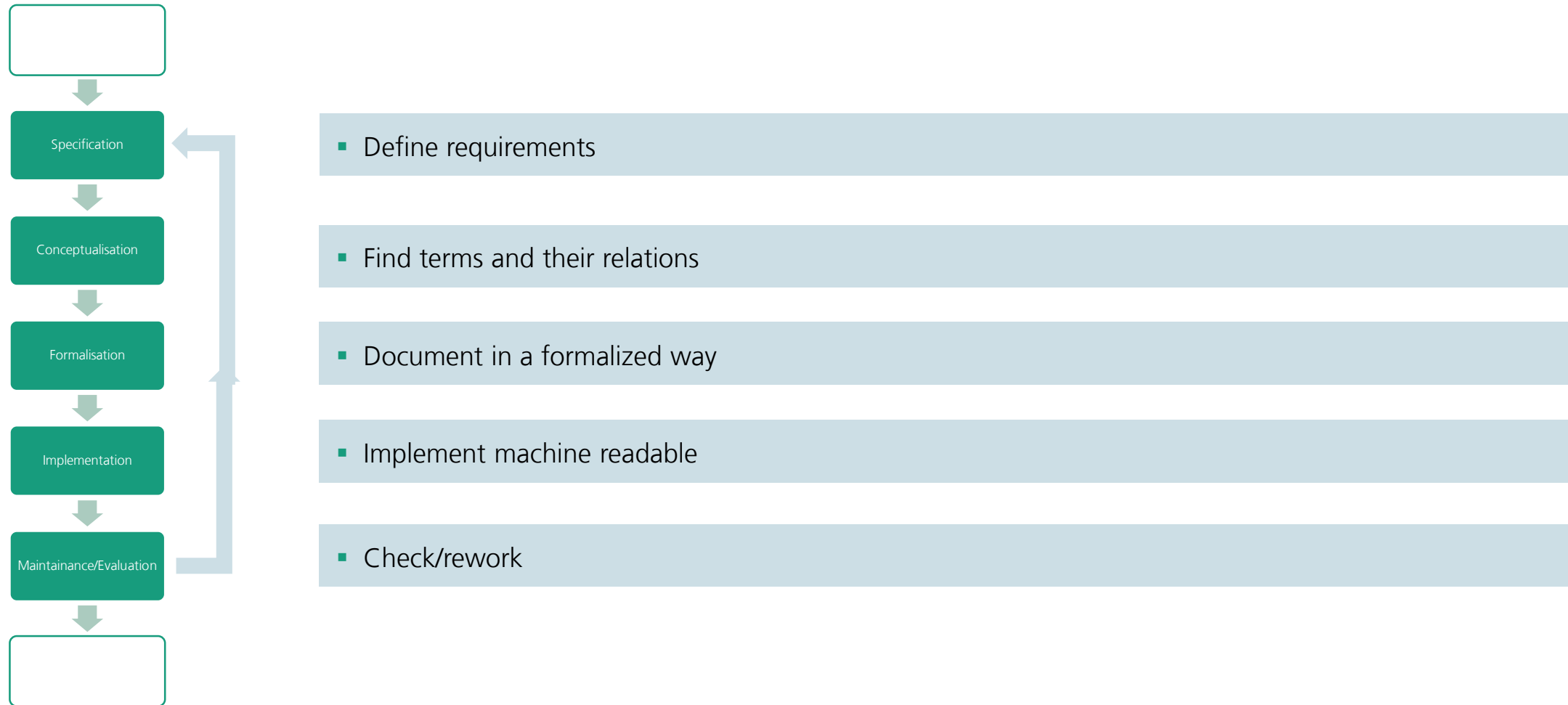
- Investigating Potential Alignments between Modelica Standard Library and SAREF Ontologies

Nachawati, Mohamad Omar ... Pop, Adrian et al @American Modelica Conference 2022

- Towards an Open Platform for Democratized Model-BasedDesign and Engineering of Cyber-Physical Systems

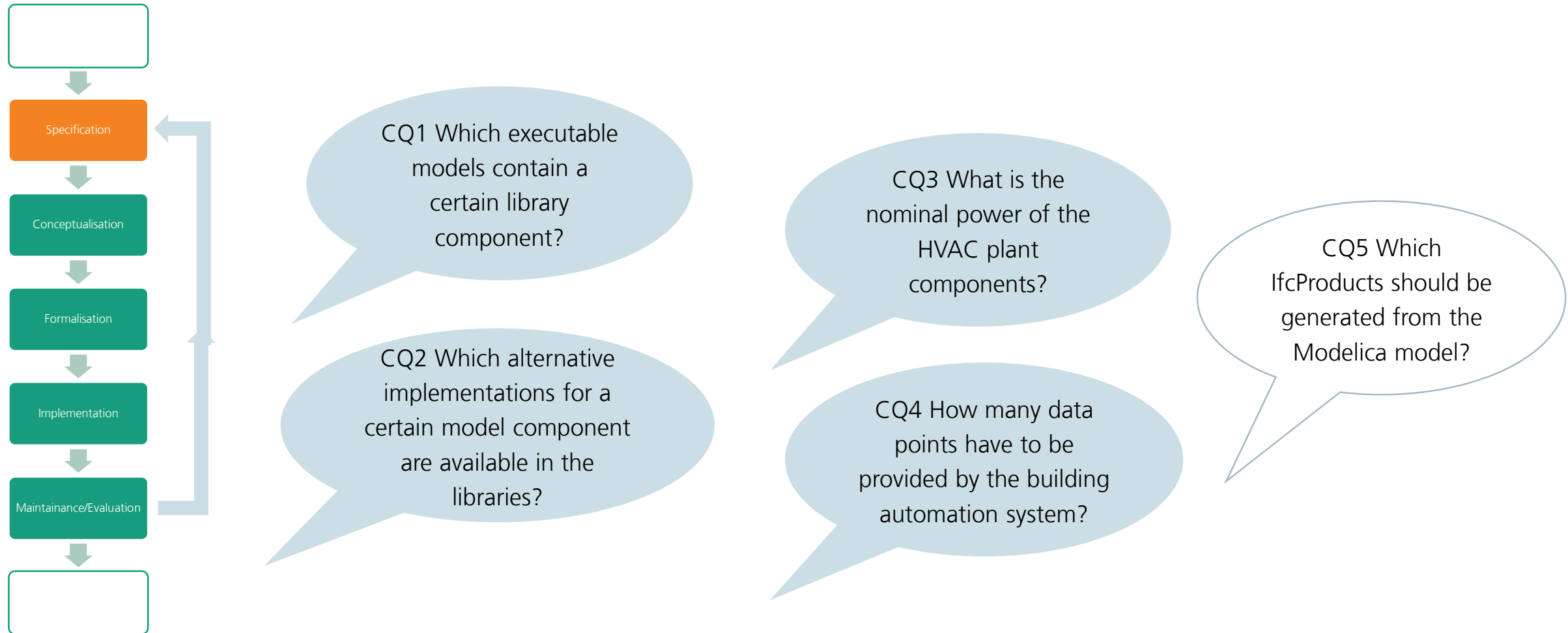
Knowledge Engineering

A 5-step systematic approach was chosen



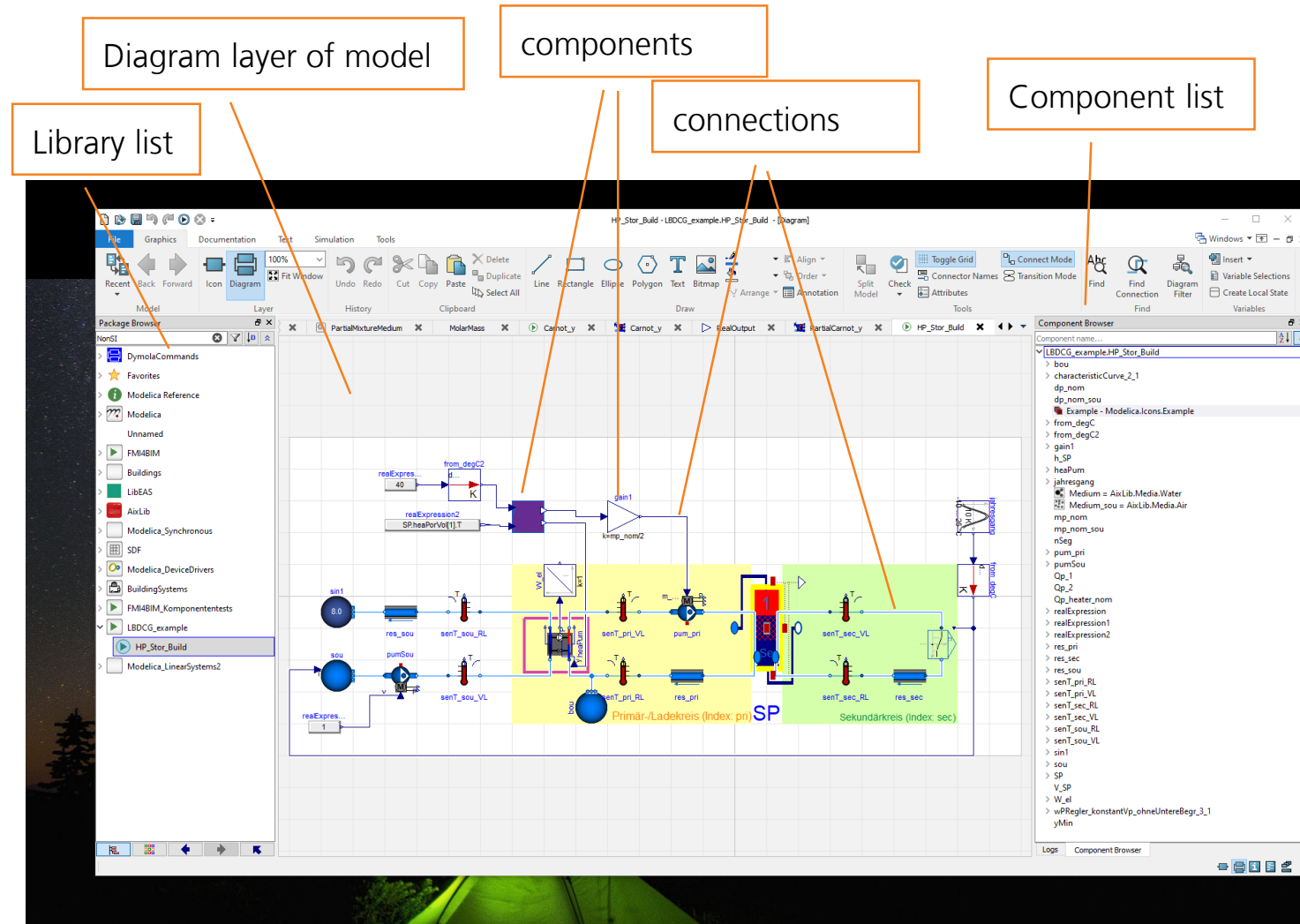
Specification

Which competency questions should the Knowledge Graph be able to answer?



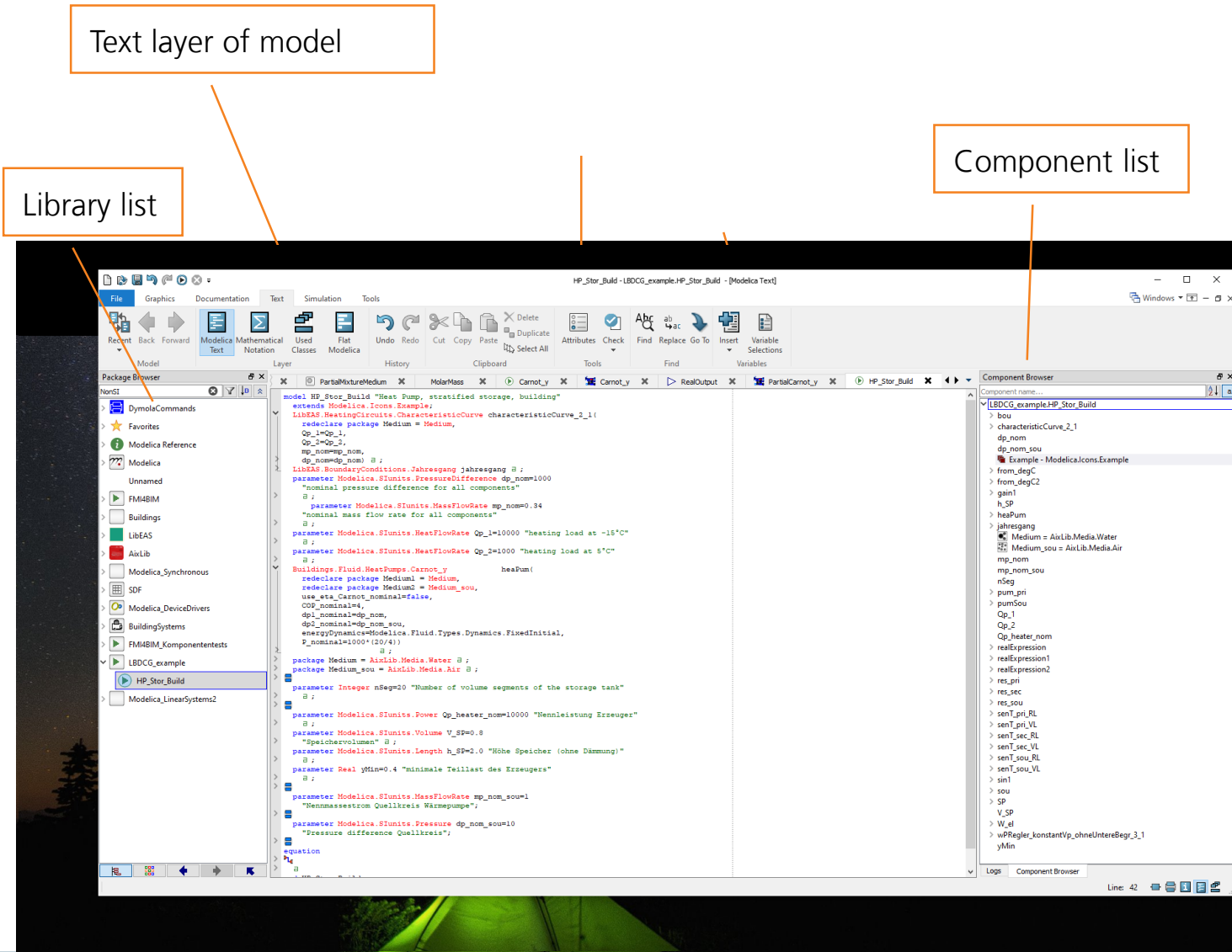
Modelica Basics

- Object oriented modeling language
- Models
 - Have components
 - Components are connected
- Equation based → connections are usually undirected
- Components
 - Are usually instances of library elements
 - Can be custommade
- model layers
 - Diagram
 - Text
 - Documentation
 - Icon
- Library elements are also called „models“



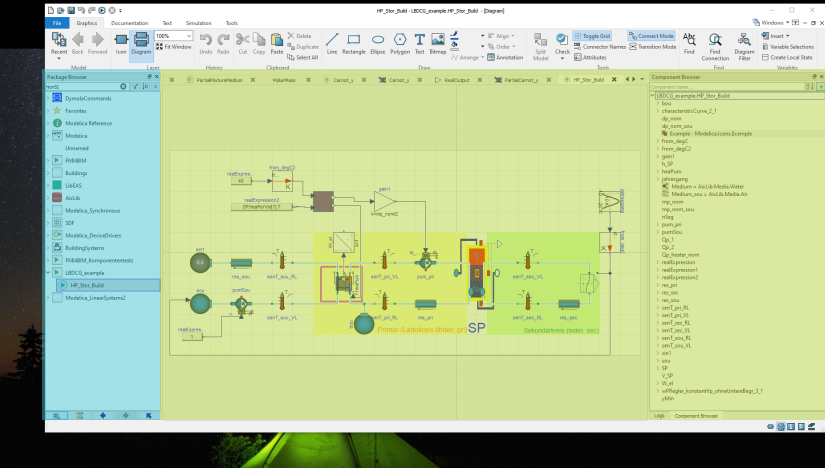
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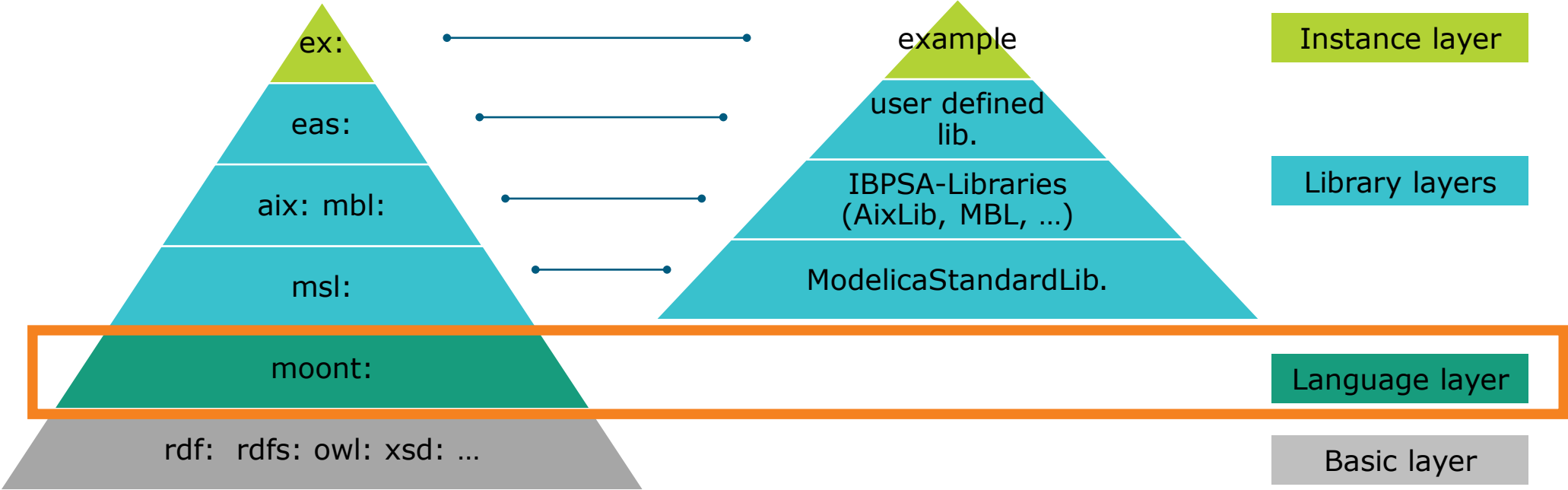
Design Decision

The Modelica library stack is mirrored by the KG stack

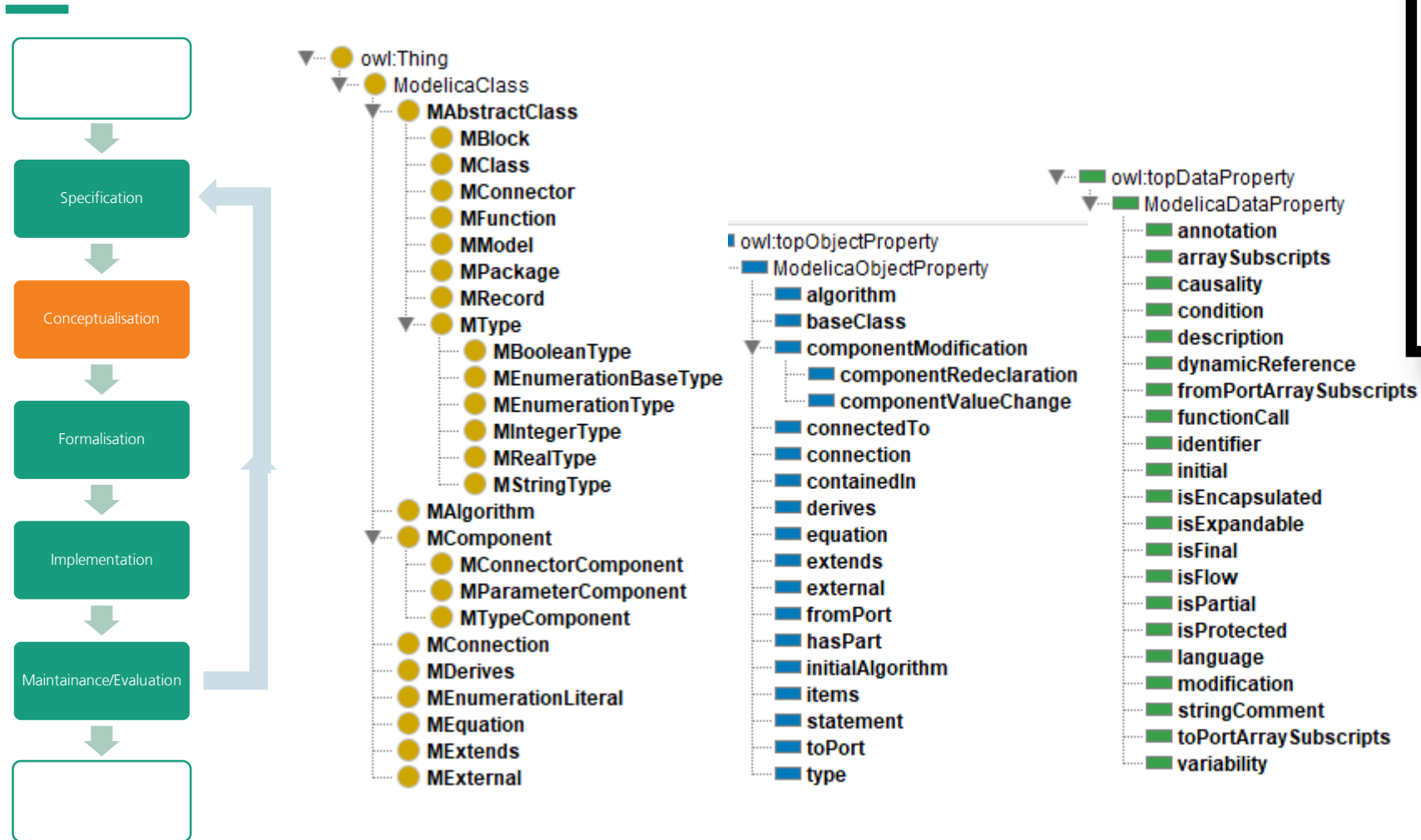


Corresponding Stack
of knowledge graphs

stack of
ModelicaLibraries



Conceptualisation



Modelica® – A Unified Object-Oriented Language
for Systems Modeling

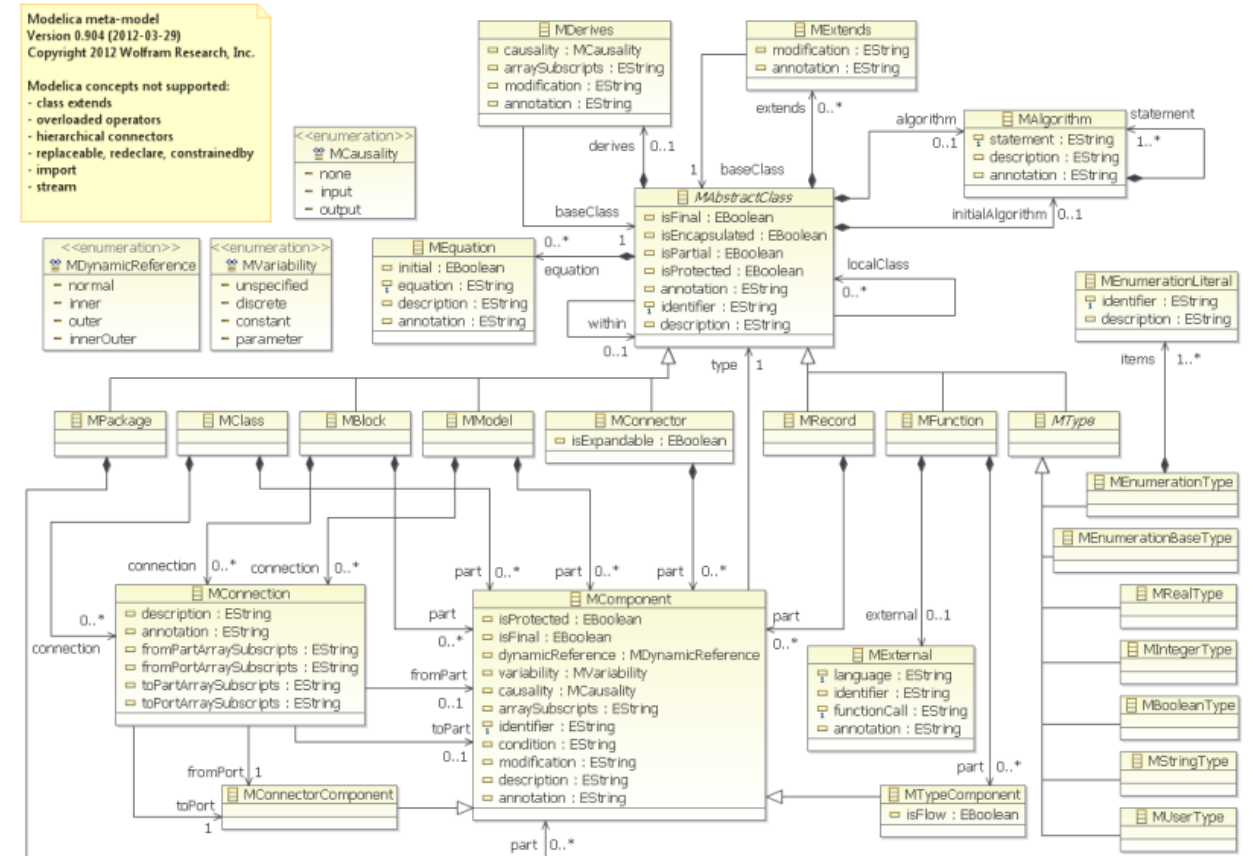
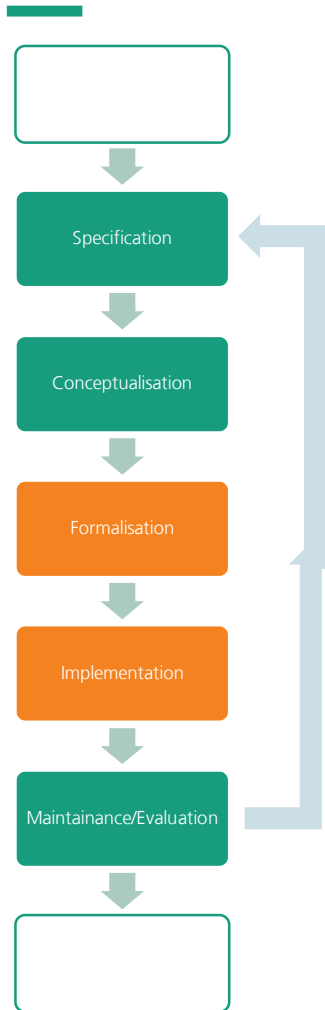
Language Specification

Version 3.5

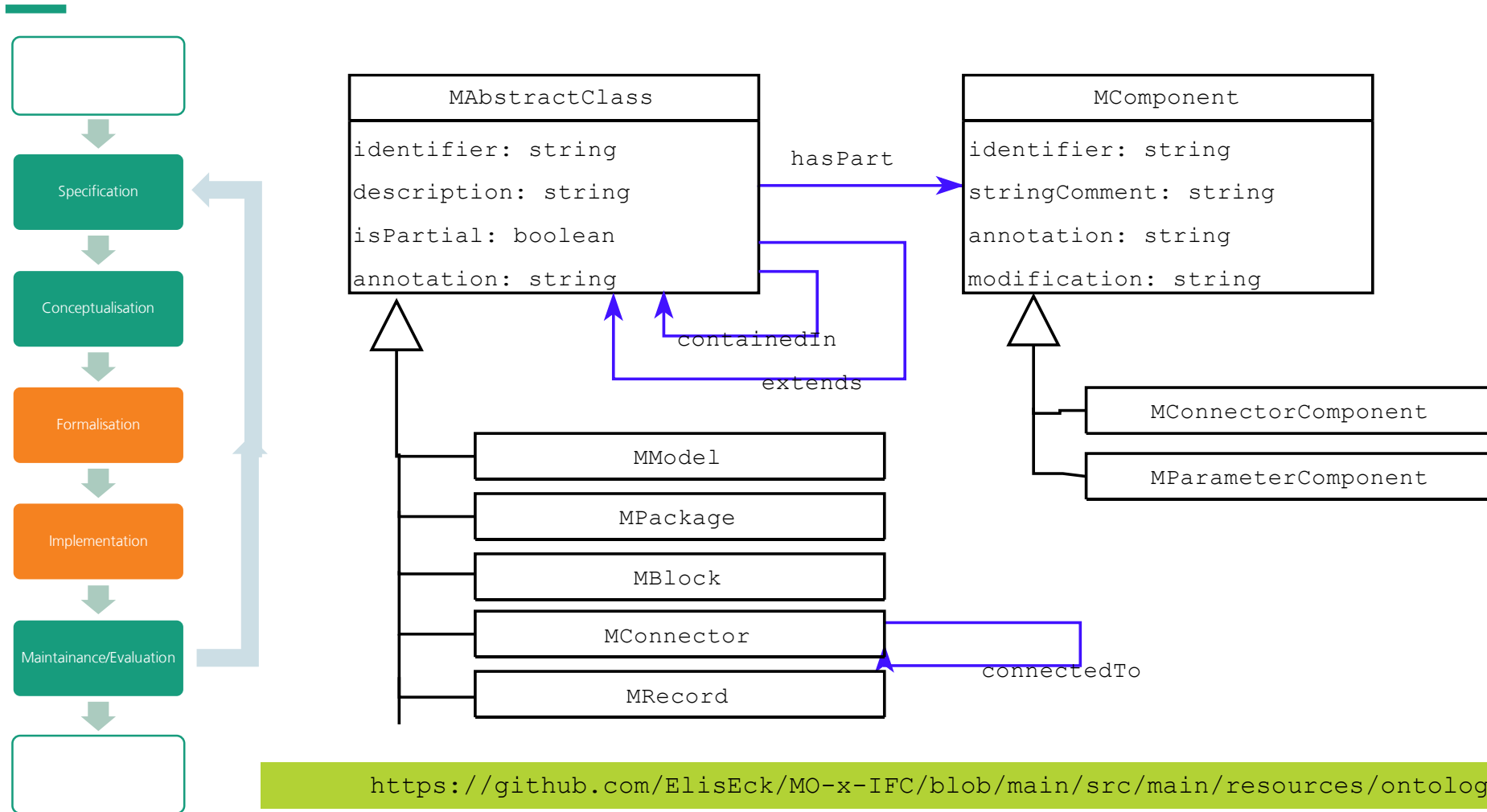
February 18, 2021

Modelica Association

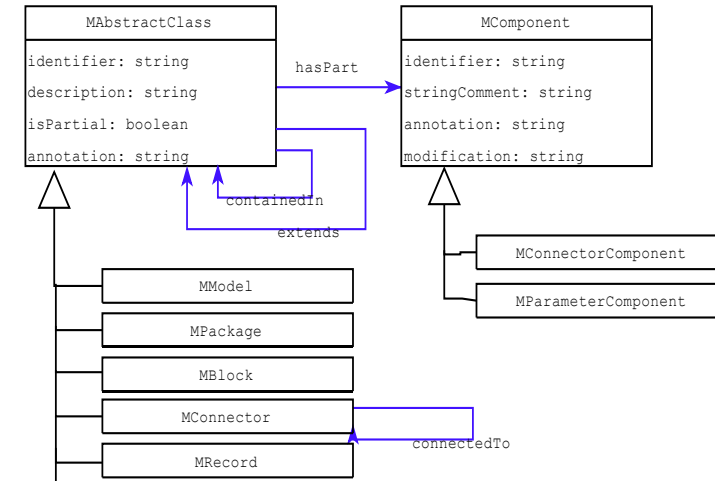
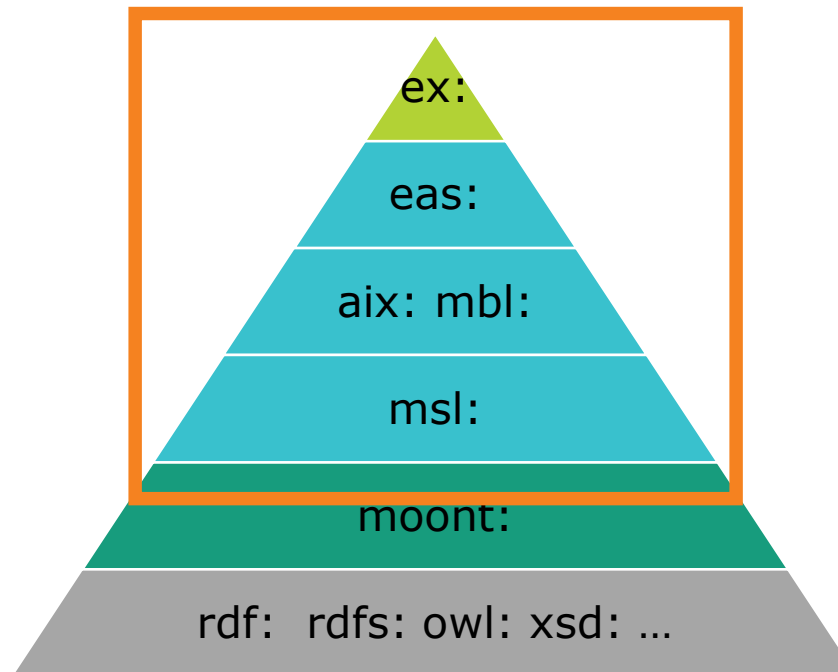
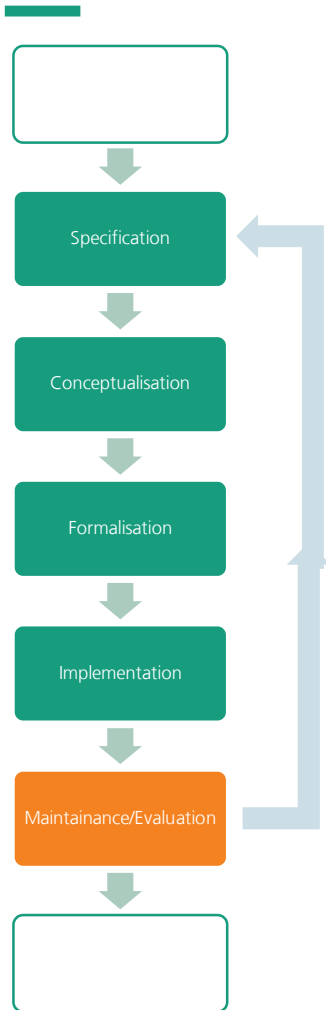
Formalization & Implementation



Formalization & Implementation

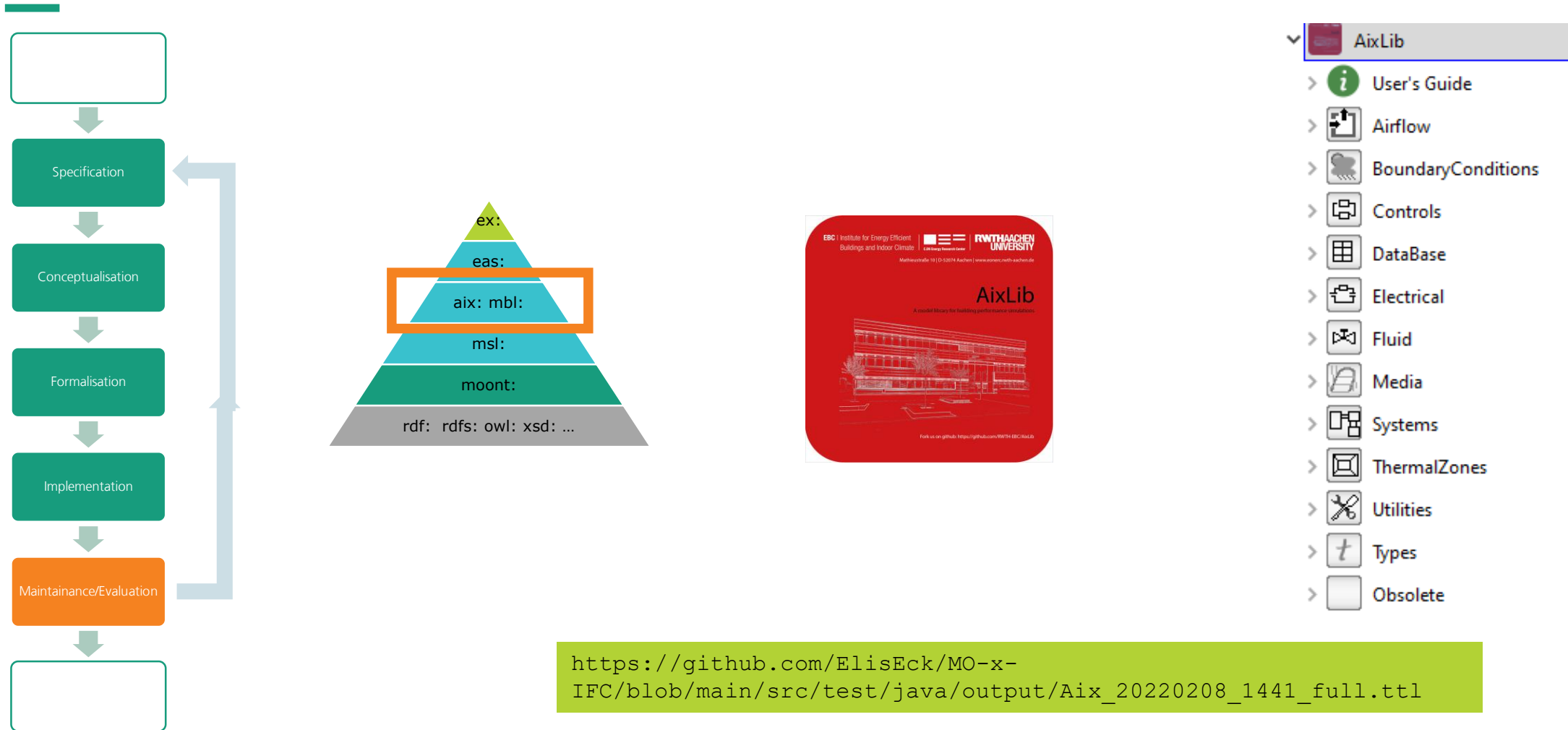


MoTTL Transcriptor

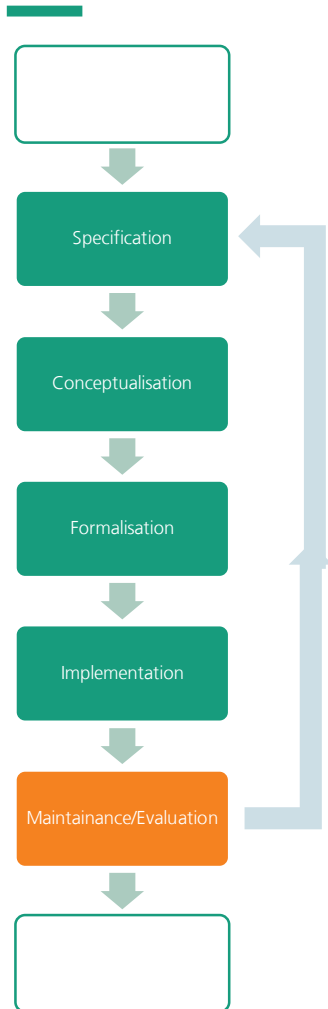


<https://github.com/ElisEck/MO-x-IFC/blob/main/src/test/java/modelicatranscriptor/parser/ModelicaFileAntlrParserTest.java>

Knowledge Graph library level – example AixLib



Knowledge Graph library level – example AixLib - excerpt

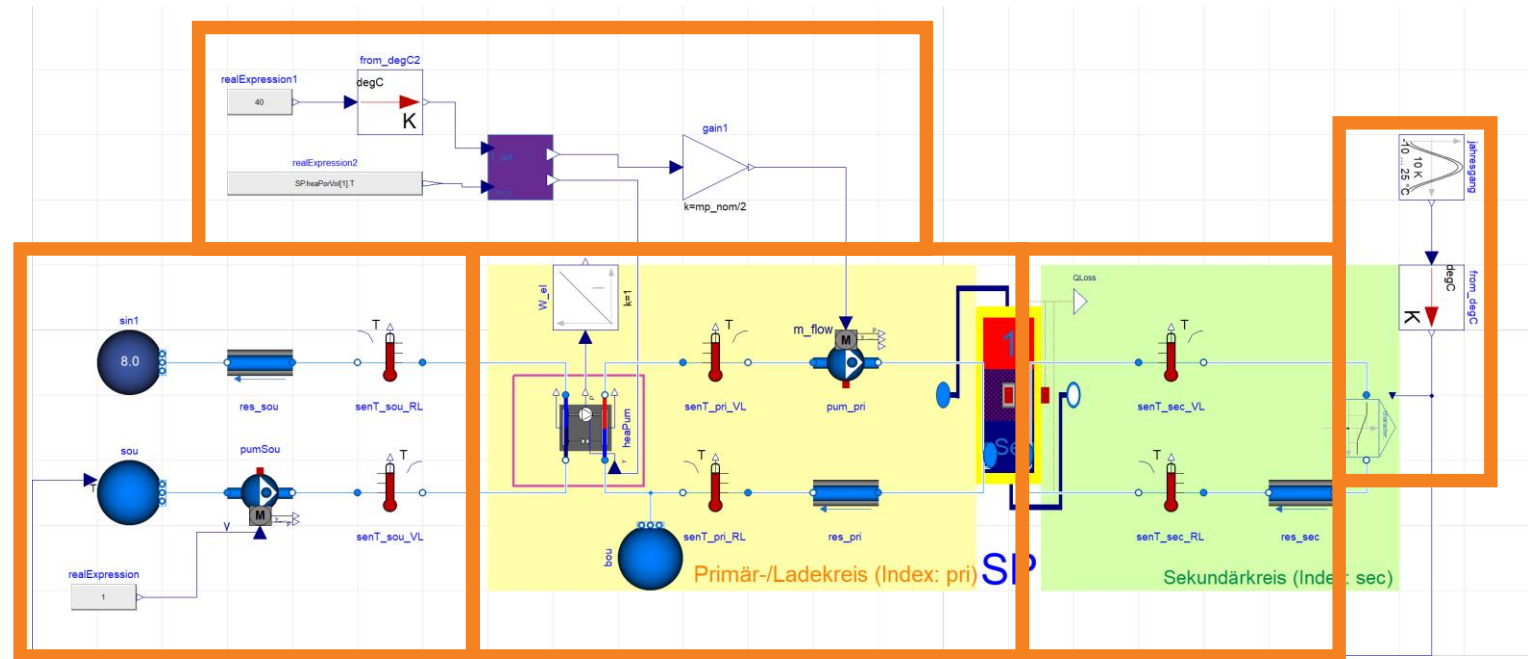
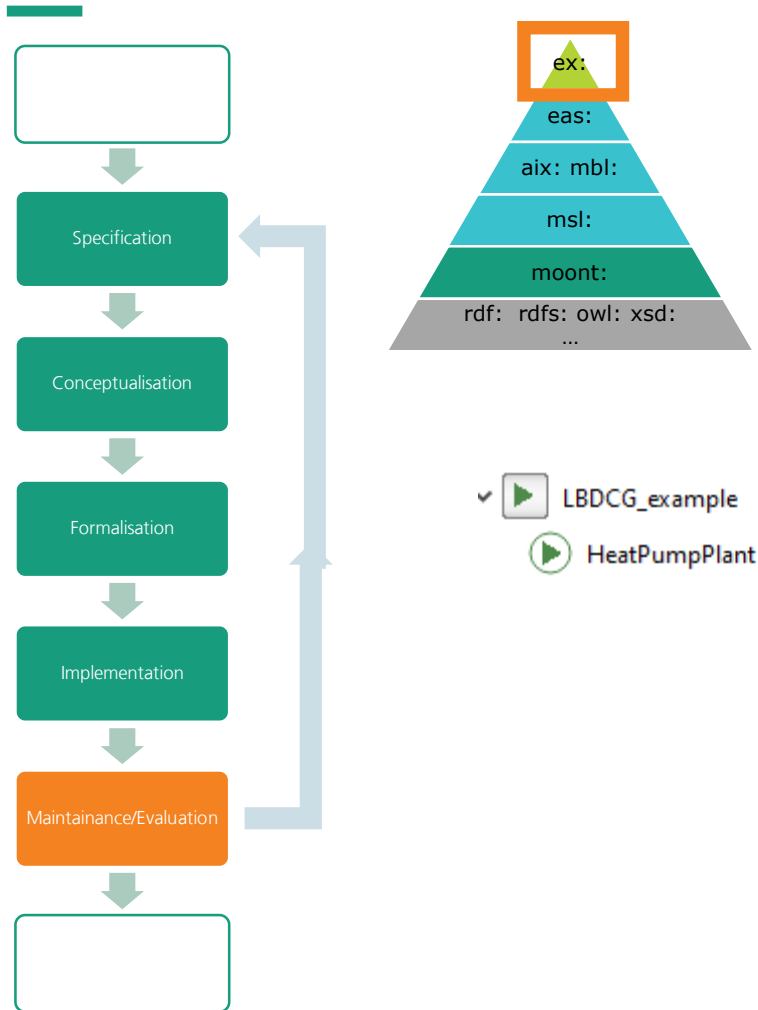


```
aix_20221114_1354_fullclean.ttl x Camot_y.mo x
1  within AixLib.Fluid.HeatPumps;
2  model Carnot_y
3  "Reversible heat pump with performance curve adjusted based on Carnot efficiency"
4  extends AixLib.Fluid.Chillers.BaseClasses.PartialCarnot_y(
5  final COP_is_for_cooling = false);
6
```

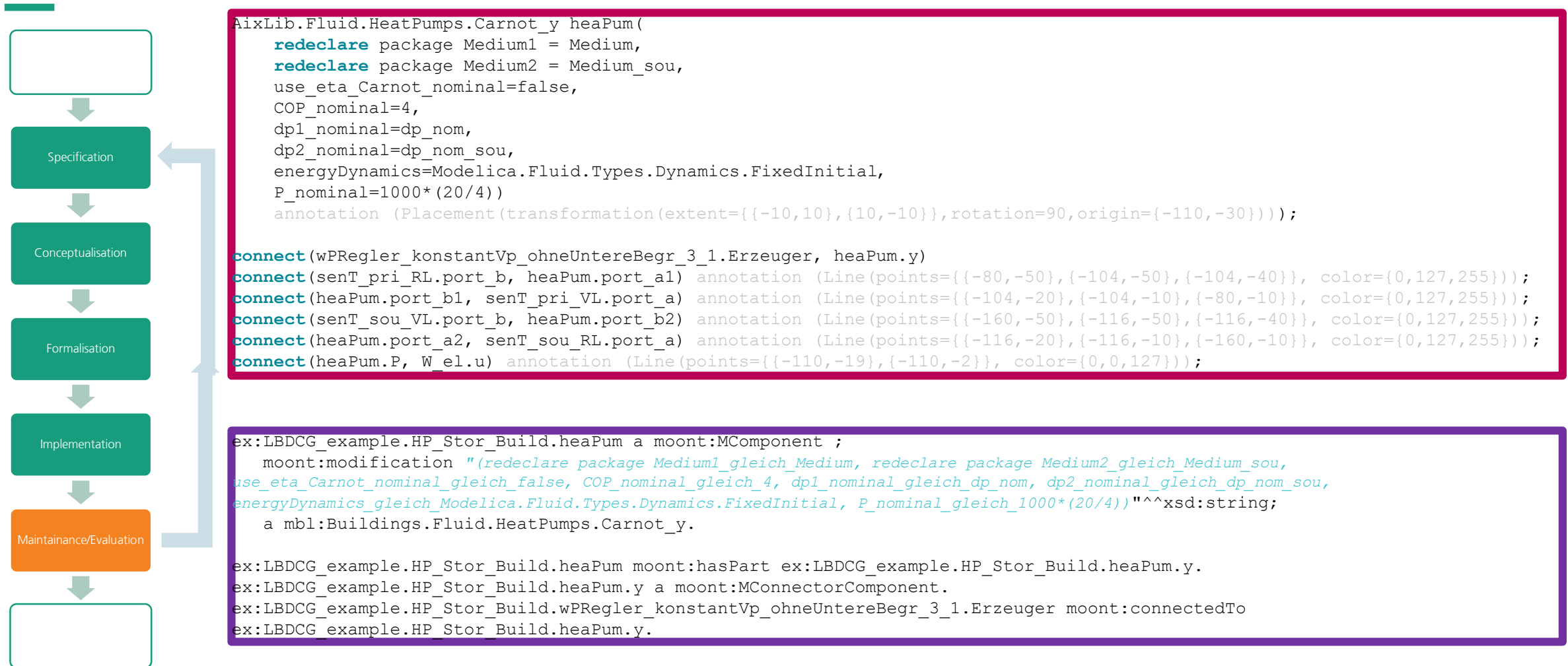
```
aix_20221114_1354_fullclean.ttl x Camot_y.mo x
75212 aix:AixLib.Fluid.HeatPumps.Carnot_TCon.eva moont:hasPart aix:AixLib.Fluid.HeatPumps.Carnot_TCon.eva.u.
75213 aix:AixLib.Fluid.HeatPumps.Carnot_TCon.eva.u a moont:MConnectorComponent.
75214 aix:AixLib.Fluid.HeatPumps.Carnot_y rdfs:subClassOf moont:MModel;
75215 moont:stringComment "Reversible heat pump with performance curve adjusted based on Carnot efficiency"^^xsd:string;
75216 moont:containedIn aix:AixLib.Fluid.HeatPumps.
75217 aix:AixLib.Fluid.HeatPumps.Carnot_y moont:extends aix:AixLib.Fluid.Chillers.BaseClasses.PartialCarnot_y.
75218 aix:AixLib.Fluid.HeatPumps.Compressors.BaseClasses rdfs:subClassOf moont:MPackage;
75219 moont:stringComment "Package with base classes for compressors"^^xsd:string;
75220 moont:containedIn aix:AixLib.Fluid.HeatPumps.Compressors.
75221 aix:AixLib.Fluid.HeatPumps.Compressors.BaseClasses moont:extends msl:Modelica.Icons.BasesPackage
```

https://github.com/EliseEck/MO-x-IFC/blob/main/src/test/java/output/Aix_20220208_1441_full.ttl

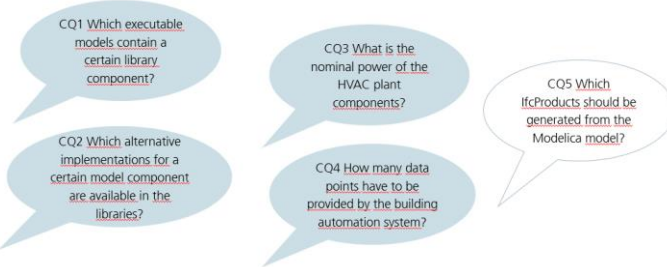
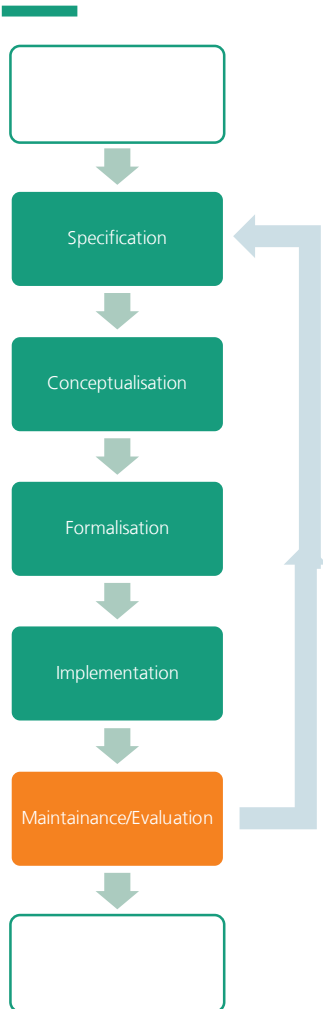
Knowledge Graph instance level – example „HeatPumpPlant“



Knowledge Graph instance level – example „HeatPumpPlant“ - excerpt

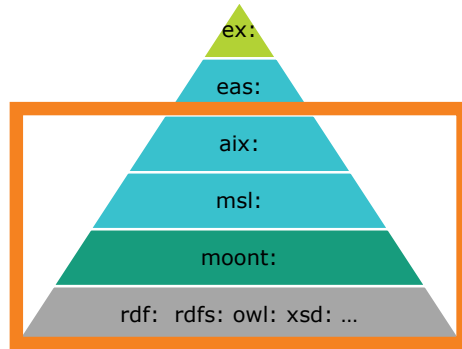
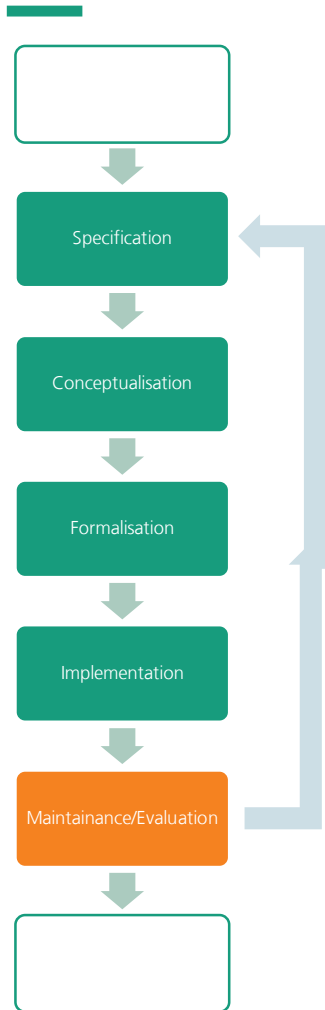


Formalising competency questions



	Competency Question	SPARQL query
CQ1	Which executable models contain a certain library component?	<pre> select ?subj ?obj where { ?subj moont:hasPart ?obj . ?obj a aix:AixLib.Fluid.Chillers.Carnot_y. }</pre> <pre> select DISTINCT ?subj ?class where { ?subj moont:hasPart ?obj . ?subj moont:extends msl:Modelica.Icons.Example . ?obj a ?class . ?class moont:extends* aix:AixLib.Fluid.Interfaces.PartialFourPortInterface . }</pre>
CQ2	Which alternative implementations for a the heat pump component are available in the library?	<pre> select ?model where { ?model moont:extends* / moont:hasPart ?a. ?a rdf:type msl:Modelica.Blocks.Interfaces.RealInput . ?model moont:extends* / moont:hasPart ?b. ?b rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_a . ?model moont:extends* / moont:hasPart ?c. ?c rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_b . ?model moont:extends* / moont:hasPart ?d. ?d rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_a . ?model moont:extends* / moont:hasPart ?e. ?e rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_b . }</pre>
CQ3	What is the nominal power of the HVAC plant components	<pre> select ?comp ?power where { ?model moont:hasPart ?comp. ?comp rdf:type moont:MComponent . ?comp moont:hasPart ?param. ?param rdf:type moont:MParameterComponent . ?param moont:type ex:Modelica.SIunits.Power; ?param moont:modification ?power }</pre>
CQ4	How many data points have to be provided by the building automation system?	<pre> select DISTINCT ?comp ?part where { ex:LBD CG_example.HP_Stor_Build moont:hasPart ?comp . ?comp rdf:type ?compclass . ?compclass moont:extends* ?father . ?father moont:hasPart ?part . {?part a msl:Modelica.Blocks.Interfaces.RealOutput .} UNION {?part a msl:Modelica.Blocks.Interfaces.RealInput .} }</pre>

Implementing competency questions



```
from rdflib import RDFS, RDF, Namespace, Graph, URIRef
h = Graph() # Initialize a new graph.
h.parse('c:/_DATEN/LBDCG/msl_20221114_1357_fullclean.ttl', format='turtle') # Load the stored graph.
h.parse('c:/_DATEN/LBDCG/aix_20221114_1354_fullclean.ttl', format='turtle') # Load the stored graph.
h.parse('c:/_DATEN/WORKSPACES/IntelliJ/mo-x-ifc/src/main/resources/ontologies/7_MoOnt/MoOnt.ttl', format='turtle') # Load the stored graph.

query1 = """
select ?subj ?obj where {
    ?subj moont:hasPart ?obj .
    ?obj a aix:AixLib.Fluid.Chillers.Carnot_y.
}
"""

res = h.query(query1)
for row in res:
    print(row[0] + "\t" + row[1])
```

Benefit from querying the AixLib-graph with SPARQL – CQ1

„Which executable models contain a certain library component?“

Query

#1 Find models using a component

```
select ?subj ?obj where {  
  ?subj moont:hasPart ?obj .  
  ?obj a aix:AixLib.Fluid.Chillers.Carnot_y .  
}
```

#2 Find executable models using a component or its descendants

```
select DISTINCT ?subj ?class where {  
  ?subj moont:hasPart ?obj .  
  ?subj moont:extends msl:Modelica.Icons.Example .  
  ?obj a ?class .  
  ?class moont:extends*  
  aix:AixLib.Fluid.Interfaces.PartialFourPortInterface .  
}
```

Result

- aix:AixLib.Fluid.Chillers.Examples.Carnot_y
- aix:AixLib.Fluid.Chillers.Validation.CarnotVerifyCOP
- aix:AixLib.Fluid.Chillers.Validation.CarnotVerifyEtaCarnot

44 models

- aix:AixLib.Fluid.Chillers.Examples.Carnot_y
- aix:AixLib.Fluid.Chillers.Validation.CarnotVerifyCOP
- aix:AixLib.Fluid.Chillers.Validation.CarnotVerifyEtaCarnot
- ...

Benefit from querying the AixLib-graph with SPARQL – CQ2

„Which alternative implementations for a the heat pump component are available in the library?“

Query

#3 Find models that have 1 RealInput and 2 FluidPorts („a controlled flow element“)

```
select DISTINCT ?model where {  
  ?model moont:extends* / moont:hasPart ?a.  
  ?a rdf:type msl:Modelica.Blocks.Interfaces.RealInput .  
  ?model moont:extends* / moont:hasPart ?b.  
  ?b rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_a .  
  ?model moont:extends* / moont:hasPart ?c.
```

Result

99 models (7 from MSL, 92 from AixLib)

- msl#Modelica.Fluid.Machines.ControlledPump
- msl#Modelica.Fluid.Machines.PrescribedPump
- msl#Modelica.Fluid.Valves.ValveIncompressible
- ...
- aix#AixLib.Fluid.HeatPumps.Carnot_TCon
- aix#AixLib.Fluid.HeatPumps.Carnot_y

#3a Find all connectors, despite RealOutputs

```
select ?part ?class where {  
  aix:AixLib.Fluid.Chillers.Carnot_y moont:extends* ?father .  
  ?father moont:hasPart ?part .  
  ?part a ?class .  
  ?class rdfs:subClassOf moont:MConnector .  
  MINUS {?part a msl:Modelica.Blocks.Interfaces.RealOutput}}
```

- aix#AixLib.Fluid.Chillers.BaseClasses.PartialCarnot_Y.Y
- aix#AixLib.Fluid.Interfaces.PartialFourPort.port_b1
- aix#AixLib.Fluid.Interfaces.PartialFourPort.port_b2
- aix#AixLib.Fluid.Interfaces.PartialFourPort.port_a1
- aix#AixLib.Fluid.Interfaces.PartialFourPort.port_a2

```
  ?c rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_b .  
  ?model moont:extends* / moont:hasPart ?d.  
  ?d rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_a .  
  ?model moont:extends* / moont:hasPart ?e.  
  ?e rdf:type msl:Modelica.Fluid.Interfaces.FluidPort_b . }
```

Benefit from querying the AixLib-graph with SPARQL – CQ4

„How many data points have to be provided by the building automation system?“

Query

#5

```
select ?con ?conclass where {
  ex:LBDCG_example.HP_Stor_Build moont:hasPart ?comp .
  ?comp moont:hasPart ?con.
  ?con rdf:type moont:MConnectorComponent .
  ?con rdf:type ?conclass .    }
```

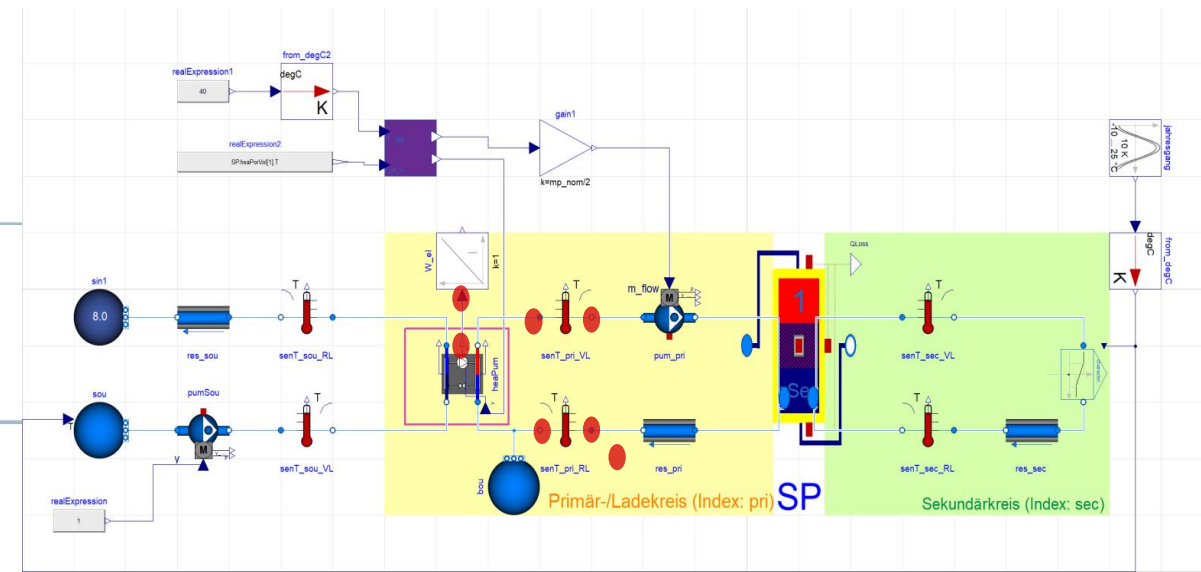
Result

- 56 connectors, which are the „used“ ones
- An Information on their class is not available

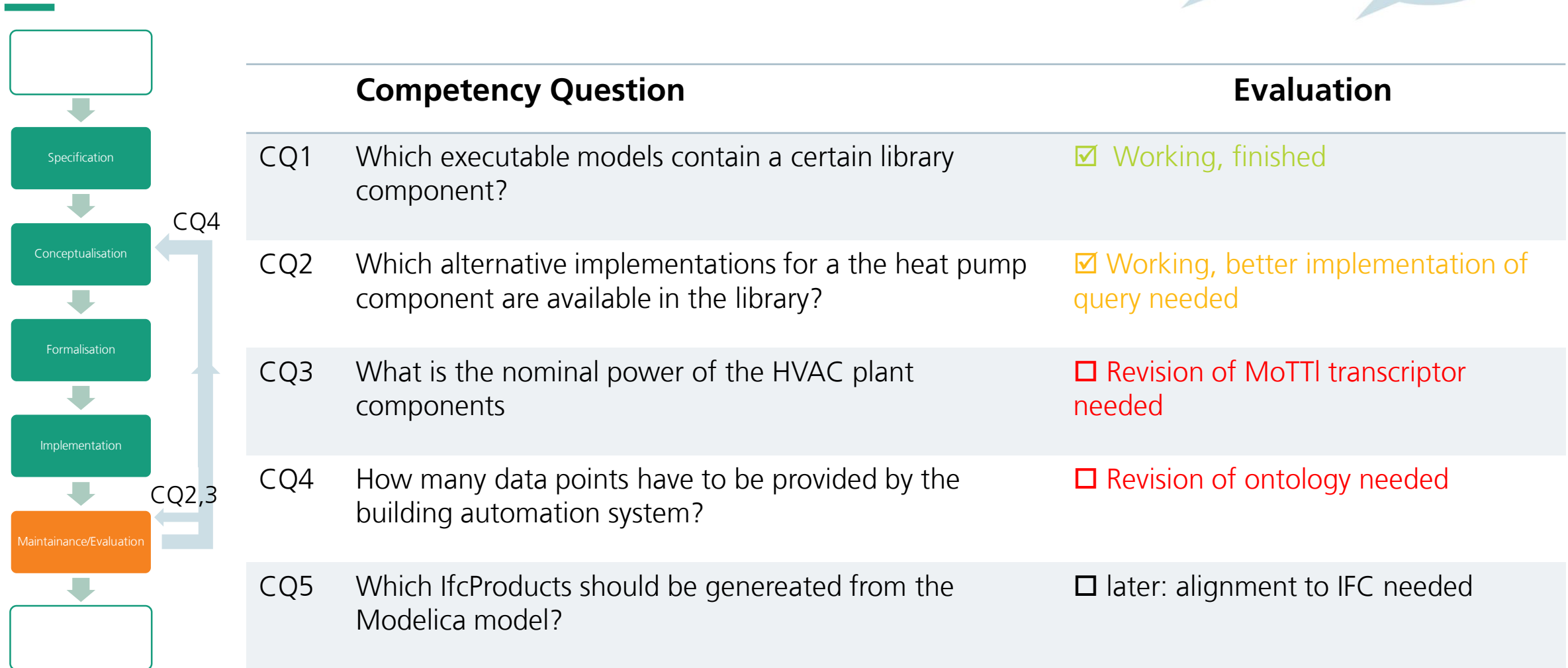
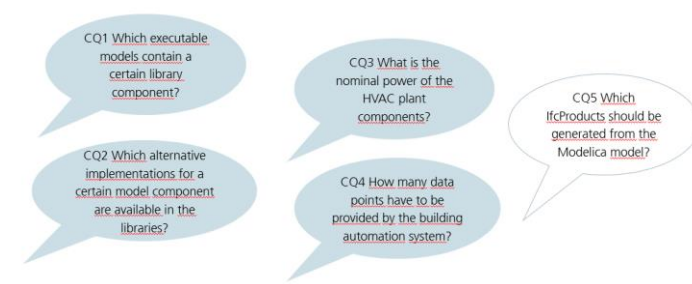
#6

```
select DISTINCT ?comp ?part where {
  ex:LBDCG_example.HP_Stor_Build moont:hasPart ?comp .
  ?comp rdf:type ?compclass .
  ?compclass moont:extends* ?father .
  ?father moont:hasPart ?part .
  {?part a msl:Modelica.Blocks.Interfaces.RealOutput .}
  UNION
  {?part a msl:Modelica.Blocks.Interfaces.RealInput .} }
```

- 53 connectors, including the not connected ones



Summary Evaluation – demand for revision



Outlook

Revise

- Revise MoOnt to be able to answer → CQ4
- Enhance transcriptor to cover parameter modifications → CQ3
- Better implementation to answer → CQ2

Polish

- Document
- Publish MoOnt, Transcriptor

Align IFC

- Engineer alignment
- Apply to generate IFC from Modelica

Reverse

- Transcriptor from semantic format to native Modelica
- Apply to generate Modelica from IFC

Looking forward to your questions!

Dipl.-Ing. Elisabeth Eckstädt
Abteilung Automatisierungs- und Regelungssysteme
Tel. +49 351 45691-381
elisabeth.eckstaedt@eas.iis.fraunhofer.de

Fraunhofer-Institut für Integrierte Schaltungen IIS
Institutsteil Entwicklung Adaptiver Systeme EAS
Münchner Straße 16
01187 Dresden
www.eas.iis.fraunhofer.de