bhOWL: BHoM and Semantic Web Technologies

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AEC design challenges

Complex projects and Co-creation using modern tools



AEC design challenges

Enabling even more complex projects

BHoM.xyz





By co-designing and reusing previous work, we can handle more complex projects

AEC design challenges Reusing previous work



Can any of these be reused on future projects?

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AEC design challenges Multi-disciplinarity of AEC projects



BHoM's approach: domain experts-defined design language



BHoM ecosystem



A central, **federated** schema: the **object Model (oM)** *(our main language)*

- organised in "domains" of expertise
- "Adapters" that convert BHoM format to/from external software format (to understand every language)
- When an adapter is written for a software, it becomes part of the BHoM ecosystem
- **29 Open Source Adapters** at the moment (and growing)

BHoM's approach to multidisciplinarity Let the industry drive categorisation

The object model is *organically grown from the roots:* domain experts define *the concepts they need for work* and *in their own namespace*



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BHoM's approach to multidisciplinarity Let the industry drive categorisation

As a result, there isn't a unique way to represent a concept. The important thing is to acknowledge this!

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



Differences with other products

Comparison with other common schemas/tools/frameworks



- Standardized schema for AEC data. Not open-source.
- Data represented in a monolithic approach. Focus on "asbuilt"/"physical" concepts (e.g. no force/energy concepts)
- Powerful in representing/ documenting element classification and product properties, but it falls when representing dynamic data.
- Around 1000 classes focused on "asbuilt"/"physical" concepts. Does not allow for flexibility.
- Most suitable to give a "snapshot" of a design rather than exchanging data during design.



- Open-source, web and geometrybased AEC data exchange and versioning platform.
- Does not focus on information modelling. Offers a compact schema centered on geometry. There are few domain-specific classes spanning different domains.
- Around 150 object models, and numerous connectors to design software`.
- Focuses on connecting software and exchanging data, rather than representing information.



- Open-source framework for AEC information modelling and design tools.
- Large schema that can include any concept useful in design, from "physical" (e.g. columns) to "theoretical" (e.g. design forces) to geometrical (e.g. polylines).
- Over 1000 object models many different domains.
- Also offers connectivity to exchange and convert data between domains and software.

Differences with other products

Tool

Tool E

Tool

Data

Exchange

Format

Comparison with other common schemas/tools/frameworks

Tool Tool Tool There is a degree of centralisation in Tool Tool Tool Tool BHoM (base Tool в В schemas), but the accent is on user-defined mappings rather Speckle IFC Tool Tool E **BHoM** Tool C than monolithically Tool Tool agreed-upon schema. Tool Tool Tool (b) (a) (c) Tool Tool Tool Tool Tool В data В user Α В exchange defined Data mapper Data Data Data Data Exchange Exchange 4--4 Exchange Exchange Exchange Format Format Format Format Format Data Data Data Data Data Schema Schema Schema Schema Schema Database Database Database Database Model Model Model Model **Federated** Distributed Centralized





Using the BHoM "Components" are always the same

Everything in BHoM can be used in the same way no matter the UI:

A Grasshopper component



An Excel formula



A C# script

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

+ web apps, Revit plugins, etc...



- Code that connects (**import/export**)
 BHoM models with other software
- Takes care of converting "BHoM format" towards the external software format
- Over 30 Open Source Adapters at the moment (and growing)

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Examples: Generative modelling beyond Grasshopper

All BHoM methods are available in Excel

Examples: Design to/from Robot



- Once the Bar(s) have been pushed, we can define how the analysis should be performed.
- We can also define Loads, Load Cases, etc. as objects in Grasshopper, then push them.
- We can run the Analysis and check the results.
- We can Pull the results using the Robot Adapter:

enabling iterative design and optimization.

Examples: Interoperability Revit-Rhino



- Push/pull of Engineering/design /geometric elements with their properties
- Overlay objects which don't have formal definition in the BHoM

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Open Street map Download a building massing model



BHoM and Graphs *Current applications and future research*

Some strict conventions followed in BHoM make it well suited for Graph representation:

- BHoM types are open to describe anything in the AEC world.
- BHoM types include classes, interfaces and enumerables. They can be instantiated into objects. Types and their object instances correspond to the facts on TBox and Abox in a knowledge graph.
- BHoM types define concepts avoiding redundant information: they only host *defining properties*.
 (e.g. a BHoM line is defined with two endpoint properties. The length of the Line is not included in its properties; it can be derived as a distance between its endpoints)
- Derived properties can be obtained via particular methods defined in BHoM_Engine (Query methods).
- All properties are public and accessible
- BHoM types do not own any functionality.

D. Elshani, T. Wortmann, and S. Staab, "Towards Better Co-Design with Disciplinary Ontologies: Review and Evaluation of Data Interoperability in the AEC Industry.," in CEUR-WS proceedings, 2022.

isA Classof

D. Elshani, T. Wortmann, and S. Staab, "Towards Better Co-Design with Disciplinary Ontologies: Review and Evaluation of Data Interoperability in the AEC Industry.," in CEUR-WS proceedings, 2022.



<> Code

Issues 33
Pull requests 2

E README.md

BHoM to bhOWL Converter

"BHoM to bhOWL Converter" is part of ongoing research by University of Stuttgart and Buro Happold. It is developed as part of a research project of the Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC). The project's name is: Knowledge Representation for Multi-Disciplinary Co-Design of Buildings.

The developed tool helps convert BHoM data to a knowledge graph in any software BHoM supports. As a result, the converter returns a Resource Description Framework (RDF) graph serialized in Terse RDF Triple Language (TTL) format. The toolkit contains a live connector to GraphDB, a highly efficient and robust graph database with RDF and SPARQL support, compliant with W3C standards.

BHoM (The Buildings and Habitats object Model) is a collaborative framework that runs within several AEC design software, and it represents data in an object-oriented database model. OWL (Web Ontology Language) provides a standardized and expressive language for representing knowledge and relationships within a domain. It allows for creating ontologies, which are formal descriptions of the concepts and relationships within a domain. Additionally, OWL can support reasoning and inference over ontologies, allowing for automated reasoning about the relationships between different concepts and data elements. This can be particularly useful in identifying inconsistencies or gaps in data or suggesting additional data sources or mappings that might be needed to support integration efforts.

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Converting to graph triples can give the following advantages:

- Convert the data to/from RDF ٠
- Store data in a graph database (e.g. Ontotext GraphDB)
- Additional means to query info ٠ (e.g. SPARQL)
- Additional ways to ٠ validate/constraint (e.g. SHACL)
- Apply inferential reasoning
- Connect concepts with additional ٠ relations



Connect concepts with additional relations ٠

Bar = structural concept, for engineers, to represent a linear element for analysis and design (e.g. a column). Can hold/link to FEM data.

□ namespace BH.oM.Structure.Elements { { [Description("1D finite element for structural analysis. Linear 2-noded element defined by a start and end node.")] public class Bar : BHoMObject, IElement1D, IElementM, ILink<Node> /**** Properties ****/ [Description("Defines the start position of the element." + "Note that Nodes can contain Supports which should not be confused with Releases.")] public virtual Node StartNode { get; set; } [Description("Defines the end position of the element." + "Note that Nodes can contain Supports which should not be confused with Releases.")] public virtual Node EndNode { get; set; } [Description("Section property of the bar, " + "containing all sectional constants and material as well as profile geometry and dimensions, where applicable.")] public virtual ISectionProperty SectionProperty { get; set; } = null;

BHoM.xyz

Column = physical world concept. Can represent an actual column in space.

namespace BH.oM.Physical.Elements

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public virtu	al IFramingElement	Property Property { get;

Connect concepts with additional relations



Combining a BHoM **Column** and a **Bar** in a graph-based data model

D. Elshani, T. Wortmann, and S. Staab, "Towards Better Co-Design with Disciplinary Ontologies: Review and Evaluation of Data Interoperability in the AEC Industry.," in CEUR-WS proceedings, 2022

Knowledge management in AEC consultancy: Design VS Operational perspectives

<u>Design & construction</u> perspective

Challenge: organise knowledge/data during design

Reason: better design & manufactory/assembly efficiency; cost cutting and efficiency

Applications: DfMA; modular construction; computational design; rapid prototyping

Existing data models: BHoM; BOT; IFC, IFCOWL;

<u>Operational</u> perspective

Challenge: organise and retrieve the operational (post-construction) data

Reasons: performance monitoring and maintenance; stakeholders engagement; data ownership and control

Applications: Sensor data management; BIM data querying; validation

Example data models: Project Haystack, Brick Schema, RealEstateCore, Azure Digital Twins, Google Digital Building Ontology

Parametric Modular Unit

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Design perspective: Digital Futures workshop



https://vimeo.com/724817479

https://www.youtube.com/playlist?list=PLZ1 uRtLJZbxAfkUXXxOaVRuMA8W52RBe2

Digital Futures workshop, 100 applicants and dozens of active users



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#### Material Ontology















#### **Design perspective:** CoDeC hackaton

Demonstrating the write to RDF (TTL) and export to GraphDB.



#### **Operational perspective:**

#### BHoM.xyz

Connecting digital and physical layers – design to "as built"



- Data comes from post-construction sources: sensors, measurements, time-series
- Need to connect to physical layer "as built"
- Little to no efforts to organise the data
- Hard to query information after construction
- Hard to connect existing concepts "as designed"

## **Operational perspective:**

## Connecting digital and physical layers – design to "as built"



## **Operational perspective:**

#### Connecting digital and physical layers – design to "as built"



Holistic interoperable twin

#### **Future research** Graphs and Machine Learning applications

- Neuro-symbolic approaches to extrapolate design information from existing, **unstructured** design data (e.g. CAD drawings)
- ML methods to identify "similar" concepts (classes) and potential ways to interconnect them
- Entity recognition/relation extraction
- Missing/incomplete entity or relation resolution; conflicts

# **Thank you!**



#### **University of Stuttgart**

- Diellza Elshani, PhD Candidate, Research Associate ٠
- Tenure-Track prof. Dr. Thomas Wortmann, Chair for Computing in Architecture ICD/CA



#### **Buro Happold, London**

- Alessio Lombardi, interop/ML lead
- Dr. Al Fisher, Head of Computational Development

#### Some refs

D. Elshani, T. Wortmann, and S. Staab, "Towards Better Co-Design with Disciplinary Ontologies: Review and Evaluation of Data Interoperability in the AEC Industry.," in CEUR-WS proceedings, 2022

D. Elshani, A. Lombardi, A. Fisher, D. Hernandez, S. Staab, and T. Wortmann, "Knowledge Graphs for Multidisciplinary Co-Design: Introducing RDF to BHoM," in CEUR-WS proceedings, 2022.

D. Elshani, A. Lombardi, A. Fisher, D. Hernandez, S. Staab, and T. Wortmann, "Inferential Reasoning in Co-Design Using Semantic Web Standards Alongside BHoM," presented at the 33. Forum Bauinformatik 2022, Munich, 2022.

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

#### **Some links**



github.com/BHoM/RDF Prototypes