bhOWL:

Federated Data Schemas and Semantic Web Technologies via Design Tools with a Focus on Grasshopper 3D

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Live demo by: **Aaron Wagner**
M.Sc. In Integrative Technologies & Architectural Design Research

Structure of the presentation:

1. Context of the Research: IntCDC Cluster of Excellence
2. Co-Design Interoperability Paradigms
3. BHoM Framework
4. BHoM to OWL/RDF translation patterns
5. Application of the developed toolkit
6. Live Demo

Context: IntCDC Cluster of Excellence

Cluster of Excellence Integrative Computational Design and Construction for Architecture

Research Areas:

- Methods
- Processes
- Systems
- Cross Sectoral
- Demonstrators

Research Units

- Architecture
- Structural Engineering, Building Physics and Geodesy
- Manufacturing and Systems Engineering
- Computer Science and Robotics
- Humanities and Social Sciences

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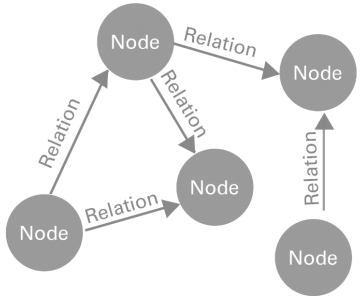
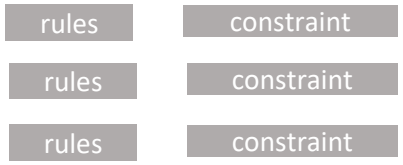
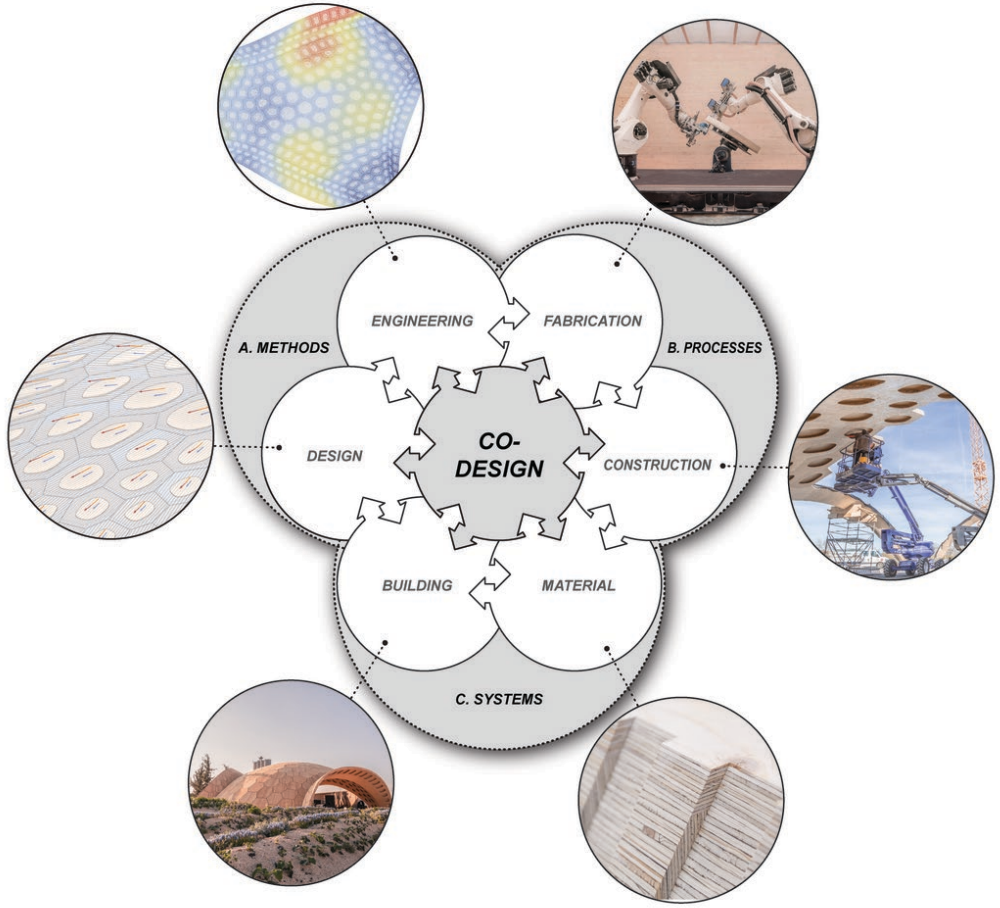
Context: Co-Design in IntCDC

Co-design: Considers design and analysis methods, manufacturing and construction processes, and material and building systems simultaneously, while integrating data from multiple disciplines.

Each discipline contains data on:
Facts, rules, constrains (reusable knowledge) + project specific data



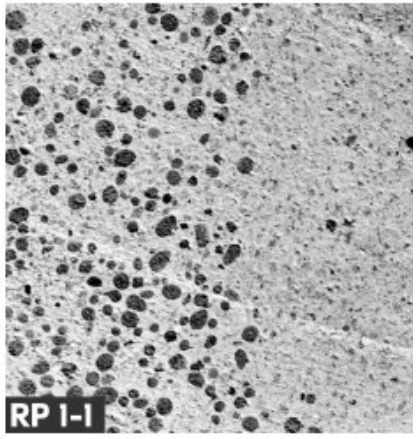




Knippers, J., Kropp, C., Menges, A., Sawodny, O., Weiskopf, D.: Integrative computational design and construction: rethinking architecture digitally. Civ. Eng. Des. 3(4), 123–135 (2021).

Context: Co-Design projects at IntCDC

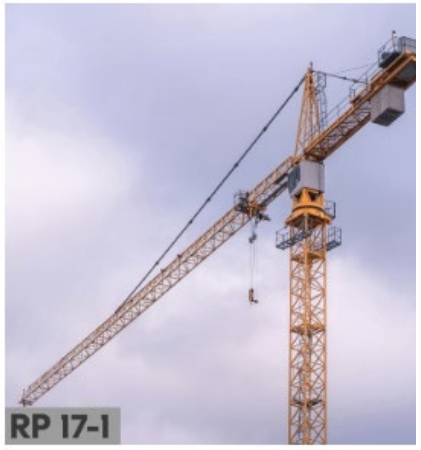
Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC)



Functionally Graded Concrete Building System

AI-Supported Collaborative Control and Trajectory Generation of Mobile Manipulators

Wood Building Systems for Distributed Robotics



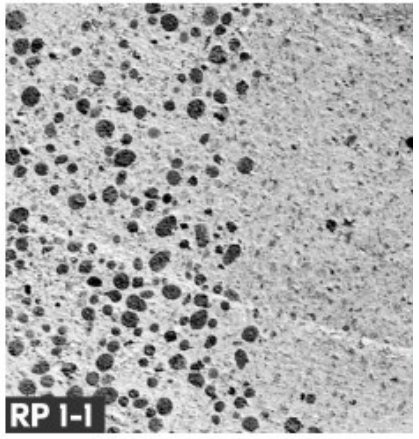
Building and Navigation Strategies for On-Site Robotics

Knowledge Representation for Multi-Disciplinary Co-Design

Context: Co-Design projects at IntCDC

Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC)

Data Engineering, Data Integration and Analytics for Co-Design



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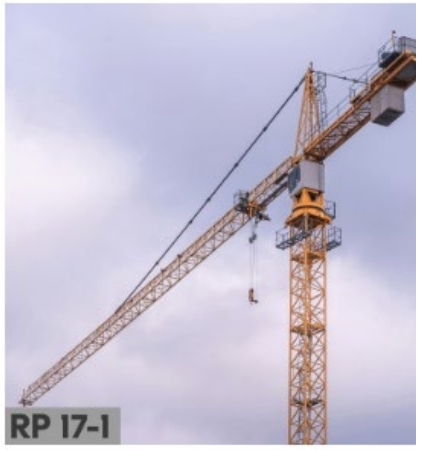
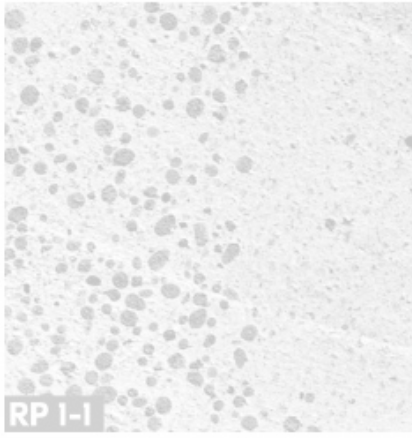


Building and Navigation Strategies for On-Site Robotics

Knowledge Representation for Multi-Disciplinary Co-Design

Context: Co-Design projects at IntCDC

RP20: Knowledge Representation for Multi-Disciplinary Co-Design of Buildings



Functionally Graded Concrete Building System

AI-Supported Collaborative Control and Trajectory Generation of Mobile Manipulators

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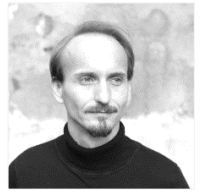
Building and Navigation Strategies for On-Site Robotics

Knowledge Representation for Multi-Disciplinary Co-Design

Context: PR20 IntCDC Cluster of Excellence

Knowledge Representation for Multi-Disciplinary Co-Design of Buildings

Data Interoperability in the AEC Industry
Building Information Modelling
Co-Design
Knowledge Representation

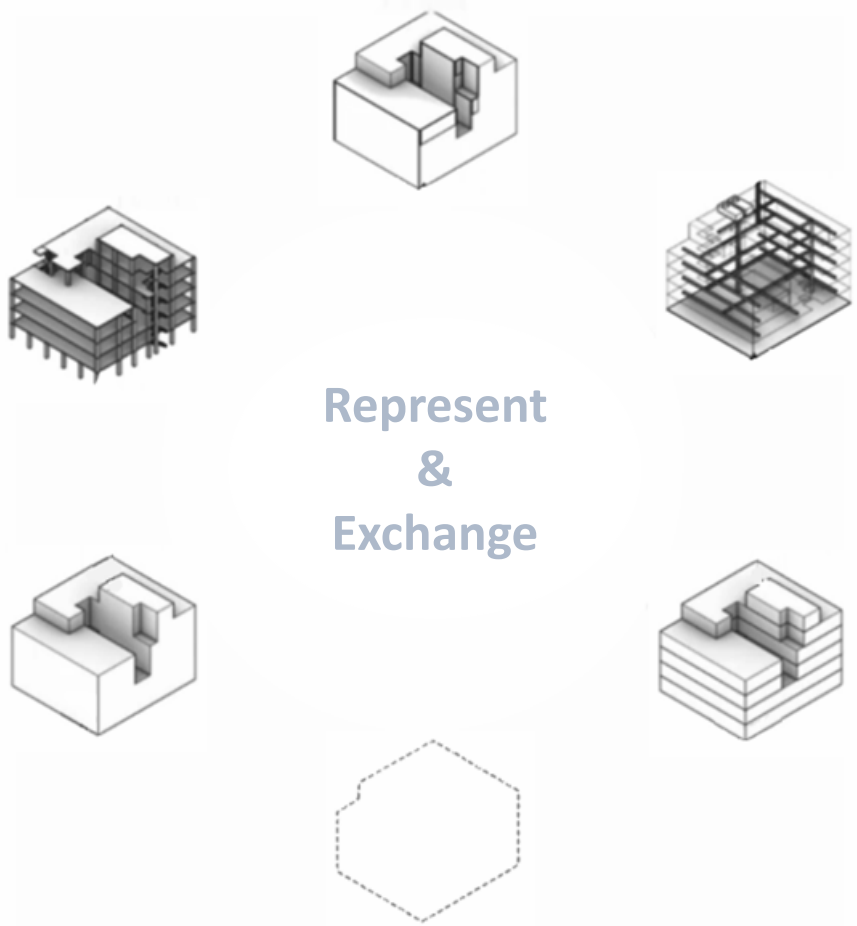
PhD. Cand. Diellza Elshani, Tenure-Track Prof. Dr. Thomas Wortmann
Chair for Computing in Architecture, Institute for Computational Design and Construction (ICD/CA), University of Stuttgart

Dr. Daniel Hérnandez (IPVS), Prof. Dr. Steffen Staab
Department for Analytic Computing (AC), Institute for Artificial Intelligence, University of Stuttgart

Context: Knowledge Representation

for Multi-Disciplinary Co-Design of Buildings

Represent	Exchange
Building data can be tool depended.	IFC with imports/exports (or via file transfer)
IFC data schema leaves out some tool-specific information.	Nested plug-ins, Tools for collaborations (like Speckle, or BHoM)
Building ontologies	



Source: adapted from: Dr. Al Fisher , 2021. Buro Happold. Building and Habitats object Model: A common language for design and multi-representational computation and Toth, B., Janssen, P., Stouffs, R., Chaszar, A., & Boeykens, S. (2012). Custom digital workflows: a new framework for design analysis integration. International Journal of Architectural Computing, 481-500.

Co-Design Interoperability Paradigms

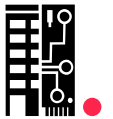
Data schemas and frameworks for interoperability

IFC data schema

- Is a standardized data schema for the AEC industry based on the EXPRESS data model;
- Represents data in a monolithic approach;
- Powerful in representing/ documenting element classification and product properties, but it falls when representing dynamic data. Rigid.

SPECKLE framework

- Open source, web-based collaborative framework
- Offers a neutral schema for the specification and creation of basic geometry types, and allows to add metadata.
- It focuses on connecting software, rather than representing information.
- Around 150 object models, and numerous connectors to design software



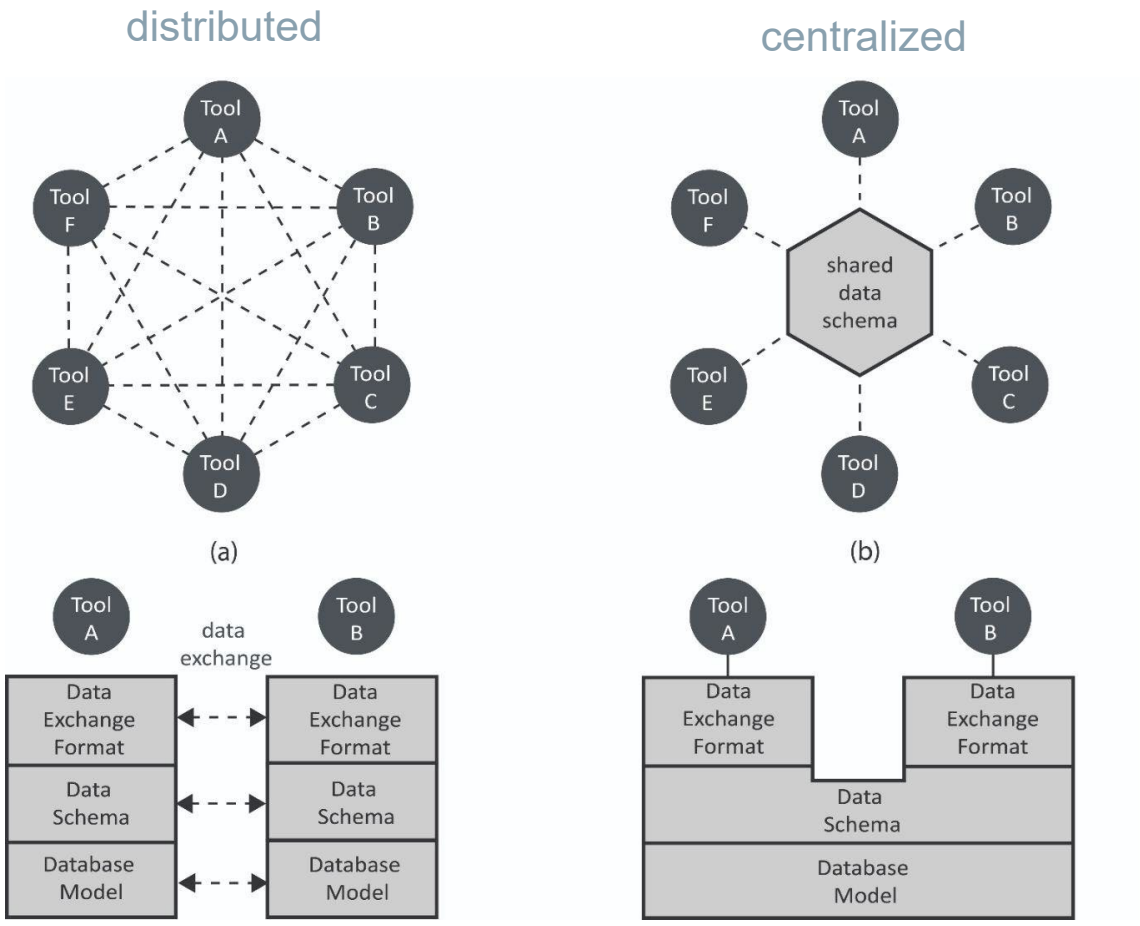
BHoM framework

- Open source, collaborative framework
- Offers multiple, discrete disciplinary representations of building elements, therefore it has over 1200 object models.
- Objects do not necessarily need to have a geometry.
- It separates objects from functions; consists of (1) object models, (2) engines that operate on data, (3) adapters that map and translate data among different software and (4) user interfaces for software where its functionality is exposed.

Co-Design Interoperability Paradigms

Distributed and Centralized

inefficient in terms of clash detection, coordination, etc.



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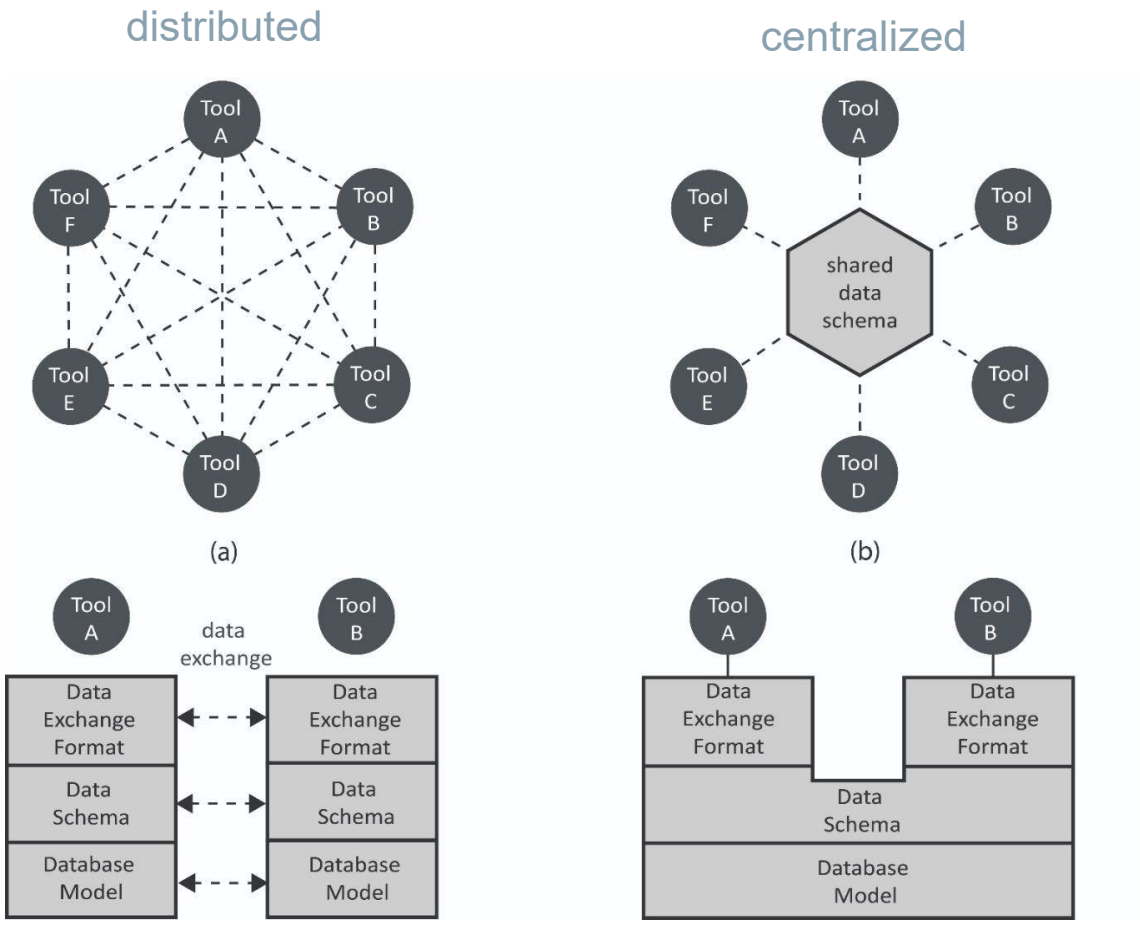
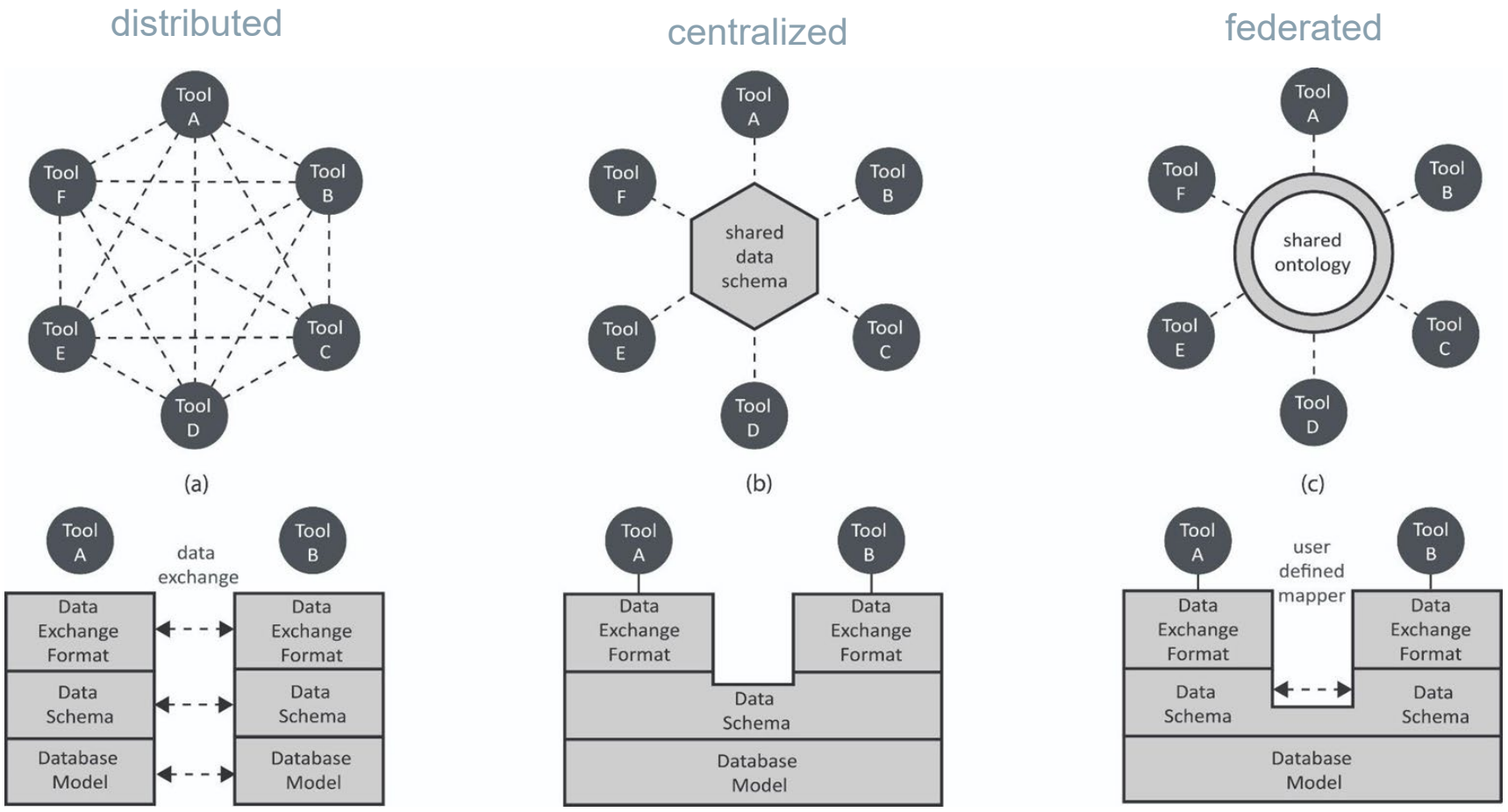


the way data is represented influences how we analyze buildings.

Toth, B., Janssen, P., Stouffs, R., Chaszar, A., & Boeykens, S. (2012). Custom digital workflows: a new framework for design analysis integration. International Journal of Architectural Computing, 481-500.

Co-Design Interoperability Paradigms

Distributed, Centralized and Federated



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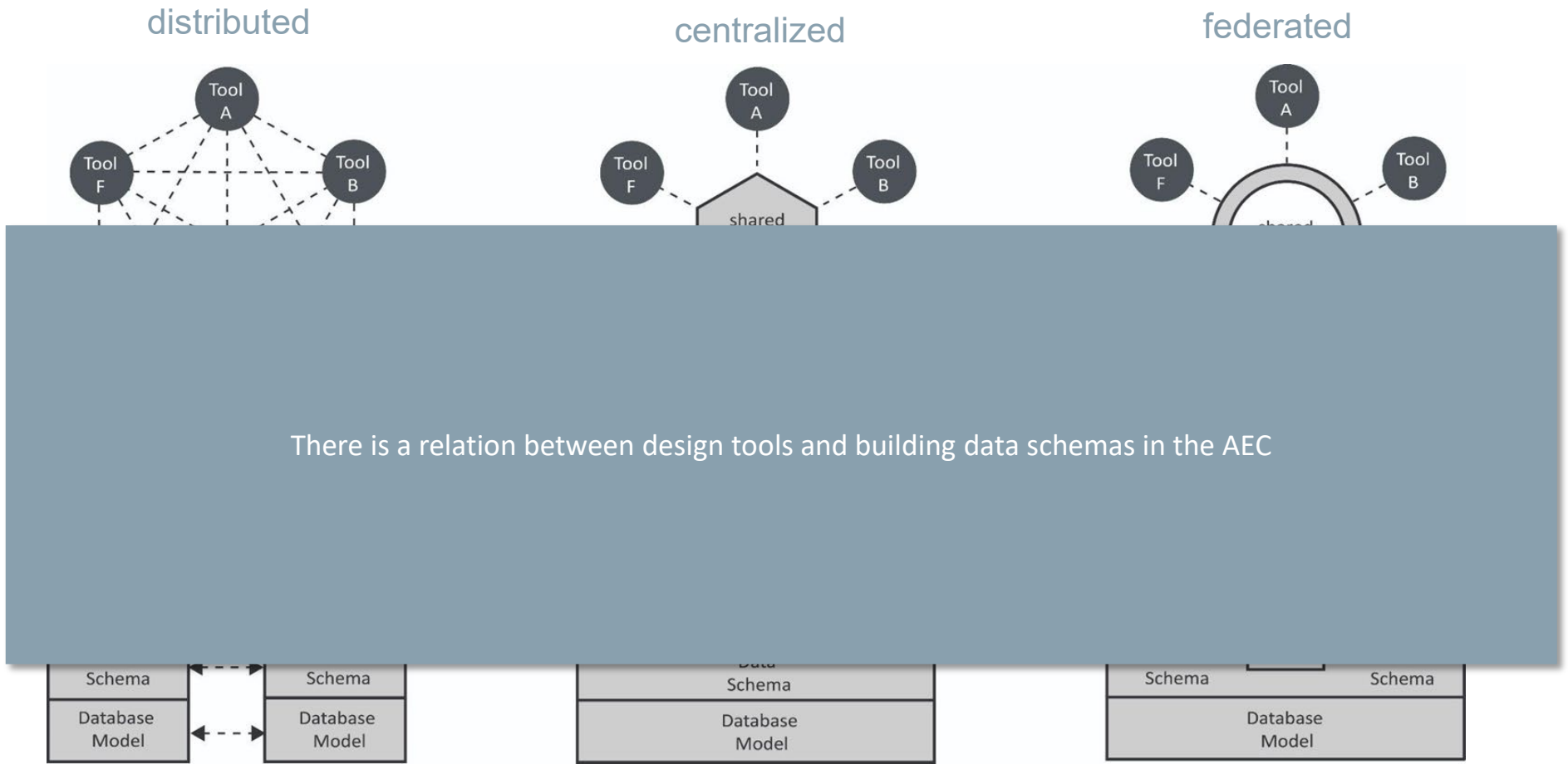
Co-Design Interoperability Paradigms

Distributed, Centralized and Federated



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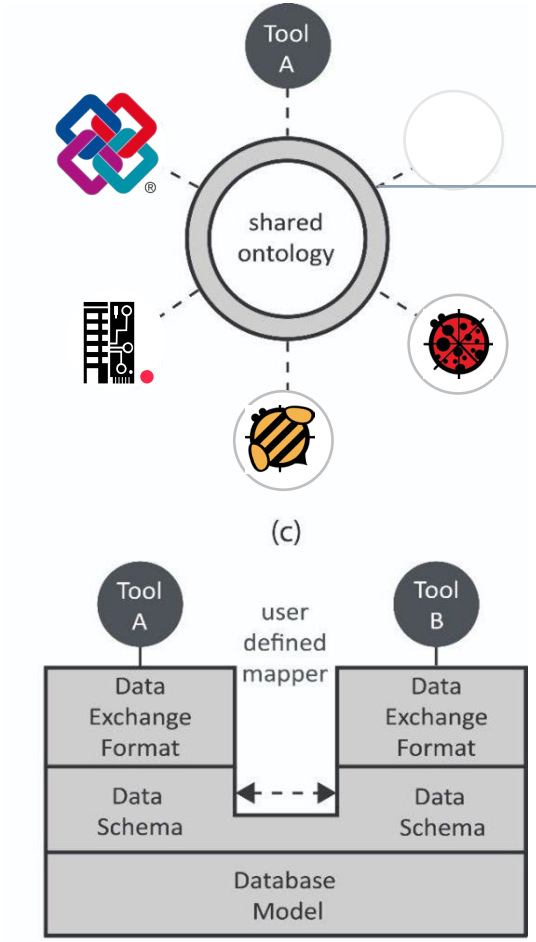
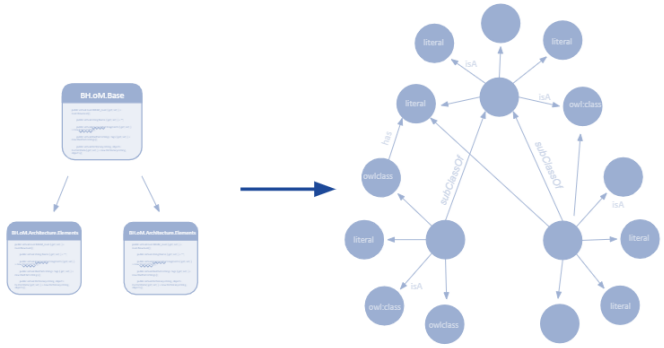
Co-Design: Federated Paradigm for Data Interoperability



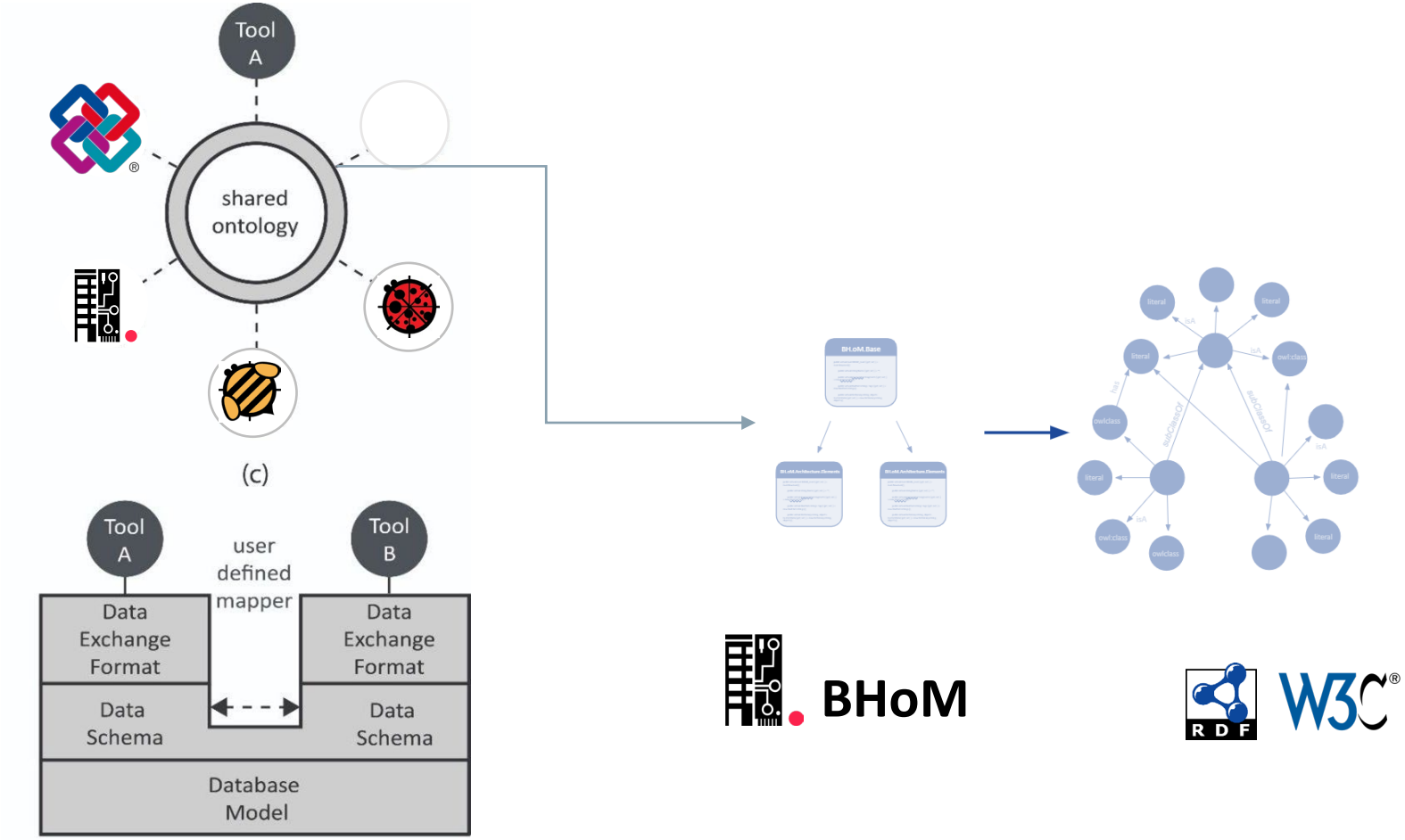
Data converter to graph from a design tool



Object oriented to RDF

Co-Design: Federated Paradigm for Data Interoperability

Link disciplinary models in a graph while designing



BHoM to RDF. Why?

It has a data dictionary
It has an open and extendable data dictionary
It provides multiple discrete representation of building elements
It has adapters to many existing AEC software
Its structure is similar with the structure of Knowledge Graphs (in terms of separating objects from functions)

Co-Design Federated Interoperability Paradigm

Possible solutions

Challenge:
disciplinary representation of building elements

Advantages:
1. Allow for the sending and receiving of data among multiple design software platforms
2. Easy definition and extension of classes within design software.

- IFC data schema
- Speckle
- BHoM

Co-Design Federated Interoperability Paradigm

Possible solutions

Speckle

BHoM

Advantages:
1. It employs a federated data approach,
2. It already has a larger library 1200 of existing objects

Co-Design Federated Interoperability Paradigm

Co-Designing using BHoM and Federated Data Schemas using the BHoM framework

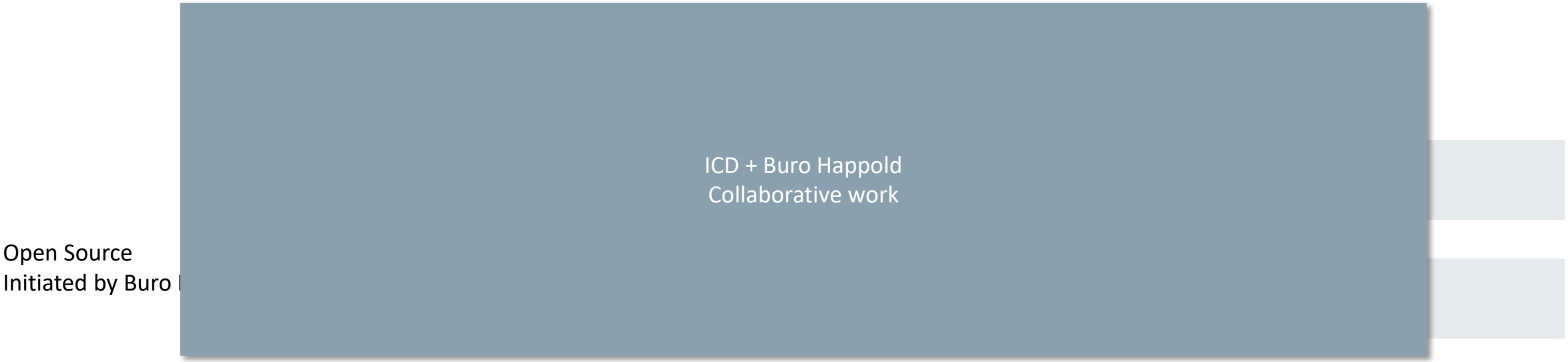
Open Source
Initiated by Buro Happold

Speckle

BHoM

IntCDC, ICD + Buro Happold

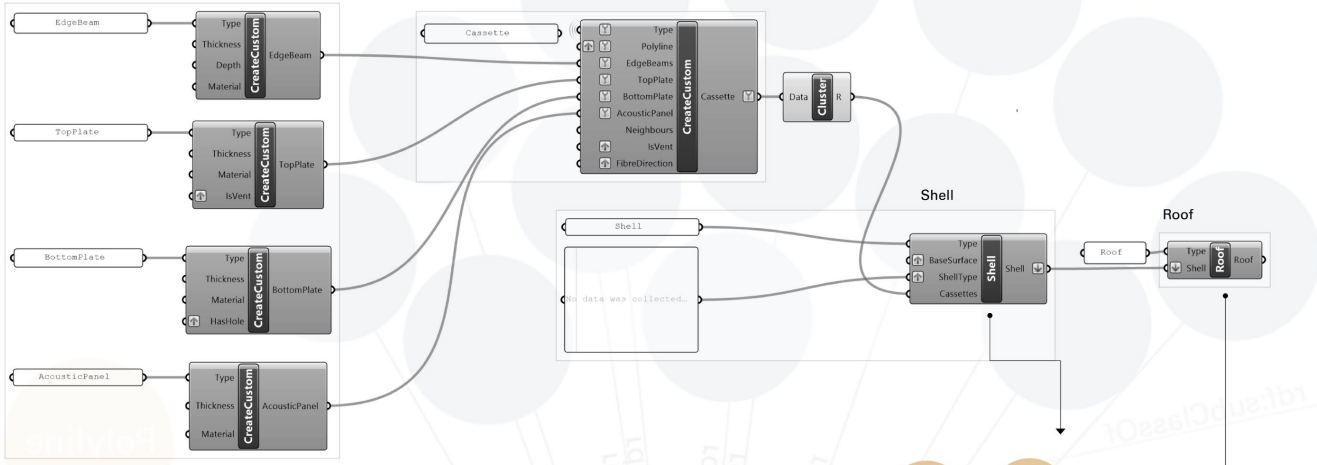
Co-Designing using BHoM and Federated Data Schemas using the BHoM framework



Convert to OWL/RDF using design tools

Co-Designing using BHoM and Federated Data Schemas

This means:
Generate ontology within Grasshopper
Including individuals.



RDF

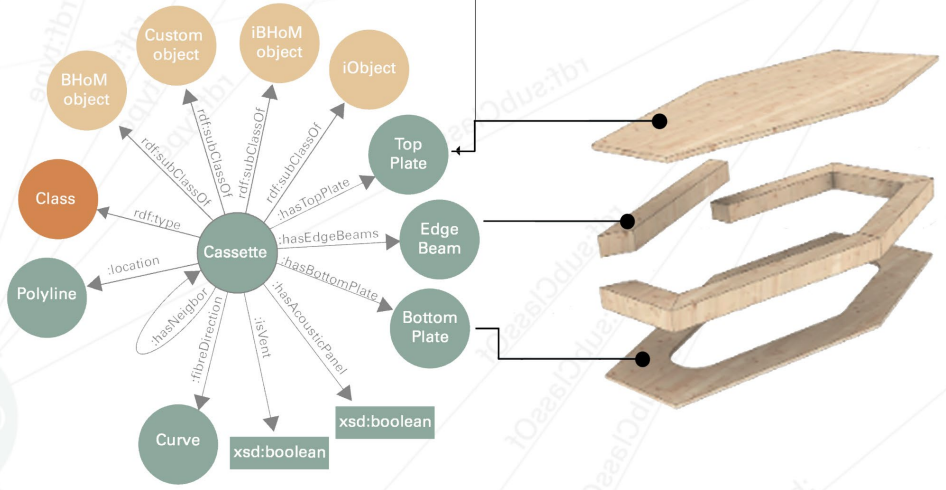
```
:Roof rdf:type owl:Class;
        rdfs:subClassOf :BH.oM.Base.CustomObject;
        rdfs:label "Roof"@en .

:Shell rdf:type owl:Class;
        rdfs:subClassOf :BH.oM.Base.CustomObject;
        rdfs:label "Shell"@en .

:Cassette rdf:type owl:Class;
        rdfs:subClassOf :BH.oM.Base.CustomObject;
        rdfs:label "Cassette"@en .

:BH.oM.Geometry.Point rdf:type owl:Class;
        rdfs:subClassOf :BH.oM.Geometry.IGeometry;
        rdfs:subClassOf :BH.oM.Dimensional.IElement0D;
        rdfs:label "Point"@en .
```

OWL class



IntCDC, ICD + Buro Happold

Building information validation and reasoning using Semantic Web Technologies while co-designing using the BHoM framework

1. Design with BHoM objects in a design platform

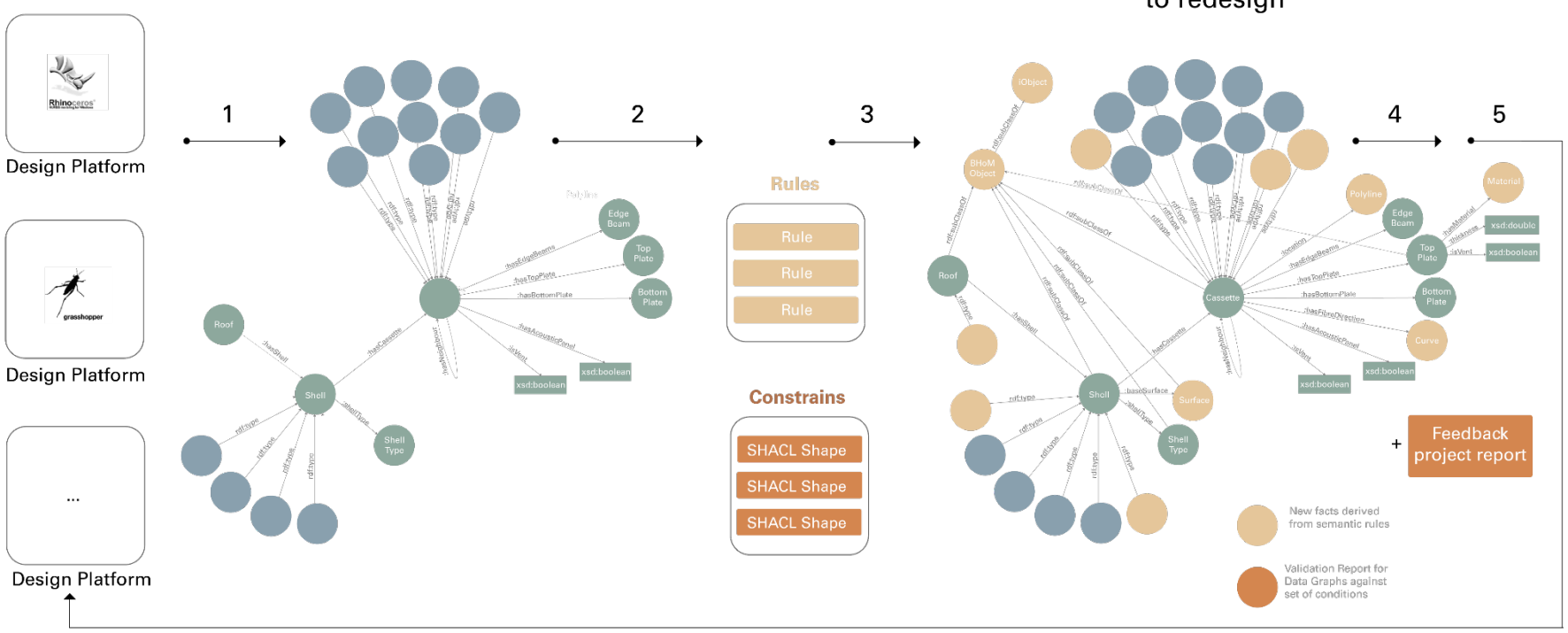
2. Convert BHoM data to OWL/RDF (using BHoM's converter)

3. Add constrains and rules (using SHACL/ SWRL)

4. Evaluate the resulting graph and report

5. Convert back the graph to BHoM objects (using BHoM's converter)

Use the report as a guide to redesign



Reasoning using the Open World Assumption (OWA)

Data Validation using the Closed World Assumption (CWA)

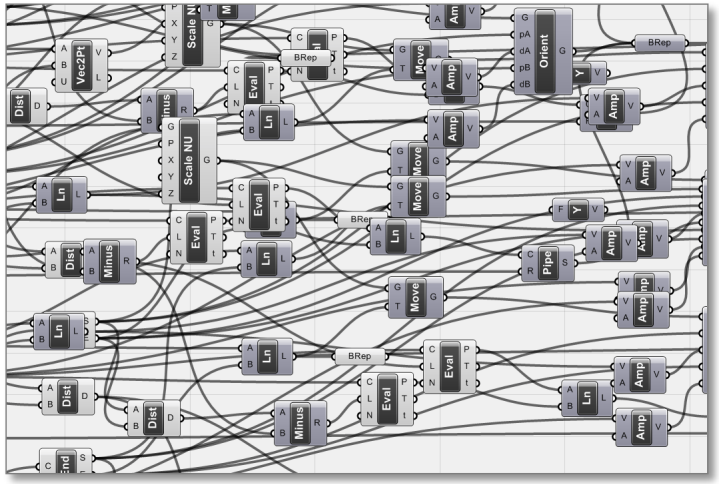
What is reusable:
BHoM objects
schema (or ontology)
+

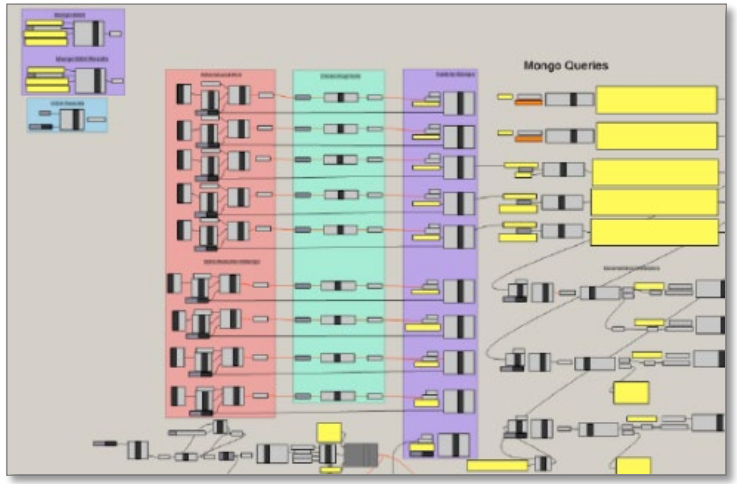
Constrains and Rules

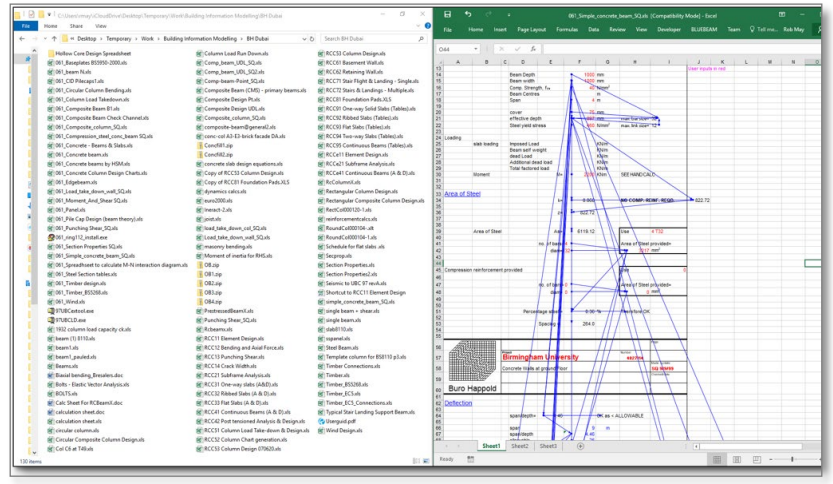
BHoM framework

BHoM framework

Idea: Reuse defined project specific object models and functions



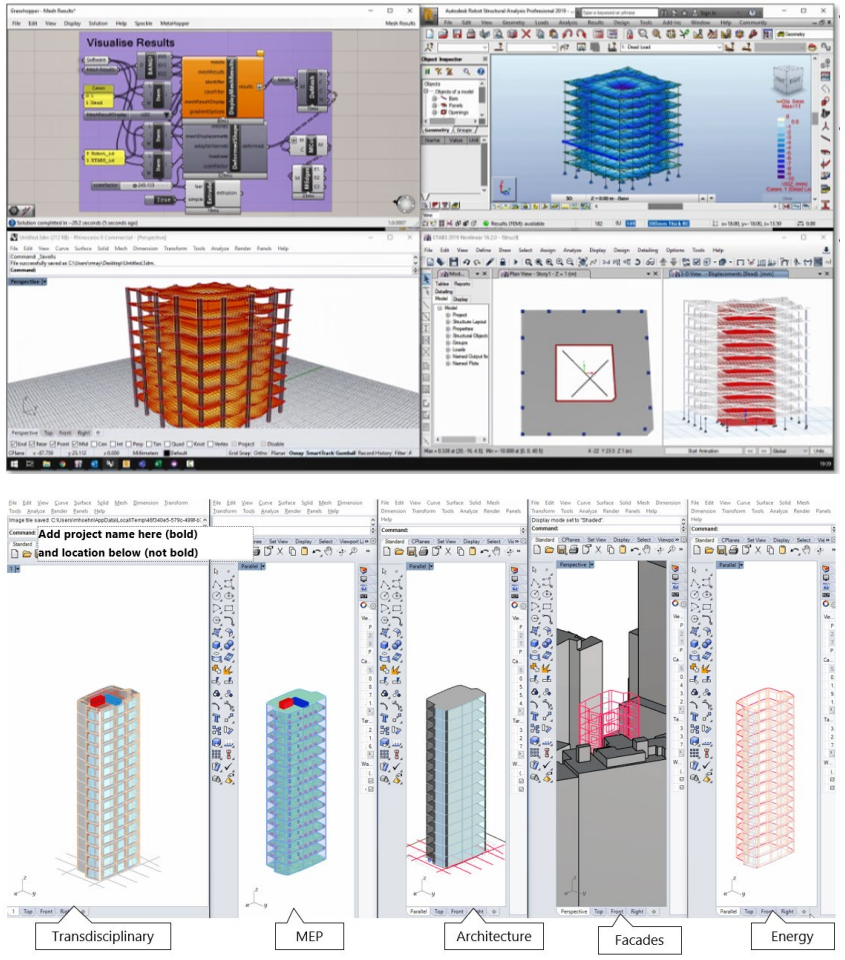


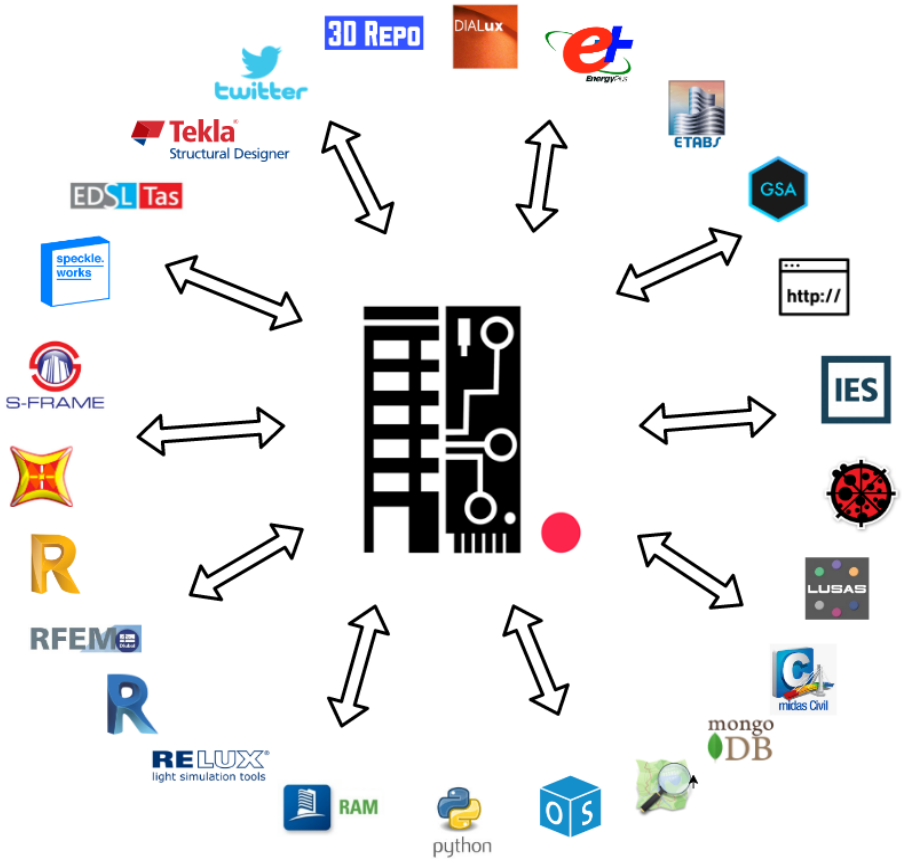


Source: Alessio Lombardi. Buro Happold. Building and Habitats object Model

BHoM framework

Runs as a plugin in multiple design software



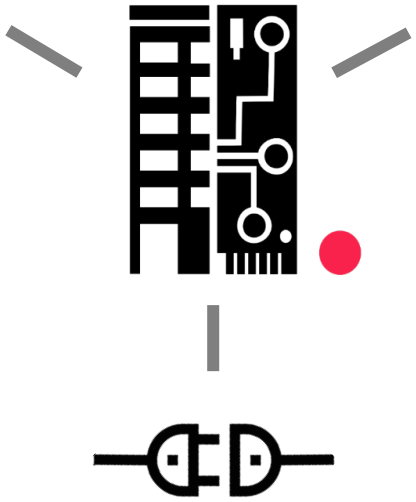


Source: Alessio Lombardi. Buro Happold. Building and Habitats object Model

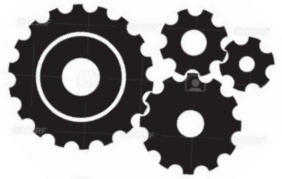
BHoM framework

Separation of definitions and functionality

The **object Model (oM)**
Our Data
contains all definitions



The **Adapter**
Connects to/from other Software



The **Engine**
Custom Functions
Adds functionality
(query, filter, calculate…)

All **exposed**
in some
User Interface software
UI
e.g. Grasshopper, Excel…

Source: Alessio Lombardi. Buro Happold. Building and Habitats object Model

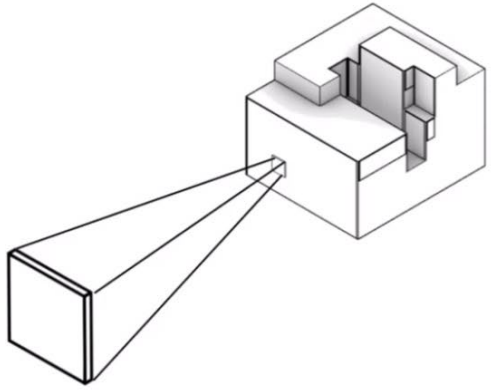
A **Toolkit**
Packets an **oM,** an **Engine** and an **Adapter specific** to a **software** or **target analysis.**

BHoM framework

Multi-disciplinarity

Common object Model (oM)
How to represent a "Wall"

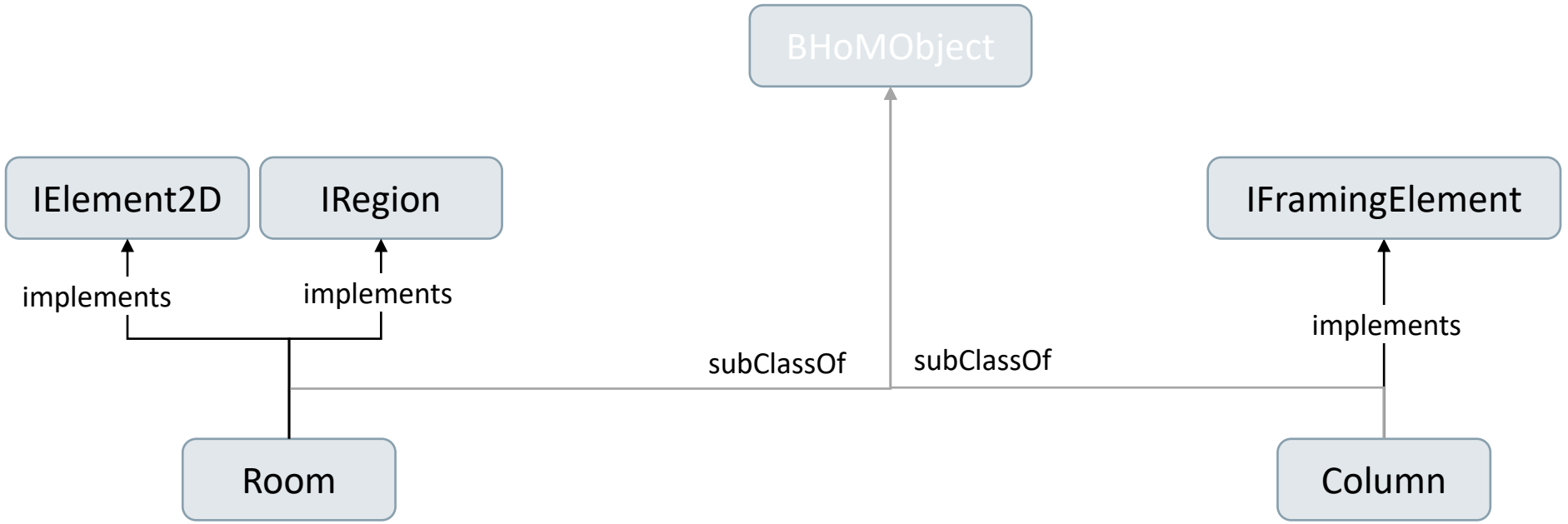
Physical	BH.oM.Physical.Elements.Wall
Analytical	BH.oM.Facade.Elements.Panel BH.oM.Structure.Elements.Panel BH.oM.Environment.Elements.Panel BH.oM.Acoustic.Elements.Panel
Geometrical	BH.oM.Geometry.PlanarSurface BH.oM.Geometry.NurbsSurface BH.oM.Geometry.NurbsCurve
Graphical	BH.oM.Graphics.RenderMesh



Source: Buro Happold. Building and Habitats object Model

BHoM framework

Composition over inheritance

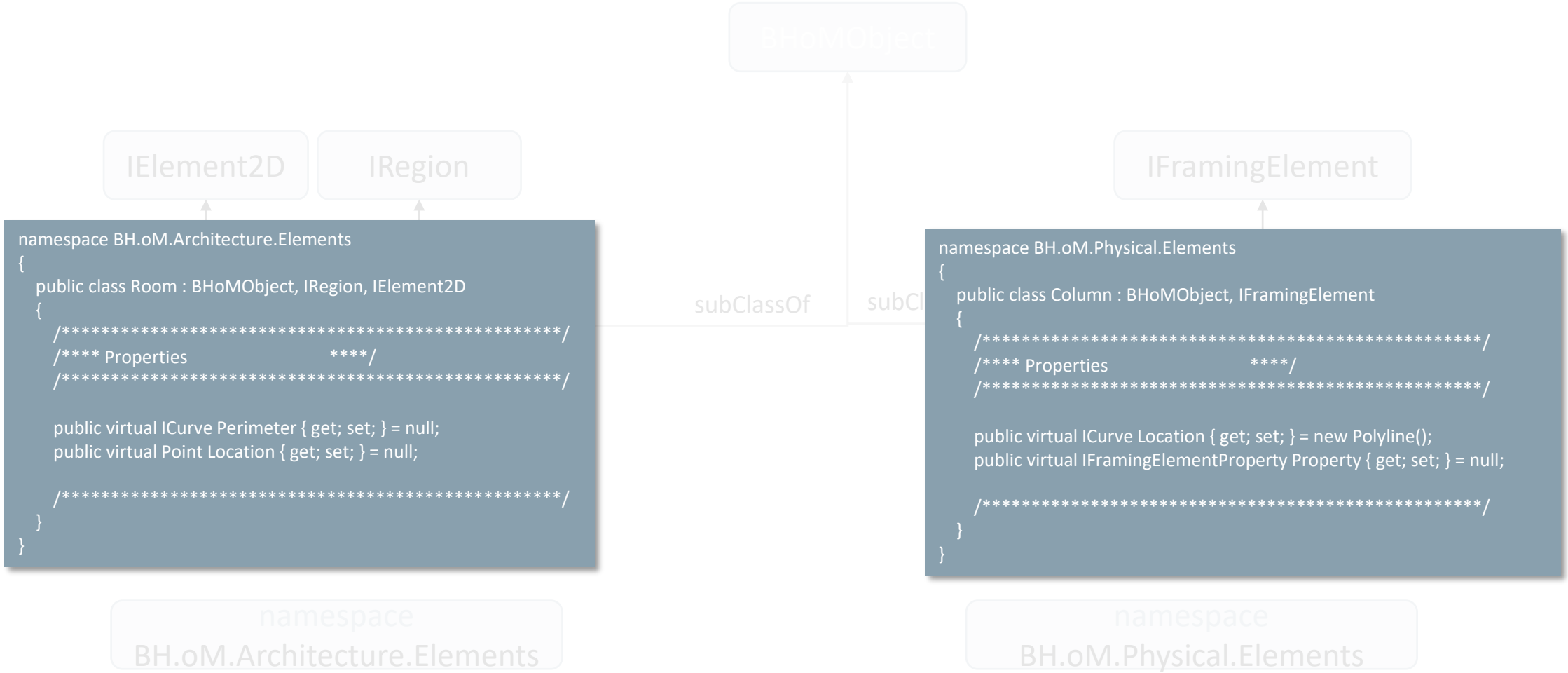


namespace
BH.oM.Architecture.Elements

namespace
BH.oM.Physical.Elements

BHoM framework

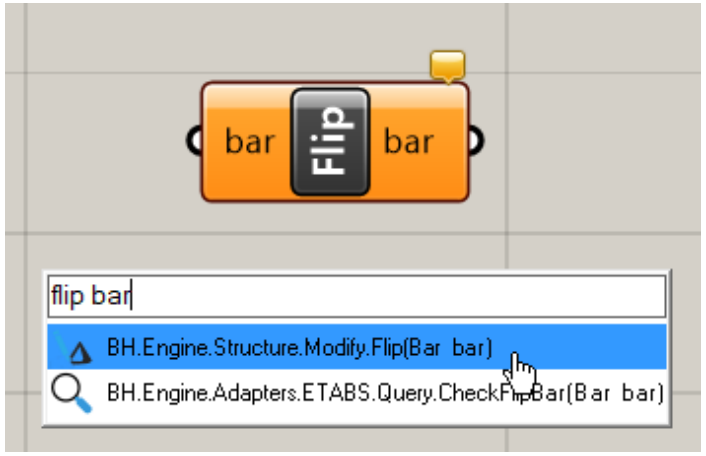
Composition over inheritance



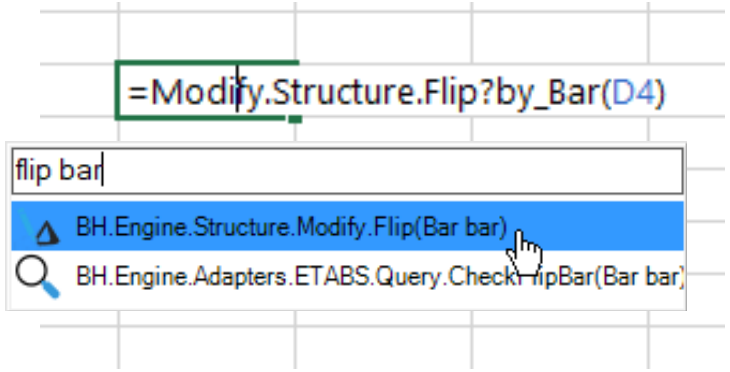
BHoM framework

BHoM User Interfaces

A **Grasshopper component**



An **Excel formula**



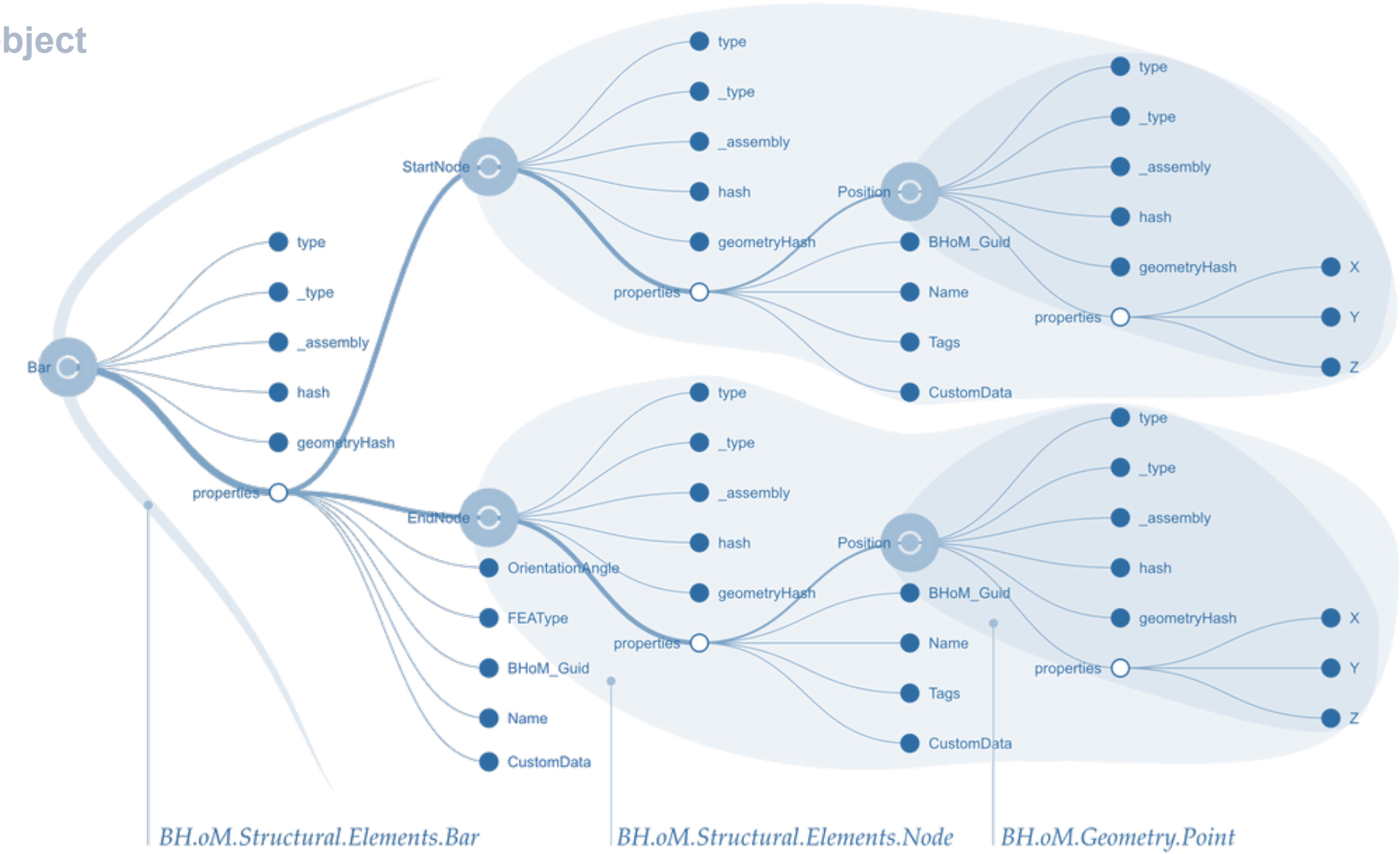
A **C# script**

```
Bar bar = new Bar();
BH.Engine.Structure.Modify.Flip(bar);
```

Source: Buro Happold. Building and Habitats object Model

BHoM framework

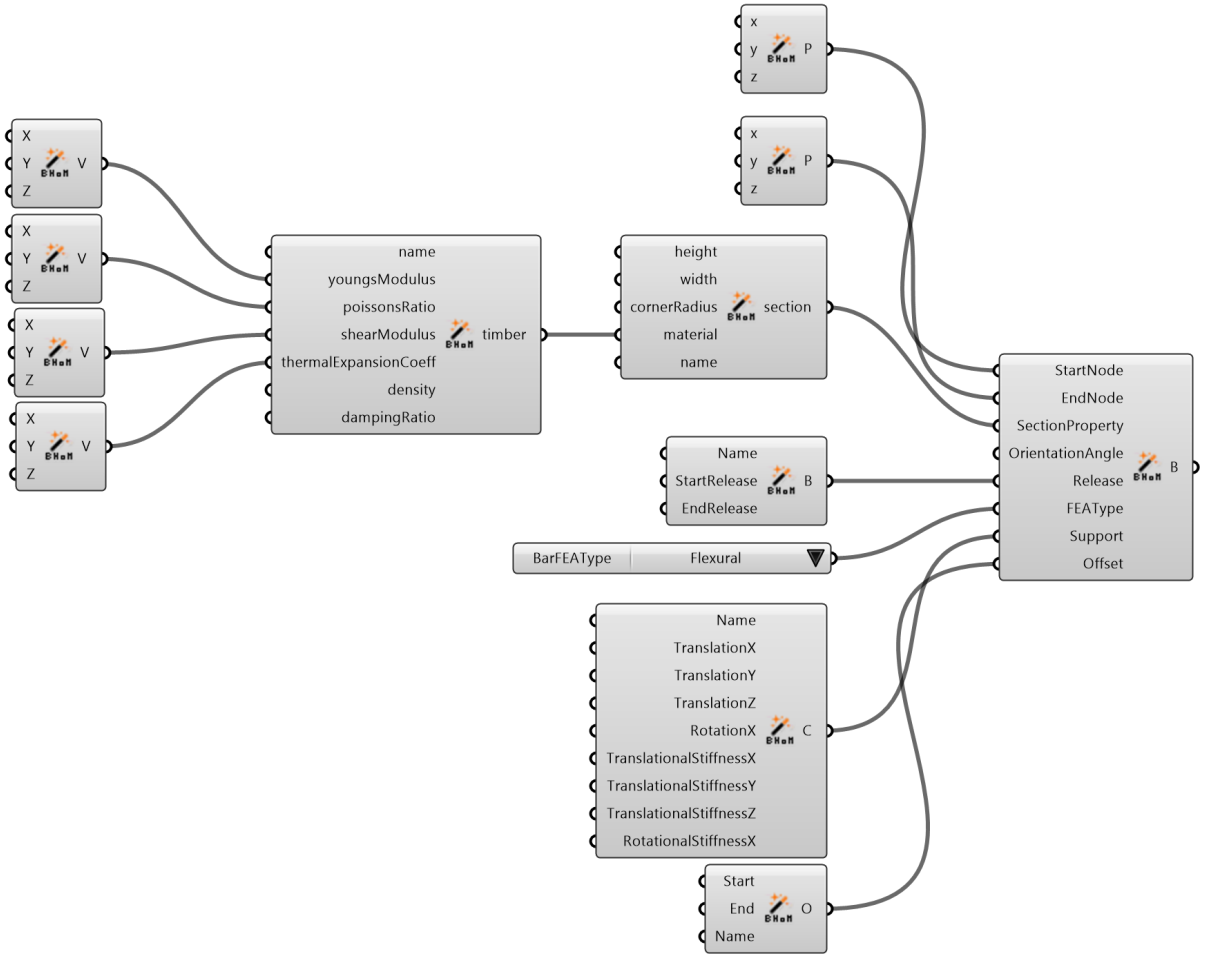
A graph of a BHoM Bar object

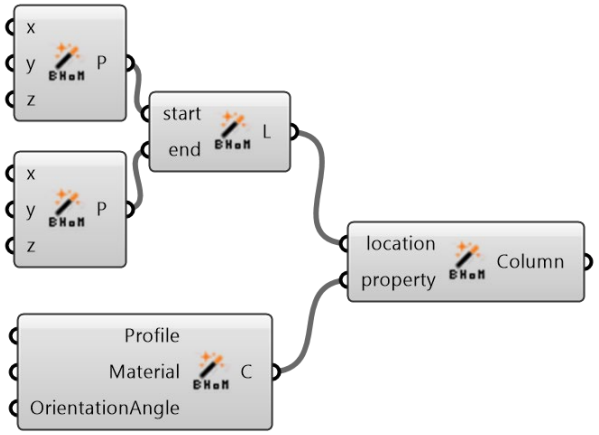


Source: Data Representation section by Dimitrie Stefanescu in thesis titled: Communication in Digital Design

BHoM framework

BHoM Column and BHoM Bar





BHoM framework

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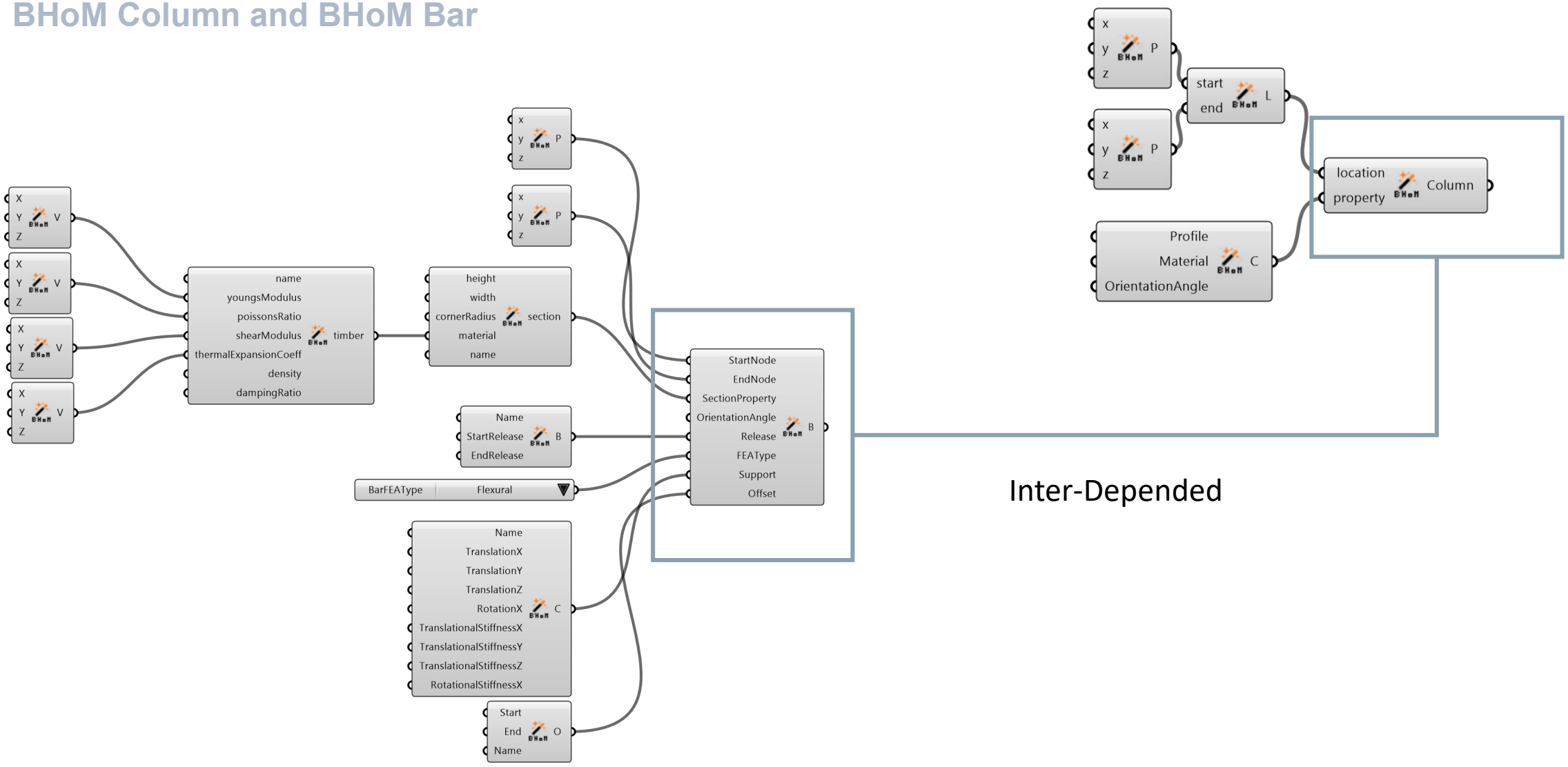
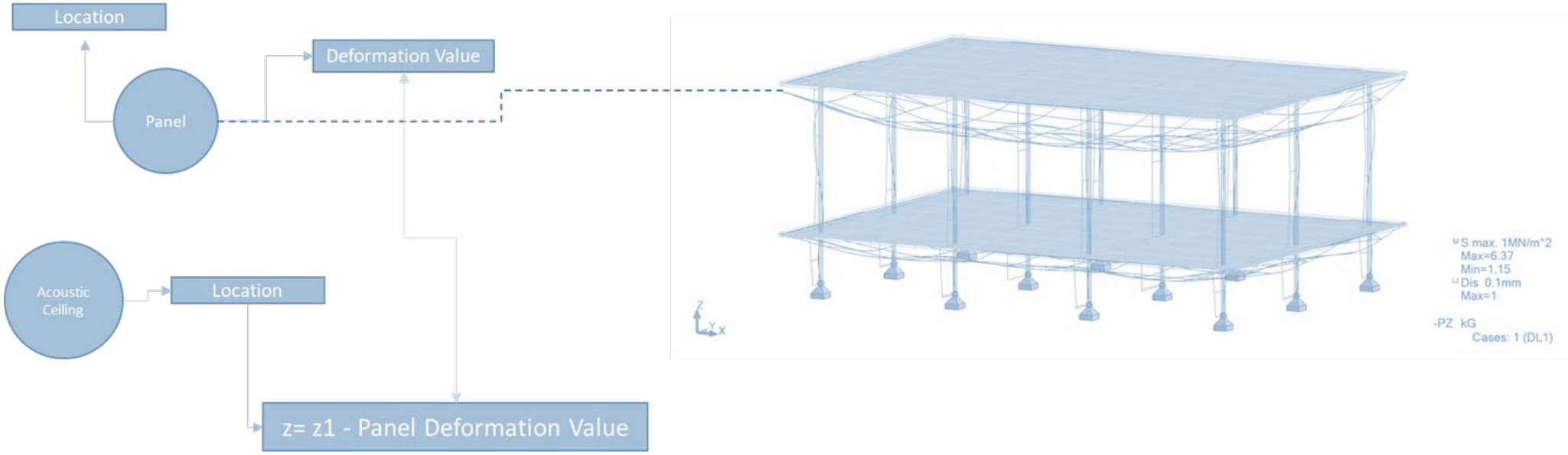


What can we know from linked design data:

Rule based design: Interdepended values between different disciplines

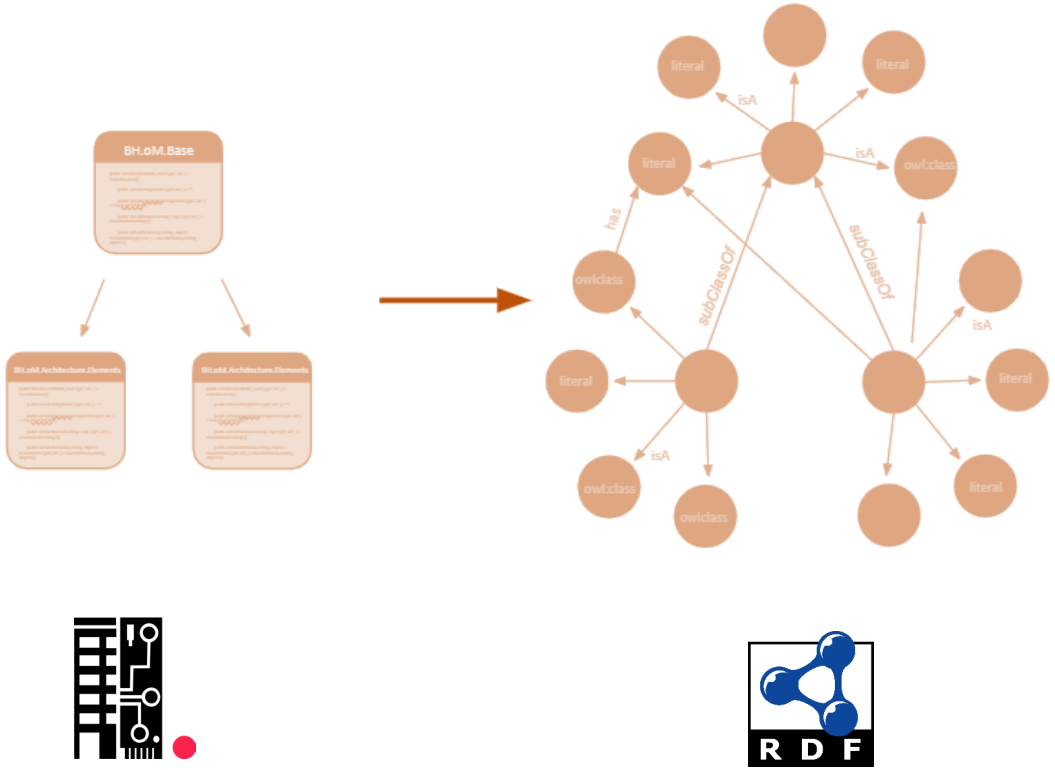
Where to place an acoustic ceiling taking into consideration the potential deformation of the structural ceiling?



BHoM framework and linked data

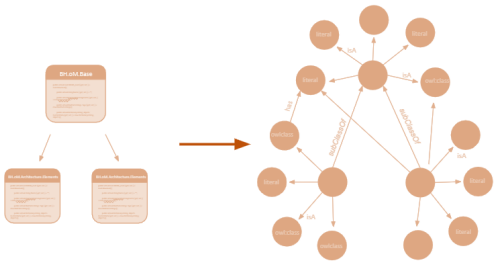
Instead of send and receive data, link them!

Translation Pattern



Translation Pattern

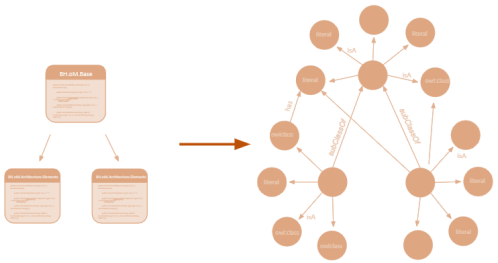
Terminological Layer TBox



BHoM component	Semantic Web equivalent
Concept identifier	The original GitHub object model class URI (temporary solution)
Object class (e.g. BH.oM.Physical.Element)	an owl:Class,
Class inheritance relation	rdfs:subClassOf
Interface (eg. IElement2D)	an owl:Class, bhom:IElement2D rdf:type owl:Class
Interface implementation relation	rdfs:subClassOf
Properties	owl:ObjectProperty or type owl:DatatypeProperty

Translation Pattern

Assertional Layer ABox

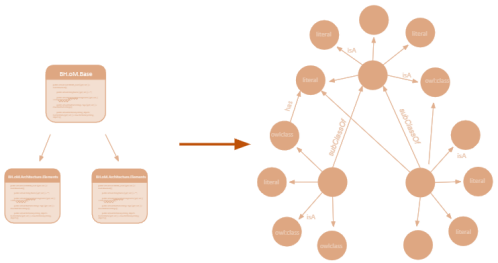


BHoM component	Semantic Web equivalent
GUID -Instance identifier	Define an URI from the grasshopper, concatenated it with the GUID of BHoM instances.

```
<http://www.example.com/3374A3DC31B4FDF6F>  rdf:type  owl:NamedIndividual,
                                                      :BH.oM.Architecture.Elements.Room ;
                                            :BH.oM.Base.BHoMObject.BHoM_Guid "aea3f8ad-bc636"8sd:string .
```

Translation Pattern

Assertional Layer ABox

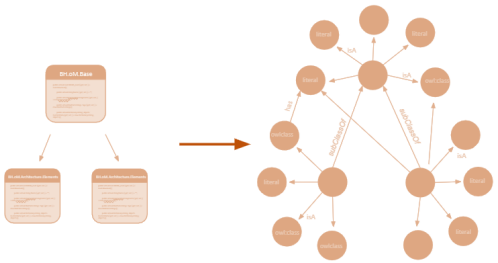


BHoM component	Semantic Web equivalent
Literals	directly mapped to primitive XML datatypes
-Lists	rdf:Seq

```
<http://www.example.com/2FB125F5C85CB3BDF08> rdf:type owl:NamedIndividual , :BH.oM.Geometry.Polyline, rdf:Seq ;
                                                rdf:_0 <http://www.example.com/50FC7044566B5230E41A962C> ;
                                                rdf:_1 <http://www.example.com/DA505DCF960046F6025394F5> ;
                                                rdf:_2 <http://www.example.com/9B9F6FE119128B7E9F3B901C> .
```

Translation Pattern

Assertional Layer ABox



BHoM component	Semantic Web equivalent
BHoM Geometry	

A *line* example:

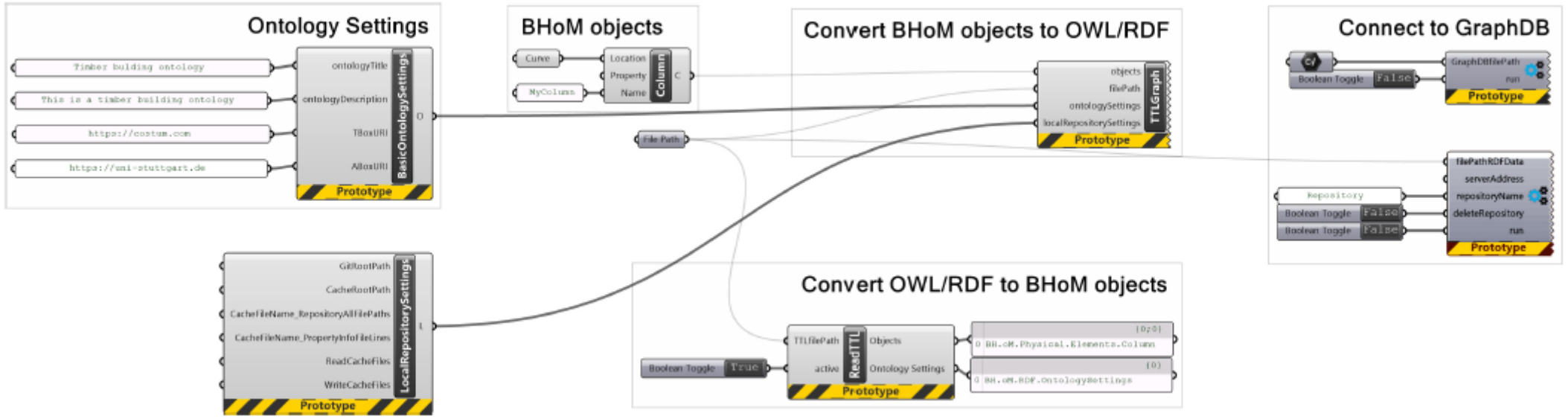
```
<http://www.example.com/2FB125F55CB3BDF08> rdf:type owl:NamedIndividual , :BH.oM.Geometry.Line ;
                                           :BH.oM.Geometry.Line.Start <http://www.uni-stuttgart.de/620E23163FAEFE> ;
                                           :BH.oM.Geometry.Line.End <http://www.uni-stuttgart.de/0E40647D8182FC1A> ;
                                           :BH.oM.Geometry.Line.Infinite "False"^^xsd:boolean .

<http://www.uni-stuttgart.de/620E23163FAEFE> rdf:type owl:NamedIndividual , :BH.oM.Geometry.Point ;
                                           :BH.oM.Geometry.Point.X "0"^^xsd:double ;
                                           :BH.oM.Geometry.Point.Y "0"^^xsd:double ;
                                           :BH.oM.Geometry.Point.Z "0"^^xsd:double .

<http://www.uni-stuttgart.de/620E23163FAEFE> rdf:type owl:NamedIndividual ,:BH.oM.Geometry.Point ;
                                           :BH.oM.Geometry.Point.X "8"^^xsd:double ;
                                           :BH.oM.Geometry.Point.Y "22"^^xsd:double ;
                                           :BH.oM.Geometry.Point.Z "-1"^^xsd:double .
```

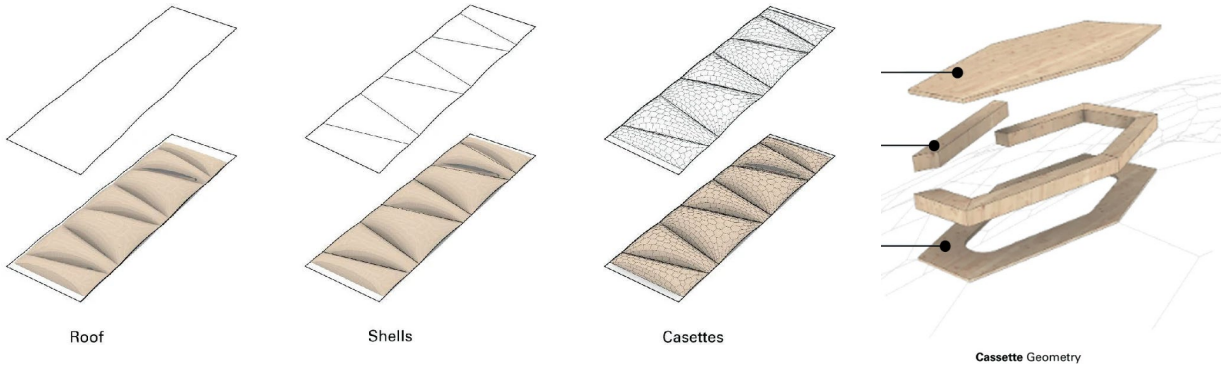
Tool Integration and developed components

Grasshopper to GraphDB



Application of the method at IntCDC & ICD

Design method suggestion: From “Computational” BIM to Knowledge Graph

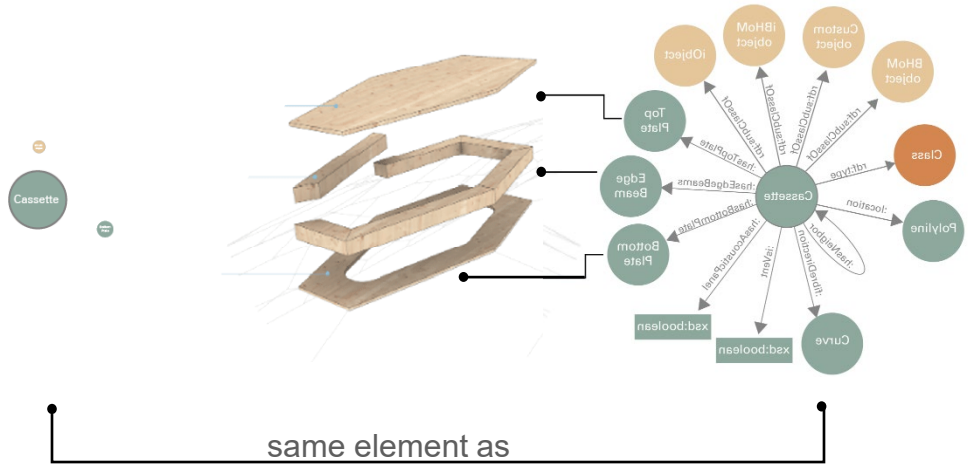


Timber roof, which consists of 7 shells, where each shell has around 200 cassettes

Elshani, Diellza & Hernández, Daniel & Lombardi, Alessio & Siriwardena, Lasath & Schwinn, Tobias & Fisher, Al & Staab, Steffen & Menges, Achim & Wortmann, Thomas. (2023). Building Information Validation and Reasoning Using Semantic Web Technologies. 470-484. 10.1007/978-3-031-37189-9_31.

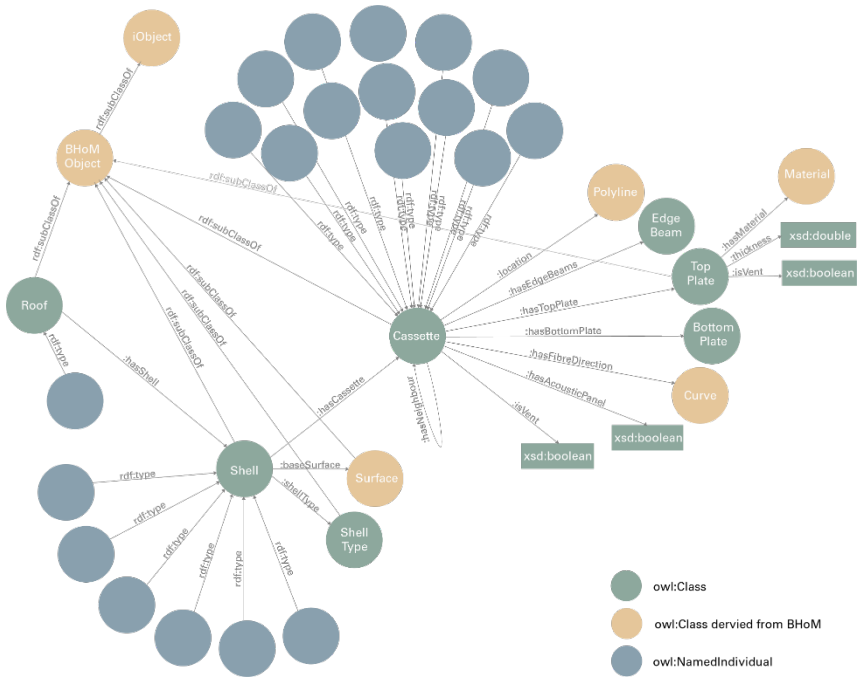
Application of the method at IntCDC & ICD

Co-Designing a shell structure



rules	constrains
Rule	SHACL Shape
Rule	SHACL Shape
Rule	SHACL Shape

rules	constrains
Rule	SHACL Shape
Rule	SHACL Shape
Rule	SHACL Shape



Linked data graph

Elshani, Diellza & Hernández, Daniel & Lombardi, Alessio & Siriwardena, Lasath & Schwinn, Tobias & Fisher, Al & Staab, Steffen & Menges, Achim & Wortmann, Thomas. (2023). Building Information Validation and Reasoning Using Semantic Web Technologies. 470-484. 10.1007/978-3-031-37189-9_31.

Application of the method at IntCDC & ICD

Data validation and reasoning with Semantic Web Technologies

SWRL Example: Inferring which Cassettes are edge cassettes based on the number of their neighbor.

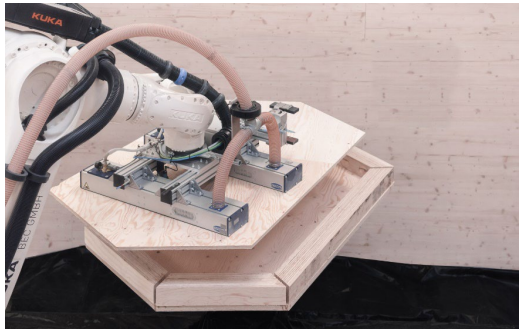
```
Cassette (?c) ^ hasNeighbor (?c, n?) ^ sqwrl:makeSet(?s, ?n) ^ swrlb:greaterThanOrEqual(?s, 2) ->
isEdgeCassette(?c, true)
```

SHACL Shapes and Validation Report Example: Check if a every cassette as a material assigned

```
:CassetteShape\;a\;sh:NodeShape;sh:targetClass\;:Cassette;sh:property\;[sh:path\;:Material;sh:minCount\;1].
```

SPARQL Example: Check if a KUKA robot can lift a Cassette by inferring the weight of cassettes

```
SELECT ?Cassette ?GUID ?volume ?weight
WHERE
{
        ?Cassette bhom:BH.oM.Base.BHoMObject.BHoM_Guid ?GUID.
        ?Cassette bhom:Volume ?volume.
        bhom:Timber bhom:MaterialDensity ?x.
        BIND ( (xsd:integer(?x) * xsd:double(?volume)) AS ?weight) .
        FILTER (?weight > 360)
}
```



Building Information Validation and Reasoning Using Semantic Web Technologies

Diellza Elshani[1(BE)], Daniel Hernández[2], Alessio Lombardi[3], Lasath Siriwardena[4], Tobias Schwinn[4], Al Fisher[3], Steffen Staab[2,5], Achim Menges[4], and Thomas Wortmann[1]

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Abstract. The integration of data from various disciplines, including requirements and regulations, is essential in the co-design of buildings. Constraints that arise during design, fabrication, or construction are mainly considered in the later stages of the design process. This often leads to costly revisions during fabrication or construction. While there are some works proposing Semantic Web approaches or ad-hoc methods to identify constraint violations in the early stages of design, they mainly rely on data derived from monolithic data schemas. This paper presents a Semantic Web approach that validates and checks building data derived from federated data schemas. The proposed approach is exemplified through the design process of a segmented timber shell, a complex structure requiring negotiations across architectural, engineering, and fabrication parameters. The Building Habitat object Models (BHoM) framework is used to represent federated building data, and the approach enables a seamless movement between the graph environment and object models to support the design process. Additionally, the study discusses various technologies that aid in knowledge inference or data validation. The results of this study suggest that the use of Semantic Web technologies in conjunction with federated data schemas has significant potential to enhance co-design processes in the building industry. While further research is needed to assess its effectiveness in other scenarios, our application of this approach in checking and validating building data for a complex segmented timber shell structure demonstrates its promise as a means to streamline the design process.

Keywords: Data Validation · Reasoning · Data Modelling · Semantic Web Technologies

M. Turrin et al. (Eds.): CAAD Futures 2023, CCIS 1819, pp. 470–484, 2023.
https://doi.org/10.1007/978-3-031-37189-9_31

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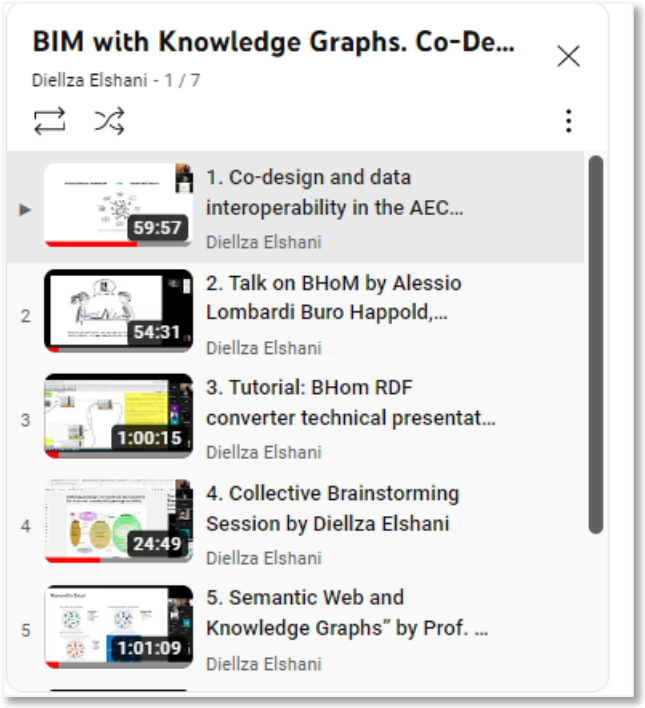
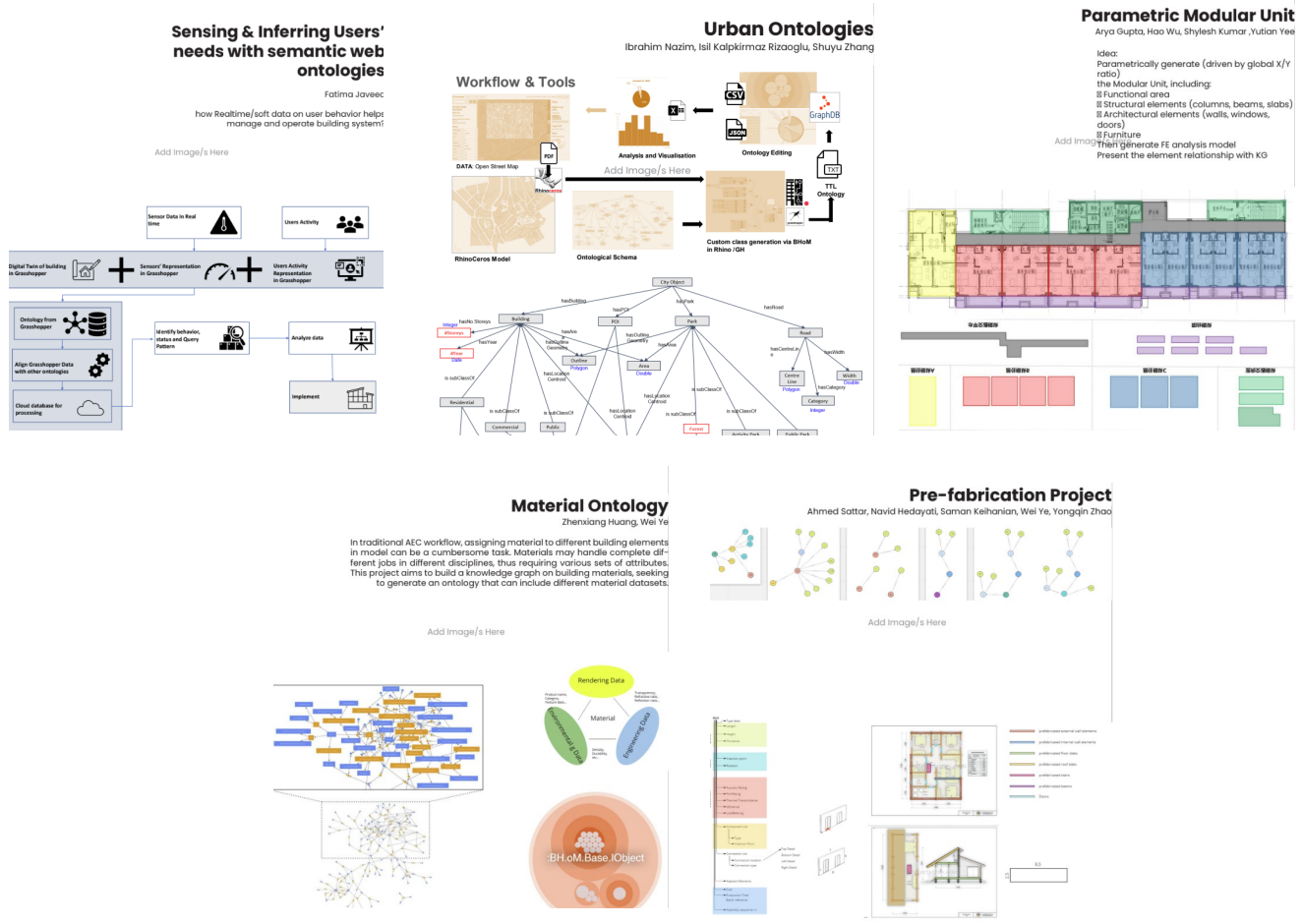
Application of the toolkit at Digital Futures Workshop

Online, June 2022

Digital Futures workshop, 100 applicants





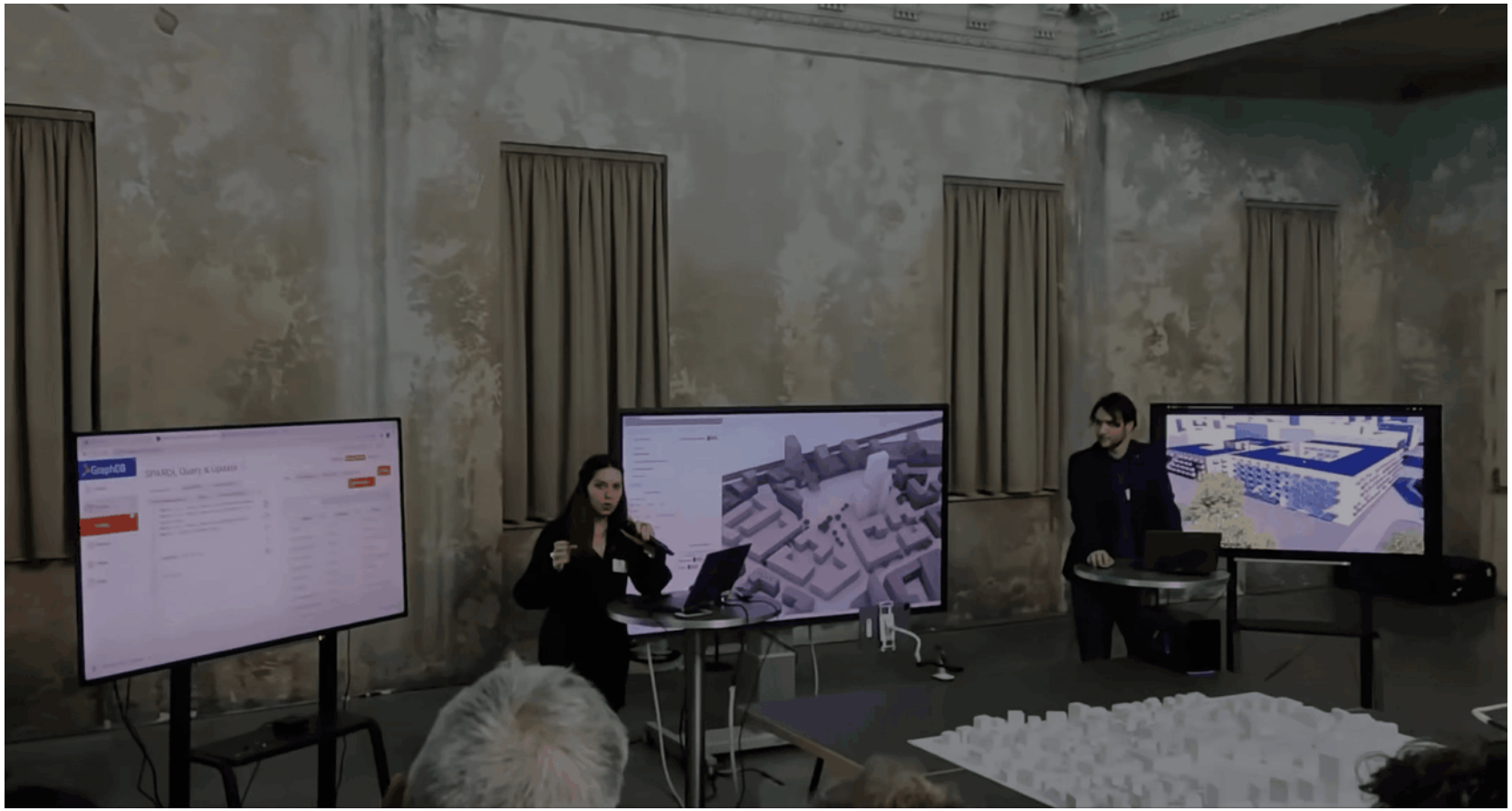
https://vimeo.com/724817479

https://www.youtube.com/playlist?list=PLZ1uRtLJZbxAfkUXXxOgVRuMA8W52RBe2

Application of the developed toolkit at the CODEC Hackathon

Austrian Institute of Technology CoDeC Symposium, Reaktor, Vienna 2023

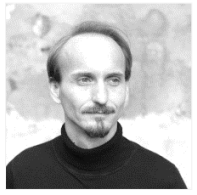
- Defined a simple City Ontology in grasshopper -> send it to GraphDB
- Created a parametric urban model in grasshopper -> send it to GraphDB
- Run Energy Analysis for each design option (Sunlight hours) -> send results to GraphDB
- Compare design options using the graph representations.



Group members: Serjoscha Düring, Viki Sándor Andrej Sluka Pol Foreman Egor Gavrilov Iuliia Osintseva, Diellza Elshani

Who is working on this project:





- Diellza Elshani, PhD researcher
- Aaron Wagner, student assistant
- Tenure-Track prof. Dr. Thomas Wortmann, supervisor, principal investigator ICD/CA Chair for Computing in Architecture, Institute for Computational Design and Construction, **University of Stuttgart**


- Alessio Lombardi, software engineer
- Dr. Al Fisher, Head of Computational Development

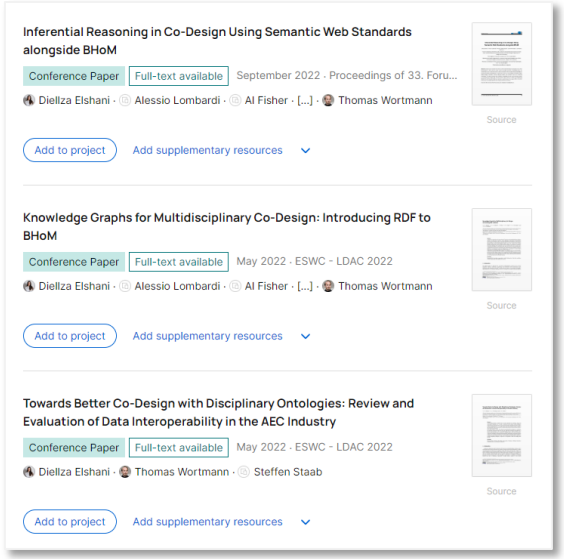
Buro Happold, London

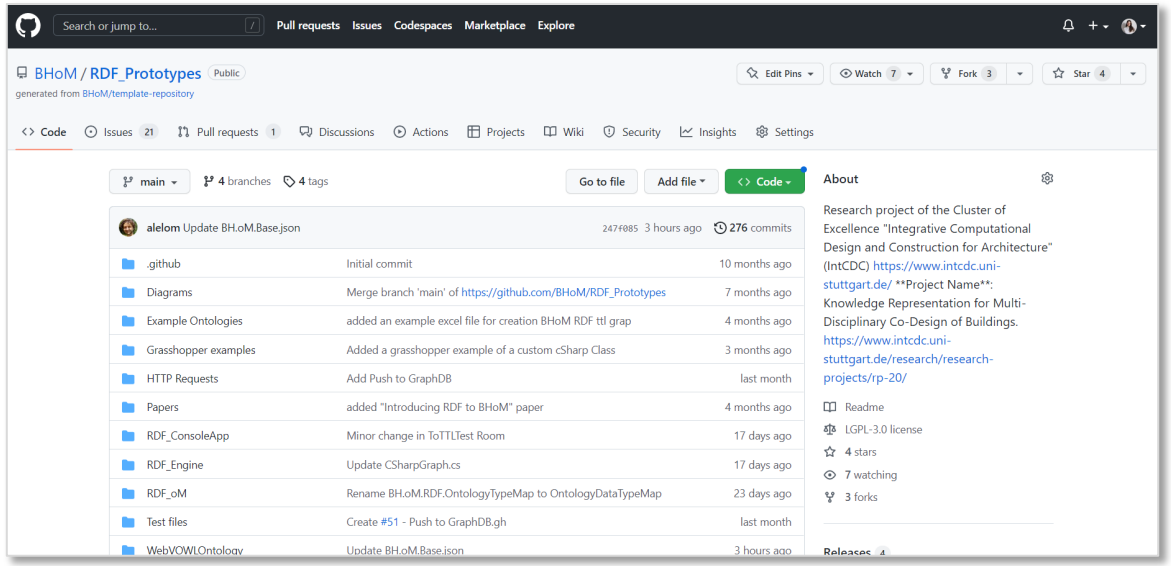

- Dr. rer. nat. Daniel Hernandez, post doc and researcher
- Prof. Dr. Steffen Staab, principal investigator

Analytic Computing department (AC), Institute for Artificial Intelligence
University of Stuttgart

Publications

Source Code
Example Datasets
4 papers published
2 public workshops





#Open-source

Thank you!

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LIVE Demo follows: