Graph Representation of Building Information Models

PhD: Zijian Wang

Supervisor: Prof. Rafael Sacks

https://zijianwang-zw.github.io/

April 22, 2024

TECHNION Israel Institute of Technology | The Faculty of Civil and Environmental Engineering | VClab Seskin Virtual Construction Laboratory | CBIM

If you want to build a house,

What tools would you use for **design**?

How can you **store** the drawings?

https://www.historyforkids.net/egyptian-houses.html

A brick in the collection of the Metropolitan Museum of Art

About 1500-1295 B.C., Egypt

Architectural Drawing of a Garden

Part of the temple

A wall

Measurements of the wall: 32 cubits

https://www.metmuseum.org/art/collection/search/544801

Milestone of design tools

Hand Drawing

Design Theory

Projection/2D drafting

Data Representation

Lines, annotations

Storage media

Walls, stones, papers

https://www.metmuseum.org/art/collection/search/544801

Milestone of design tools

Computer-Aided Design

🏛 Design Theory

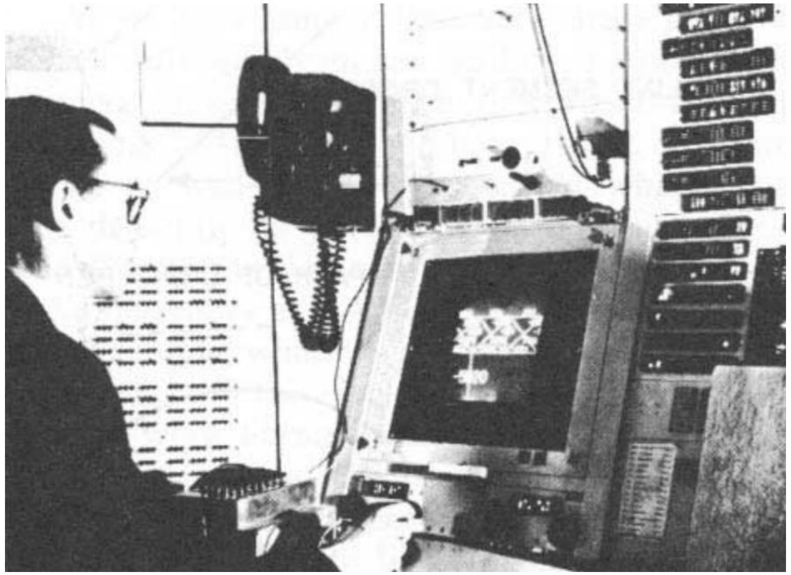
Projection/2D drafting

📐 Data Representation

Lines, annotations

📋 Storage media

Digital files

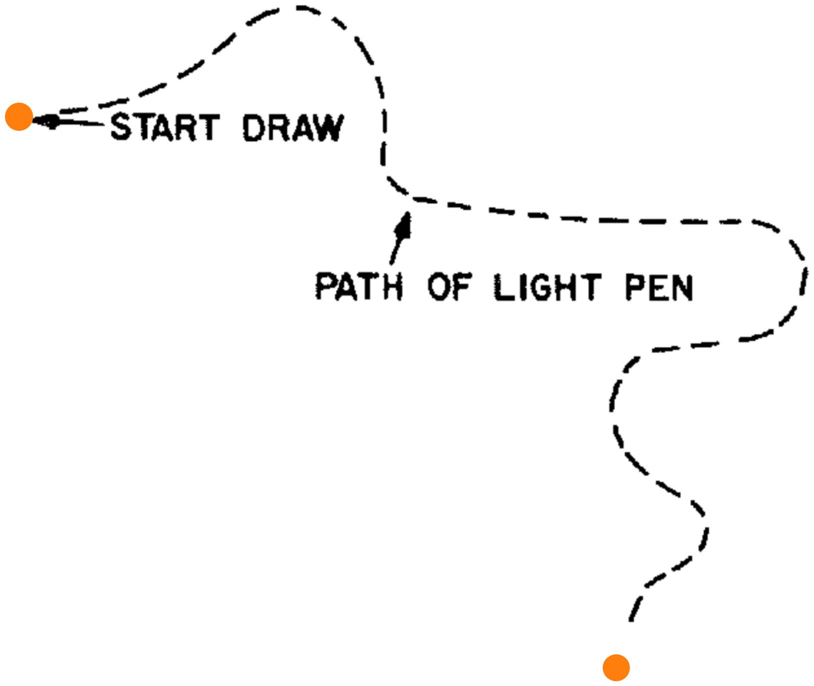


The first CAD software

SKETCH PAD

1963, MIT

Ivan Edward



Lize SOHO, Beijing, China 2019

Designed by Zaha Hadid

https://www.sohochina.com/project.aspx?projectid=12

Complicated curves extend inside and outside

Multi-functional building

Challenging structural analysis

Design in 3D

Office building

Metro station

https://www.sohochina.com/project.aspx?projectid=12

Milestone of design tools

Building Information Modeling

Design Theory

3D modeling

Data Representation

Objects, relationships

Storage media

Digital files

https://www.sohochina.com/project.aspx?projectid=12

Federated nature of the AEC industry

Involved many experts from different background

Architects Engineers Contractors …

Domain-specific models resulting in multiple source data

Arc model Structural Piping Mechanical …

Multiple software vendors provide specific services

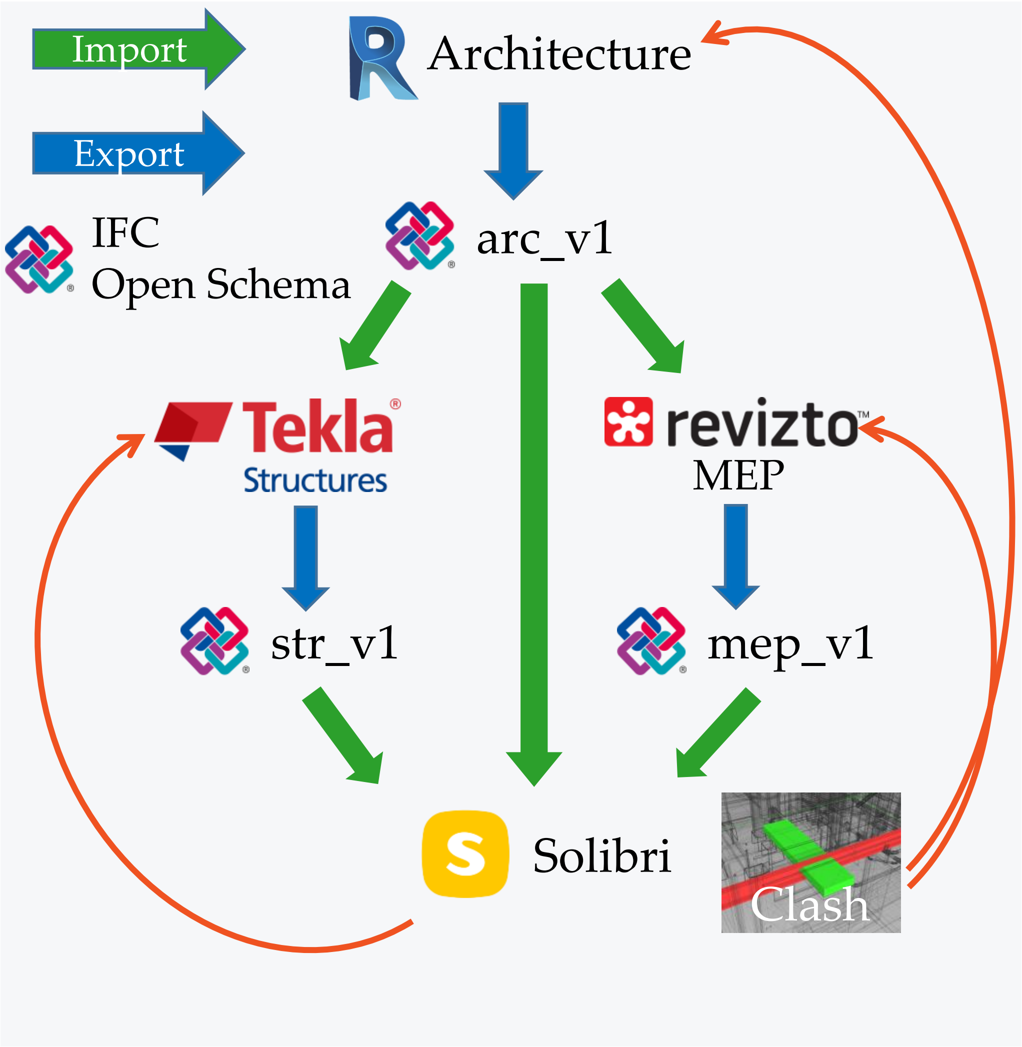
Tekla Structures revizto

BIM vendors set limitations for data exchange

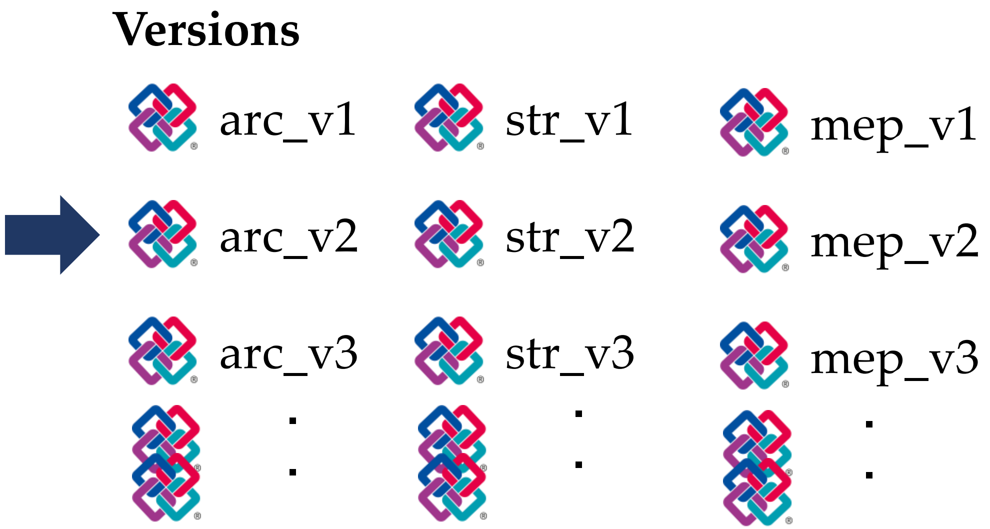
X

Tekla Structures

Close interdisciplinary collaboration is essential in AEC



A typical design workflow
involving different experts and software

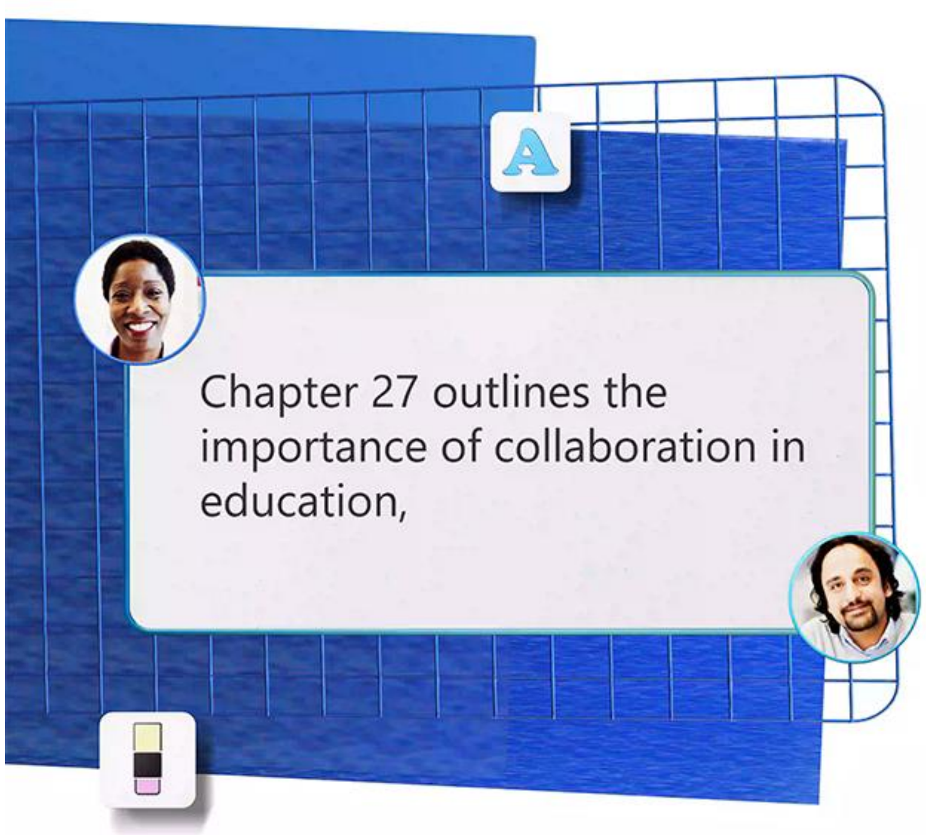


Headaches:

1. File-based exchange resulting in sequential design
2. Manually check and resolve conflicts
3. Cumbersome version control

Microsoft 365

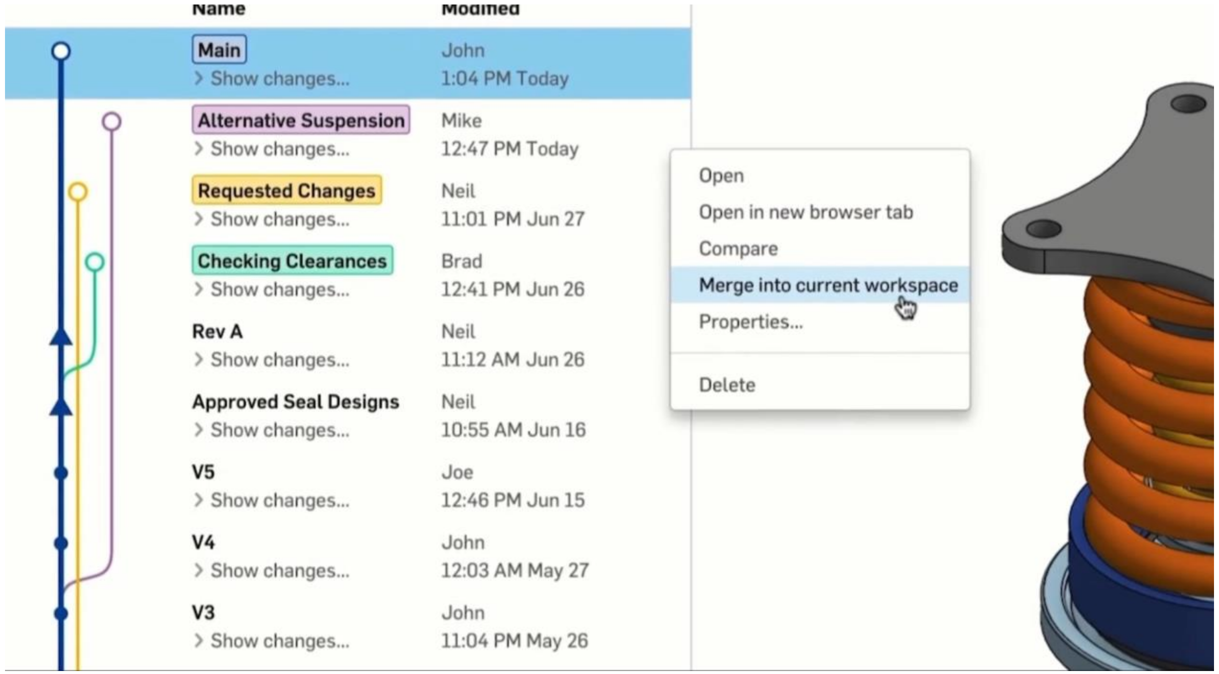
Create and edit together



https://www.microsoft.com/en-us/microsoft-365/word

Onshape (Manufacturing)

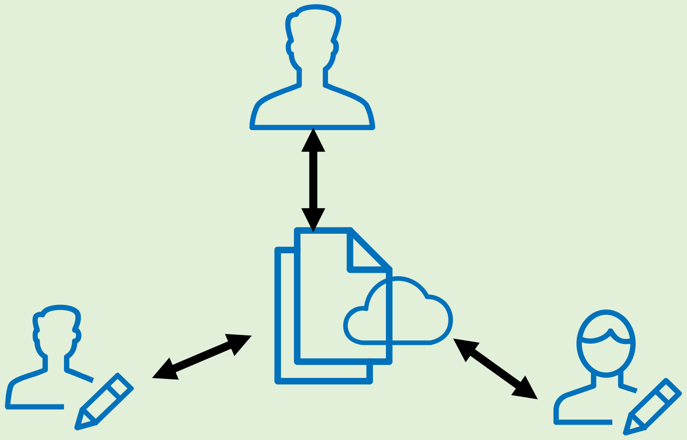
Streamline collaboration from any device



https://www.onshape.com/en/

Cloud collaboration difference

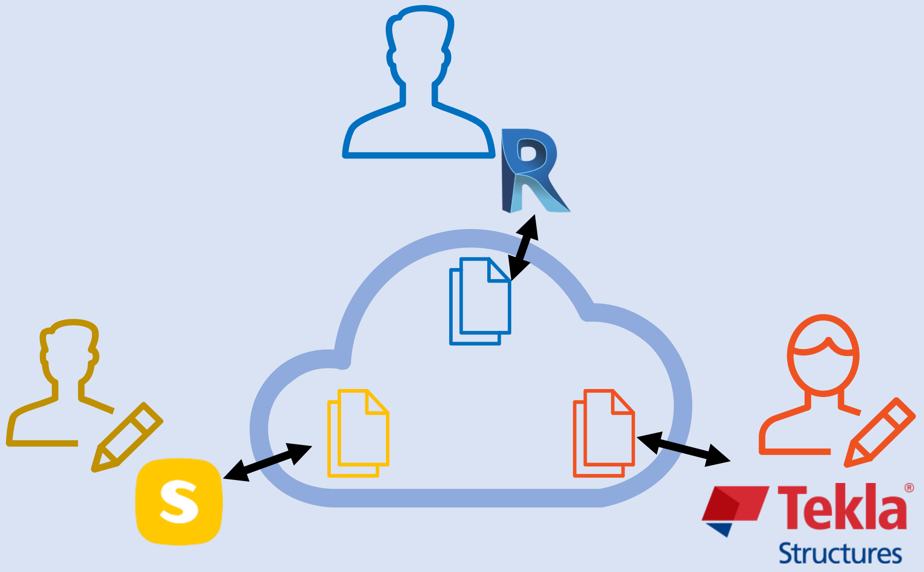
Collaboration in other domains



Single software

Single-source data

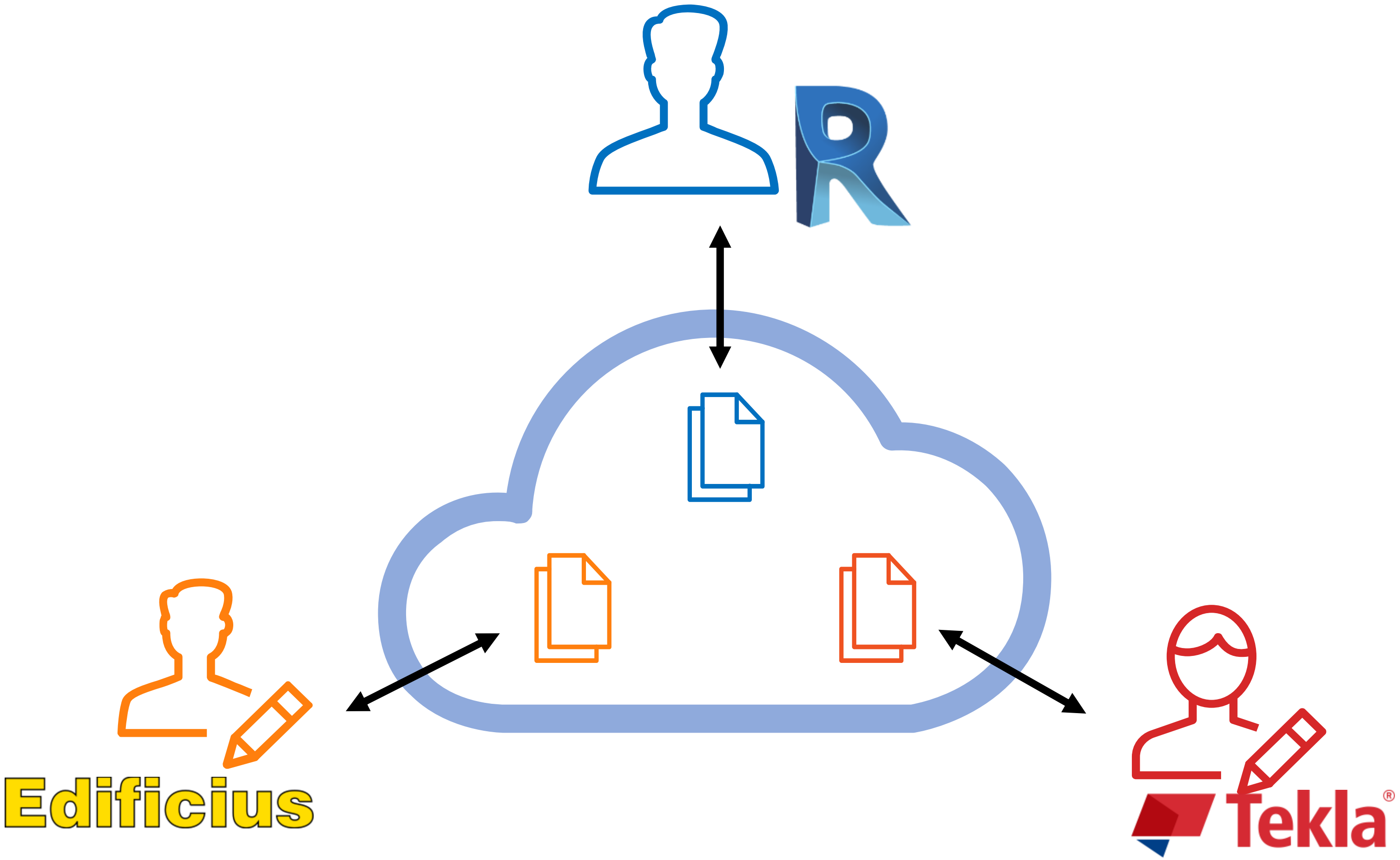
Collaboration in BIM



Multiple software

Heterogenous data

How to enable BIM cloud collaboration?



State-of-the-art (industry)

BIM vendors provide cloud platforms, but mainly file-based and lacking intelligence

Autodesk BIM Collaborate

https://www.autodesk.com/products/bim-collaborate/

• Upload files from local editors to the cloud repository • Record design history in files • Manually select model files to check clashes	• Cannot identify and resolve conflicts automatically • Cannot process the change at the object level • Designed for Autodesk ecosystem

- ➢ **Similar platforms: Trimble Connect, Konstru**
- ➢ **Move files from local to the cloud: not designed for multi-design-discipline collaboration**

Speckle

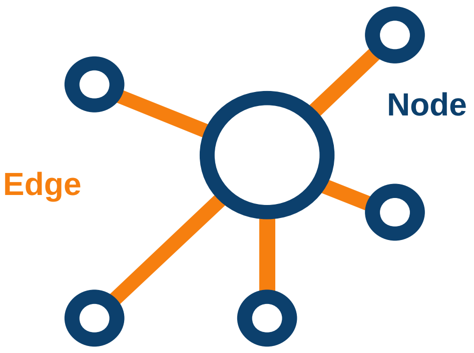
https://speckle.systems/

• Provides connectors for various design tools for retrieving and reconstructing models • Computes changes at the object level	• Records the design history of whole models • Cannot detect and resolve conflicts • No semantic enrichment process

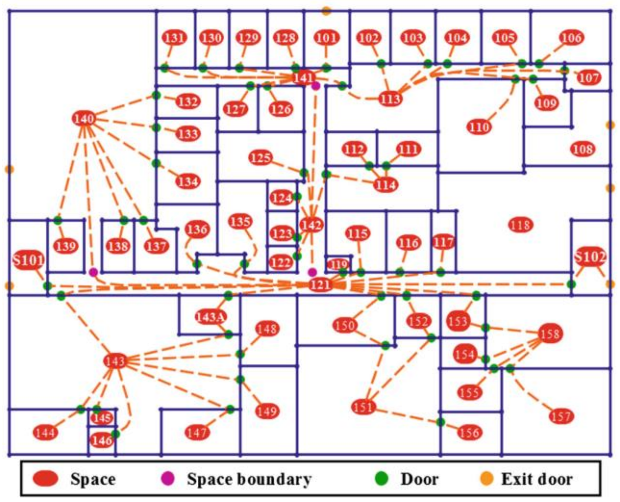
- ➢ **Regards design data as objects but barely uses it**
- ➢ **Lacks intelligent functions to support multi-design-discipline collaboration**

State-of-the-art

Researchers have started to explore BIM graph applications, within a single domain



- Graphs consist of nodes and edges, each of which associates two nodes [1]
    - Graphs have the natural advantage of representing relationships explicitly



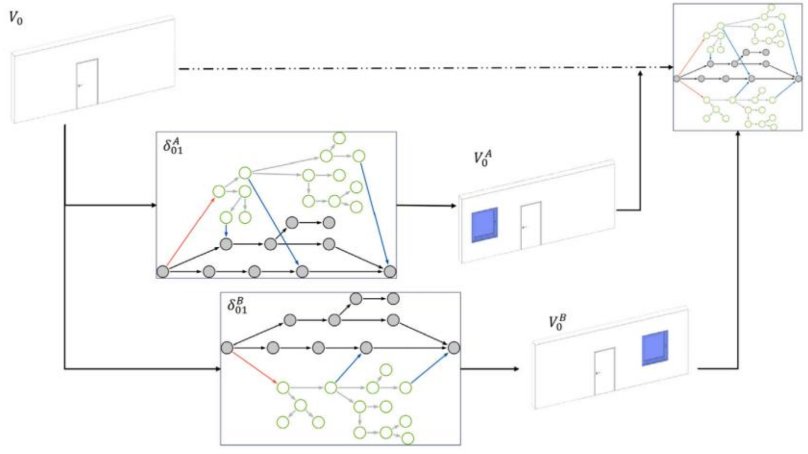
- An early study compiles building layouts as graphs and utilizes graph search algorithms to find the shortest path as the emergency exit routes [2]

[1] Deo, N., 2017. Graph theory with applications to engineering and computer science. Courier Dover Publications.
[2] Ismail, A., Strug, B. and Ślusarczyk, G., 2018. Building knowledge extraction from BIM/IFC data for analysis in graph databases. ICAISC 2018, Zakopane, Poland, June 3-7, 2018, Proceedings, Part II 17 (pp. 652-664). Springer International Publishing.

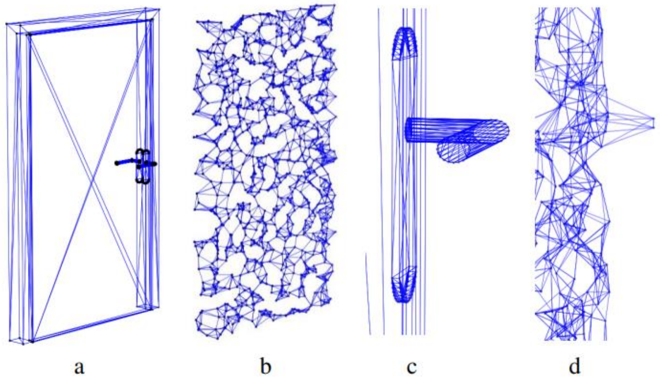
State-of-the-art

Researchers have started to explore BIM graph applications, within a single domain

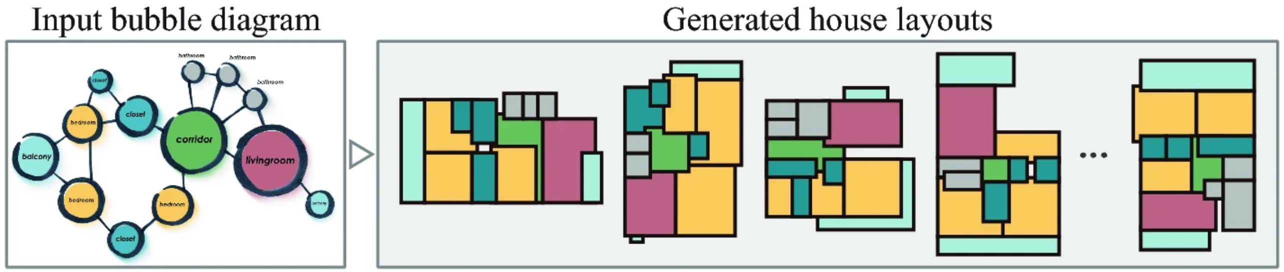
- Design models are compiled as graphs to compute and merge changes, achieving the object-level version control [1]
- Machine learning is applied to BIM graphs for classifying BIM objects, generative design, code checking, etc [2-4]



Design change computes and merges [1]



Parsing object geometries into graphs [2]



Graph generative design for house layouts [3]

[1] Esser, S., Vilgertshofer, S. and Borrmann, A., 2023. Version control for asynchronous BIM collaboration: Model merging through graph analysis and transformation. Automation in Construction, 155, p.105063.
[2] Collins, F., Braun, A., Ringsquandl, M., Hall, D. and Borrmann, A., 2021. Assessing IFC classes with means of geometric deep learning on different graph encodings. In Proc. of the 2021 European Conference on Computing in Construction.
[3] Nauata, N., Chang, K.H., Cheng, C.Y., Mori, G. and Furukawa, Y., 2020. House-gan: Relational generative adversarial networks for graph-constrained house layout generation. In Computer Vision–ECCV 2020, UK, August 23–28, 2020
[4] Bloch T, Borrmann A, Pauwels P. Graph-based learning for automated code checking–Exploring the application of graph neural networks for design review. Advanced Engineering Informatics. 2023 Oct 1;58:102137.

State-of-the-art

- The Linked Building Data (LBD) community has explored storing building information in web-based graphs and linking with heterogeneous built environment data such as time-series sensor data [1]
- Technologies from the semantic web are used to store, and query graphs, such as RDF, and SPARQL [3]
- The LBD community has developed various ontologies to encapsulate expert knowledge and understanding which provide uniform vocabularies and formats [2]
- Converters are developed to compile IFC files into RDF graphs with information loss [4]

Ontology	Acronym	Domain	Purpose
Building Topology Ontology	BOT	AEC	Topological concepts of a building
Building Element Ontology	BEO	AEC	Define common building elements
Damage Topology Ontology	DOT	AEC	Damage representations and their relations with objects
Brick	-	IoT	Description of physical, logical and virtual assets in a building

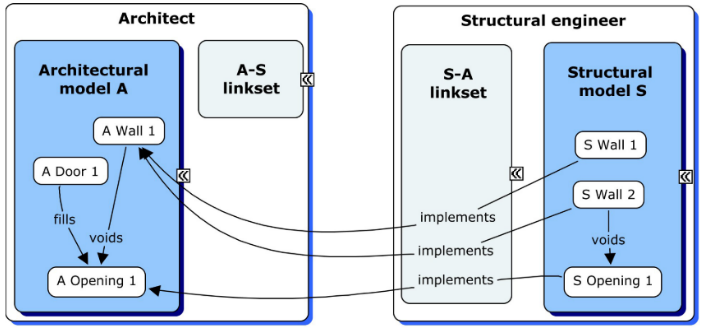
- The application scope is mainly about integrating and retrieving data

[1] Pauwels, P., Costin, A. and Rasmussen, M.H. (2022) 'Knowledge Graphs and Linked Data for the Built Environment', in. Springer, pp. 157–183
[2] Rasmussen, M.H., Lefrançois, M., Schneider, G.F. and Pauwels, P., 2021. BOT: The building topology ontology of the W3C linked building data group. Semantic Web, 12(1), pp.143-161.
[3] Pauwels, P., Zhang, S. and Lee, Y.C. (2017) 'Semantic web technologies in AEC industry: A literature overview', Automation in Construction. Elsevier B.V., pp. 145–165
[4] Bonduel, M., Oraskari, J., Pauwels, P., Vergauwen, M. and Klein, R., 2018. The IFC to linked building data converter: current status. In 6th linked data in architecture and construction workshop (Vol. 2159, pp. 34-43).

State-of-the-art

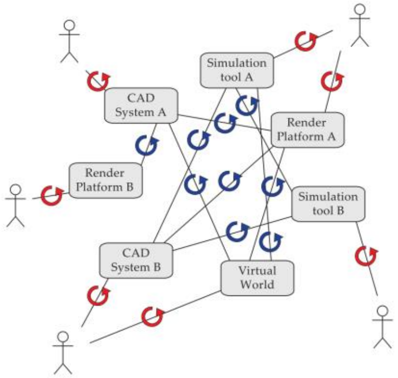
Graph across-domain applications have been explored partially and without validation

- (2013) Linking the individual models together would support functionalities such as cross-model information access and aggregation, status monitoring, and change management [1]
- (2014) Built data from a project can be linked to address the interoperability problem [2]
- (2016) Using 'equivalent' relations to link heterogeneous data to support decision making in highway asset management [3]



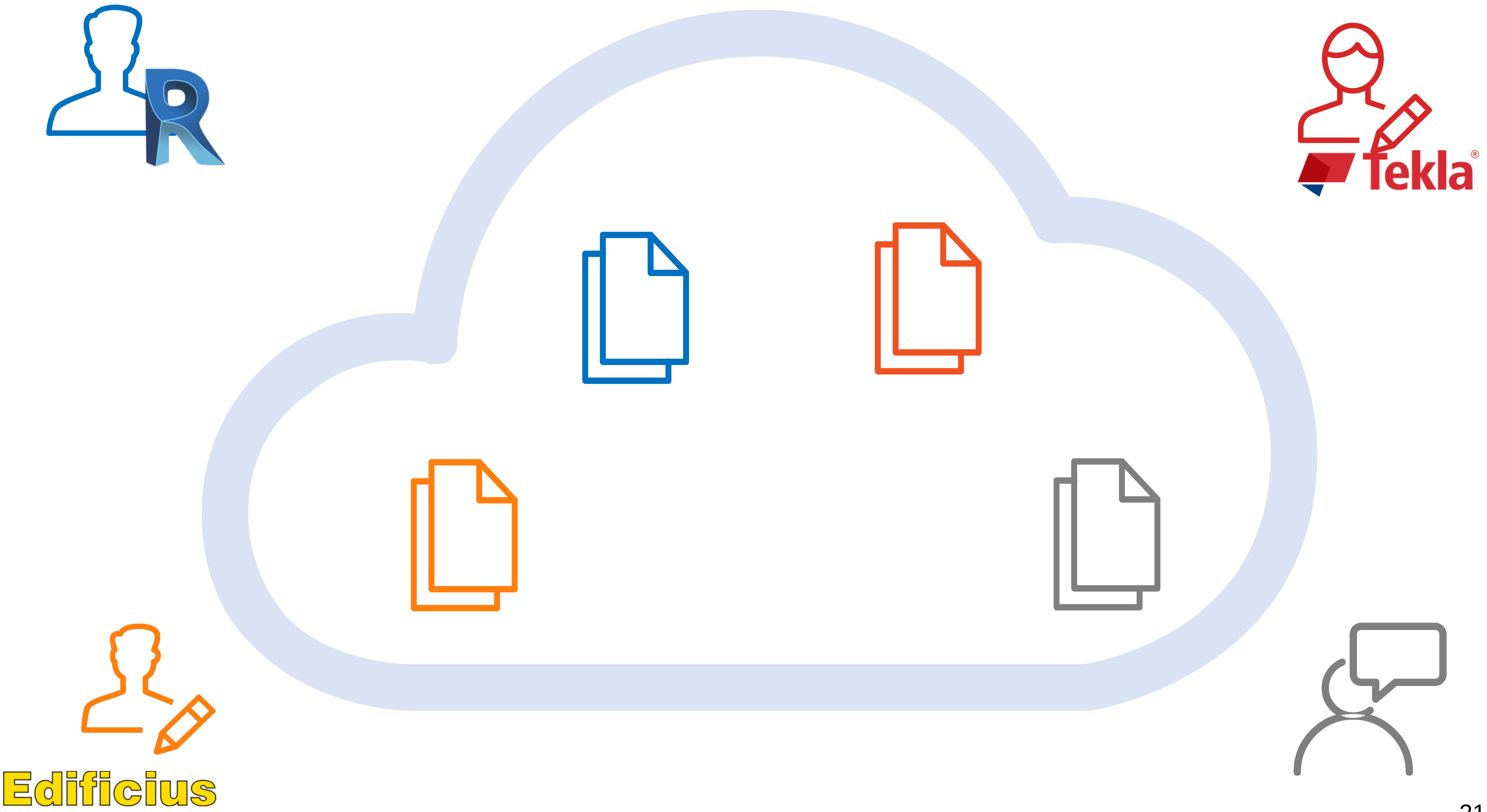
Semantic linking of building information models [1]

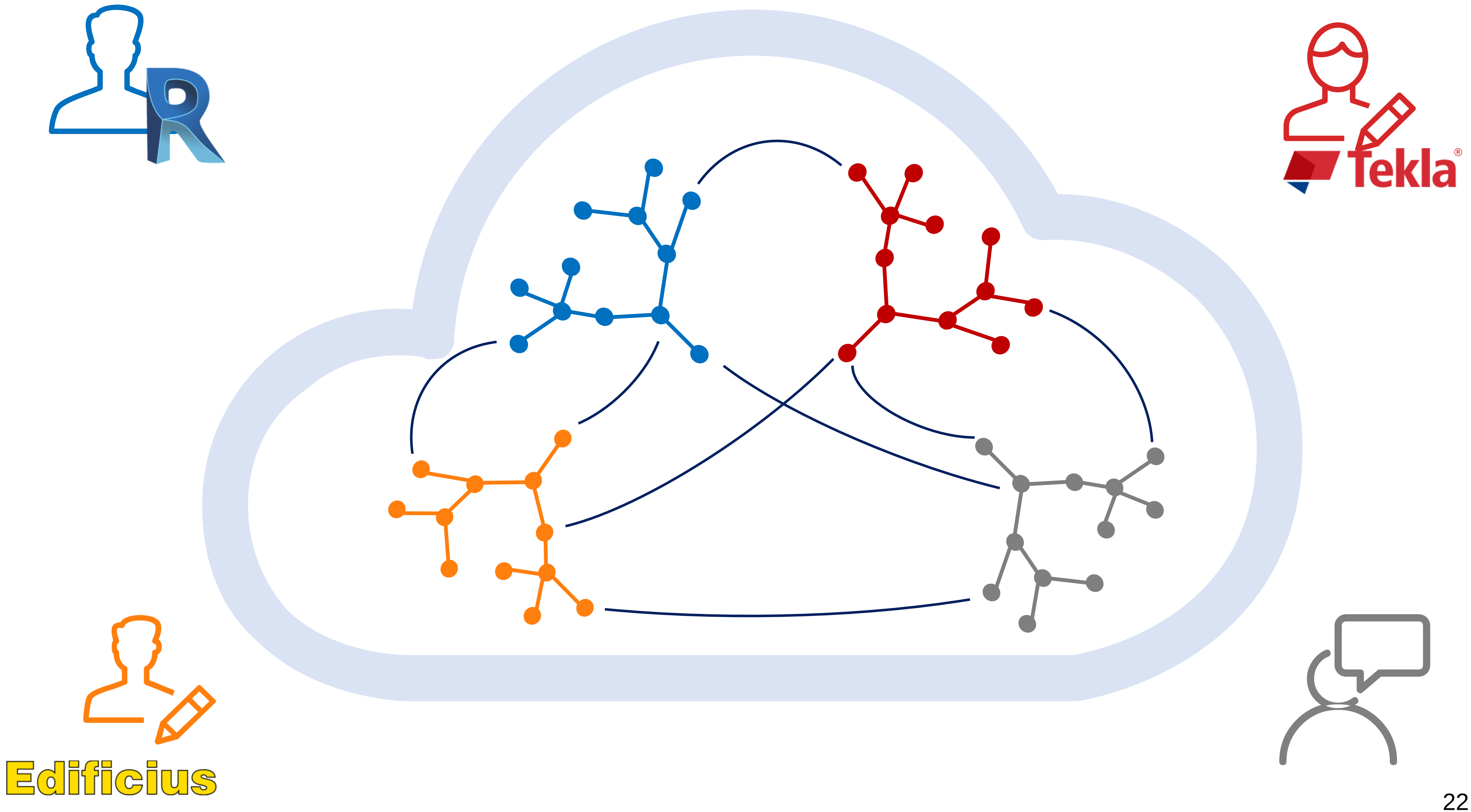
- ➢ **The theory and framework of graph representation to support across-domain intelligent applications are missing**
- ➢ **No formal validation of the graph-based concept**

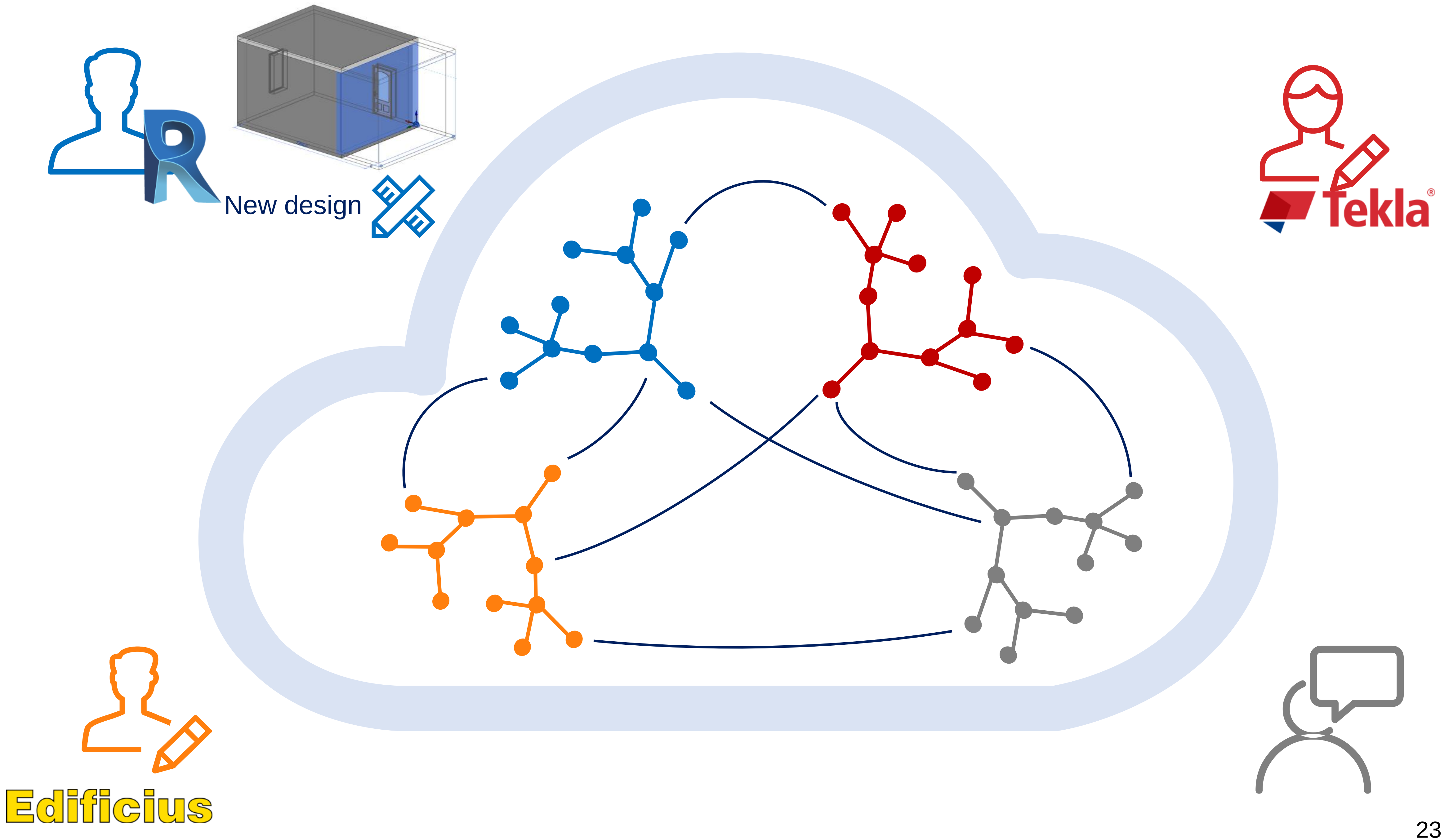


Linking an AEC project [2]

[1] Törmä, S. (2013) 'Semantic linking of building information models', in Proceedings - 2013 IEEE 7th International Conference on Semantic Computing, ICSC 2013, pp. 412–419.
[2] Pauwels, P. (2014) 'Supporting decision-making in the building life-cycle using linked building data', Buildings, 4(3), pp. 549–579.
[3] Le, T. and David Jeong, H. (2016) 'Interlinking life-cycle data spaces to support decision making in highway asset management', Automation in Construction, 64, pp. 54–64.


Tekla
Edificius


Tekla
Edificius


New design
Tekla
Edificius

Graph Representation of Building Information Models

Research goals

BIM cloud collaboration

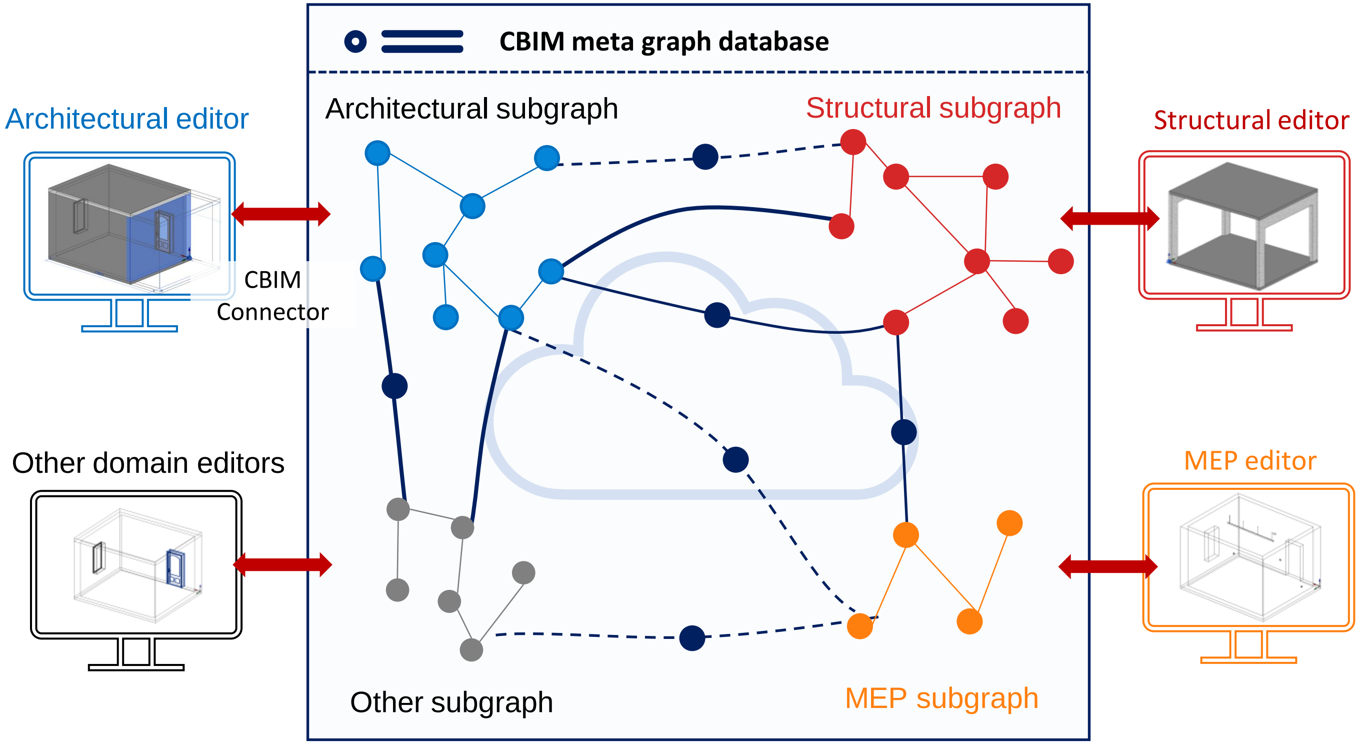
- Explore and validate a graph-based approach of representing and linking BIM models for enabling across-domain collaboration (Experiment 1)

AI for enriching BIM semantics and enhancing interoperability

- Propose a generic semantic enrichment framework for reconstructing BIM graphs from pure object geometries (Experiment 2)
- Explore graph neural networks (GNNs) on BIM graphs (Experiment 3)

Exp1: Graph-based consistency maintenance → Exp2: Generic semantic enrichment → Exp3: GNNs on BIM graphs → Discussion Conclusion

Graph-based consistency maintenance

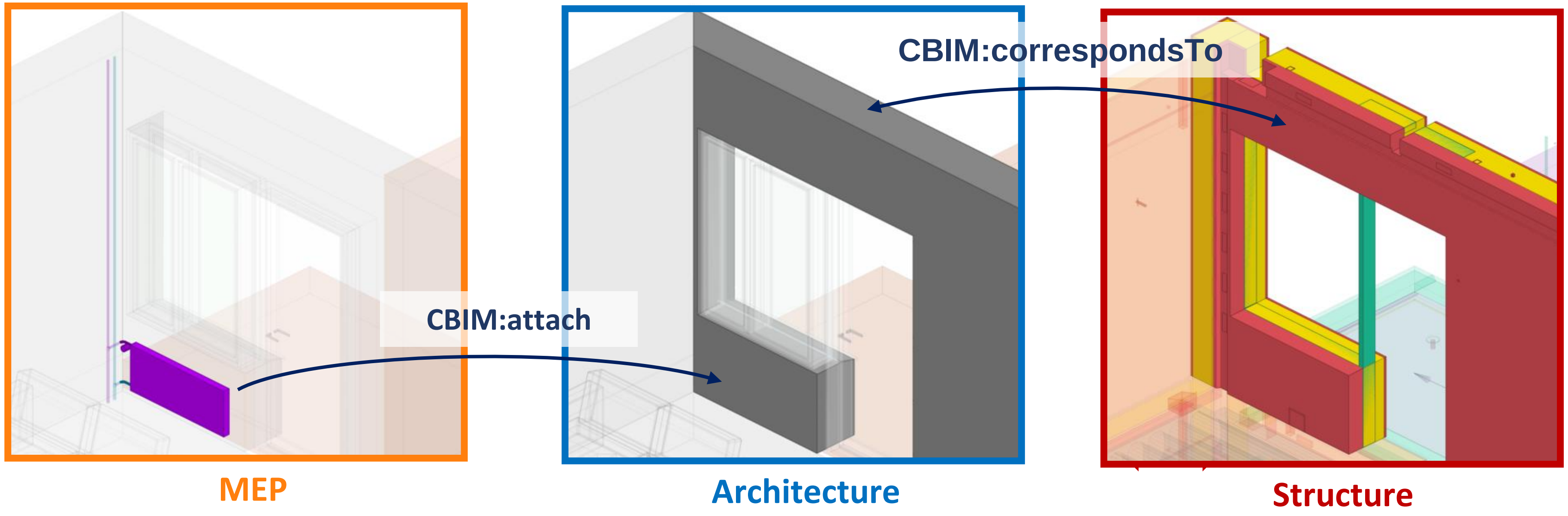


Relationship types:

1) Topology
2) Functional semantics
3) Design intent and constraint

Wang, Z., Ouyang, B. and Sacks, R., 2023. Graph-based inter-domain consistency maintenance for BIM models. Automation in Construction, 154, p.104979.

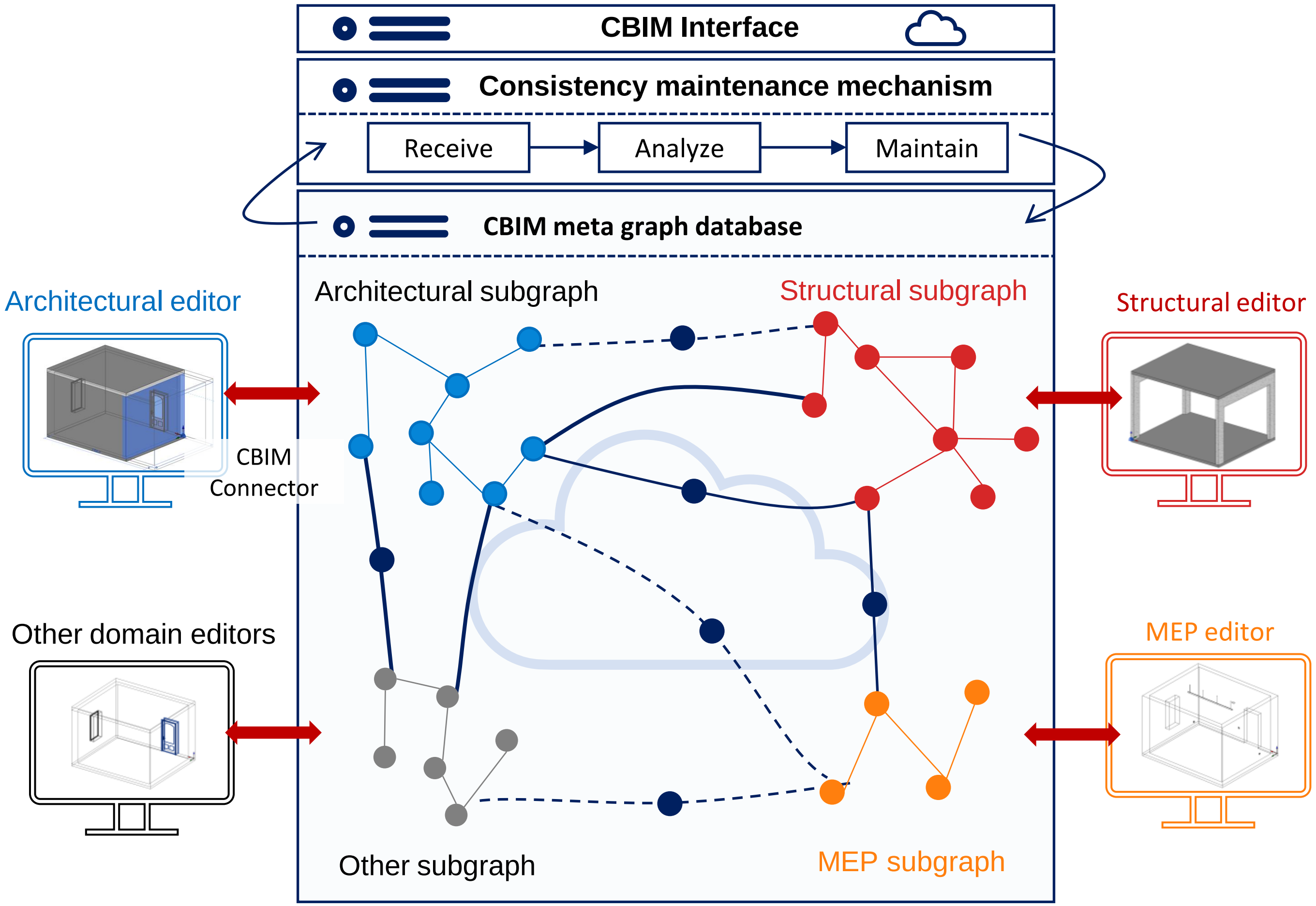
Examples of relationships

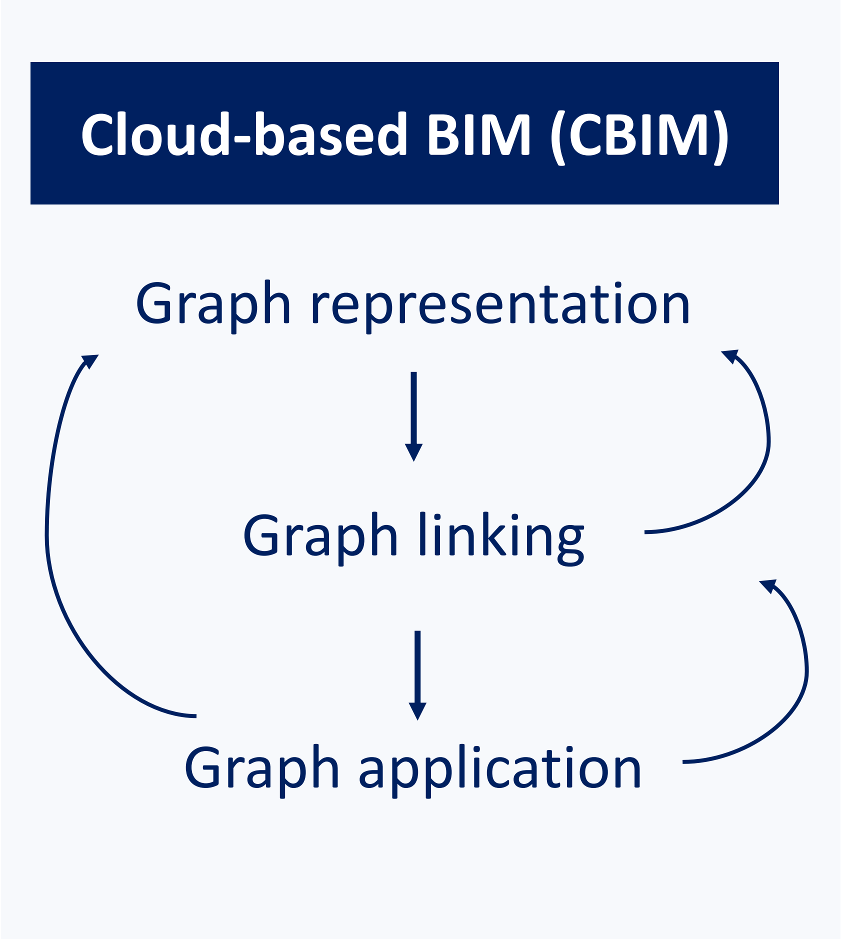


‘corresponds to’ between the architectural wall and the structural wall

‘attached to’ between the radiator and the architectural wall, which can be extended to constraints

Graph-based consistency maintenance

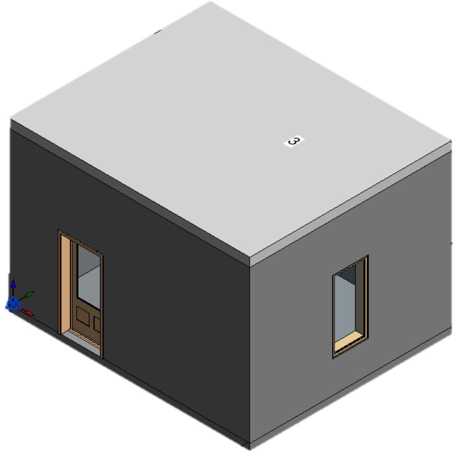


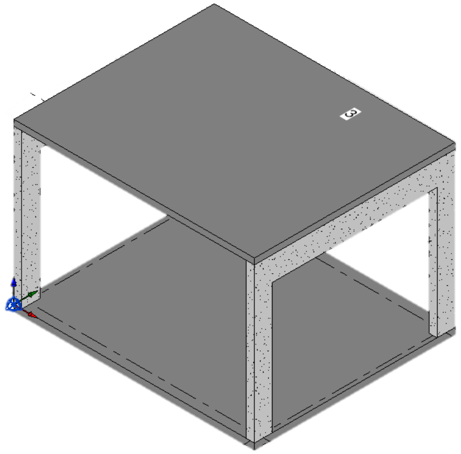


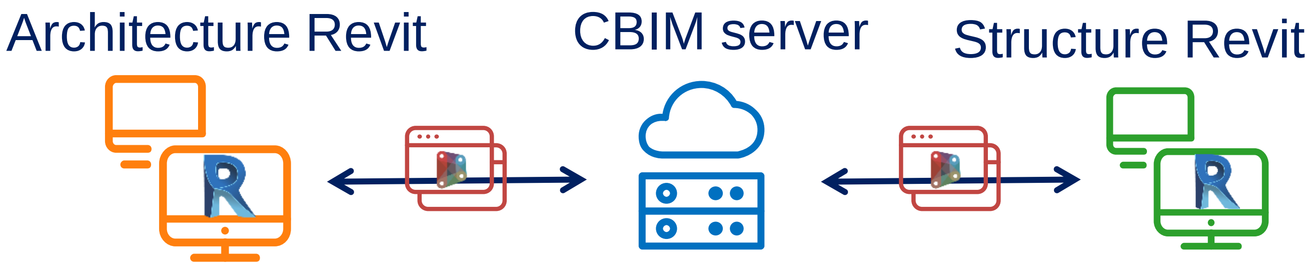
Wang, Z., Ouyang, B. and Sacks, R., 2023. Graph-based inter-domain consistency maintenance for BIM models. Automation in Construction, 154, p.104979.

CBIM Prototype

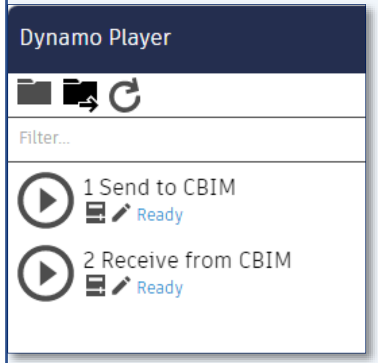
Maintaining consistency on linked architectural and structural models







CBIM-Revit Connector

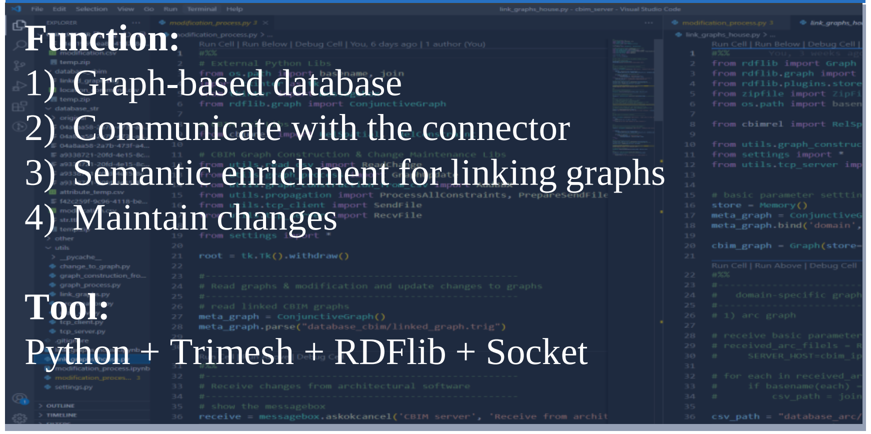


Function:

1) Extract data from Revit database
2) Execute commands from CBIM server
3) Communicate with CBIM server

Tool: Dynamo + Python

CBIM server

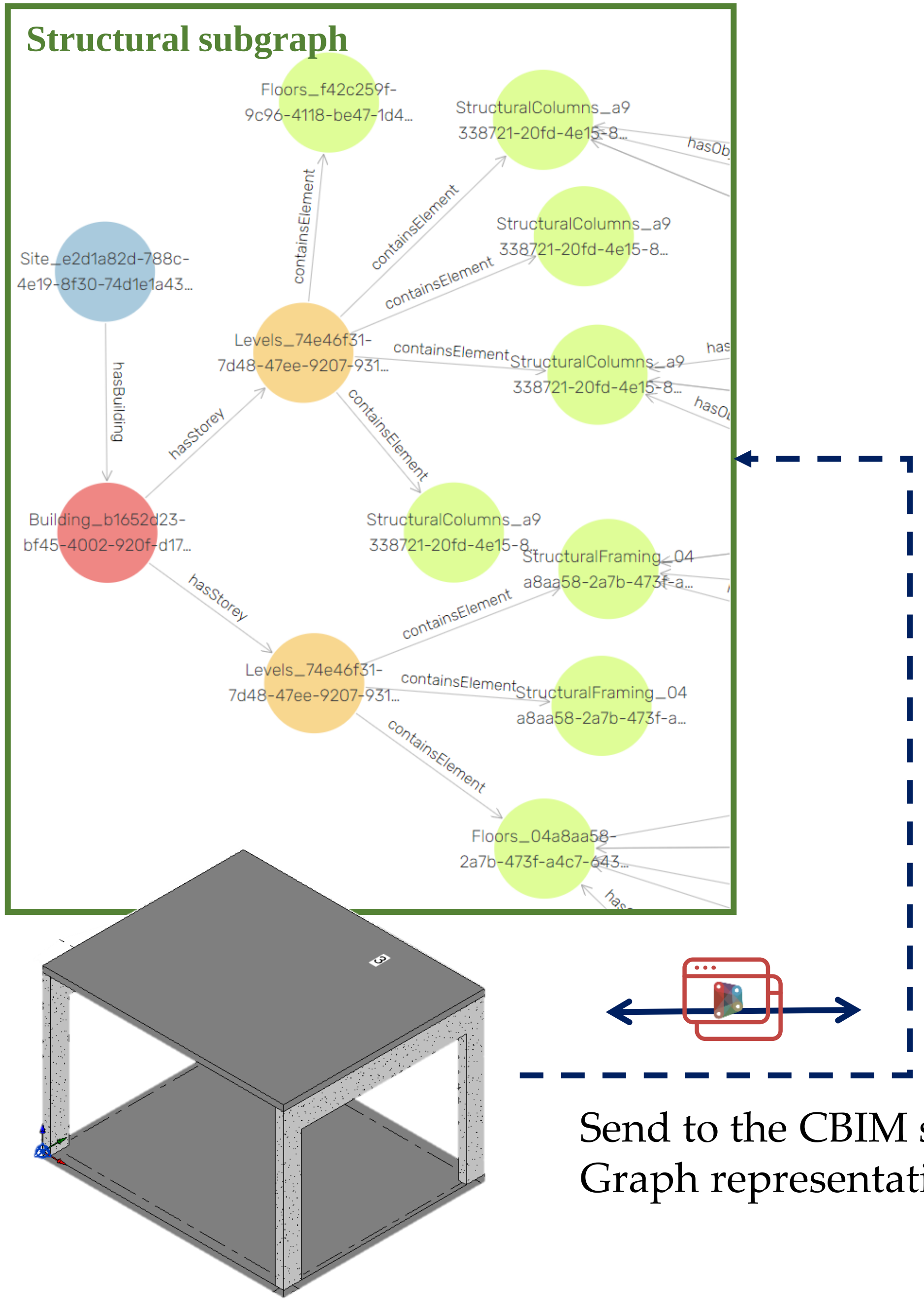


Function:

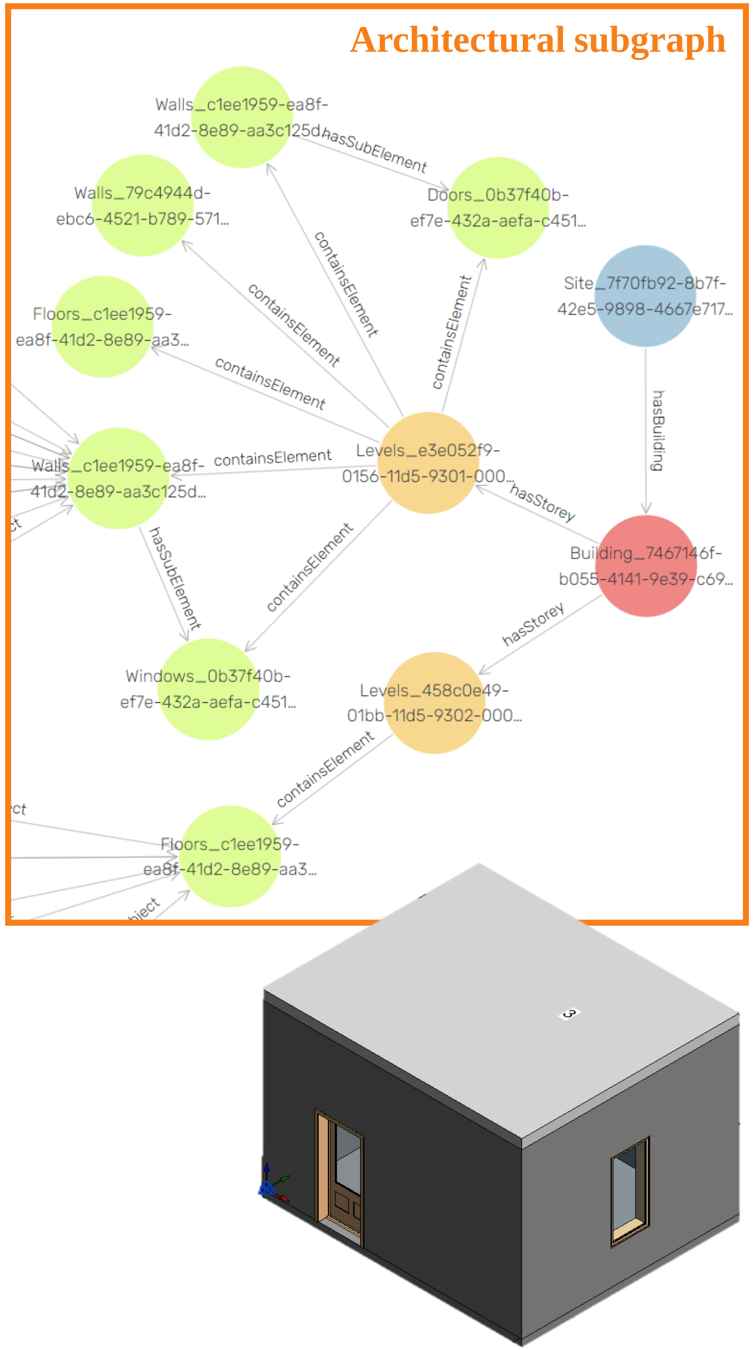
1) Graph-based database
2) Communicate with the connector
3) Semantic enrichment for linking graphs
4) Maintain changes

Tool:

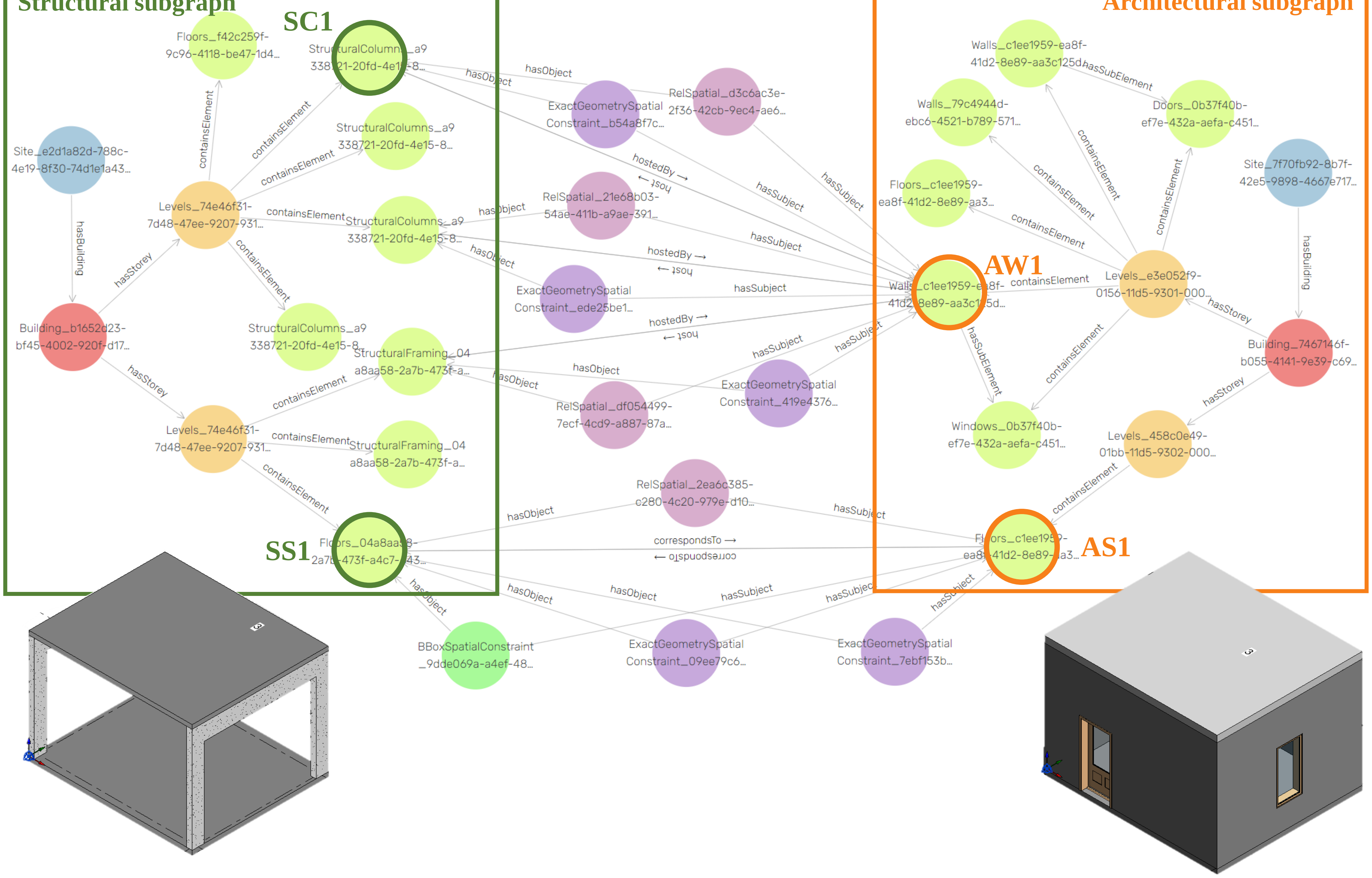
Python + Trimesh + RDFlib + Socket



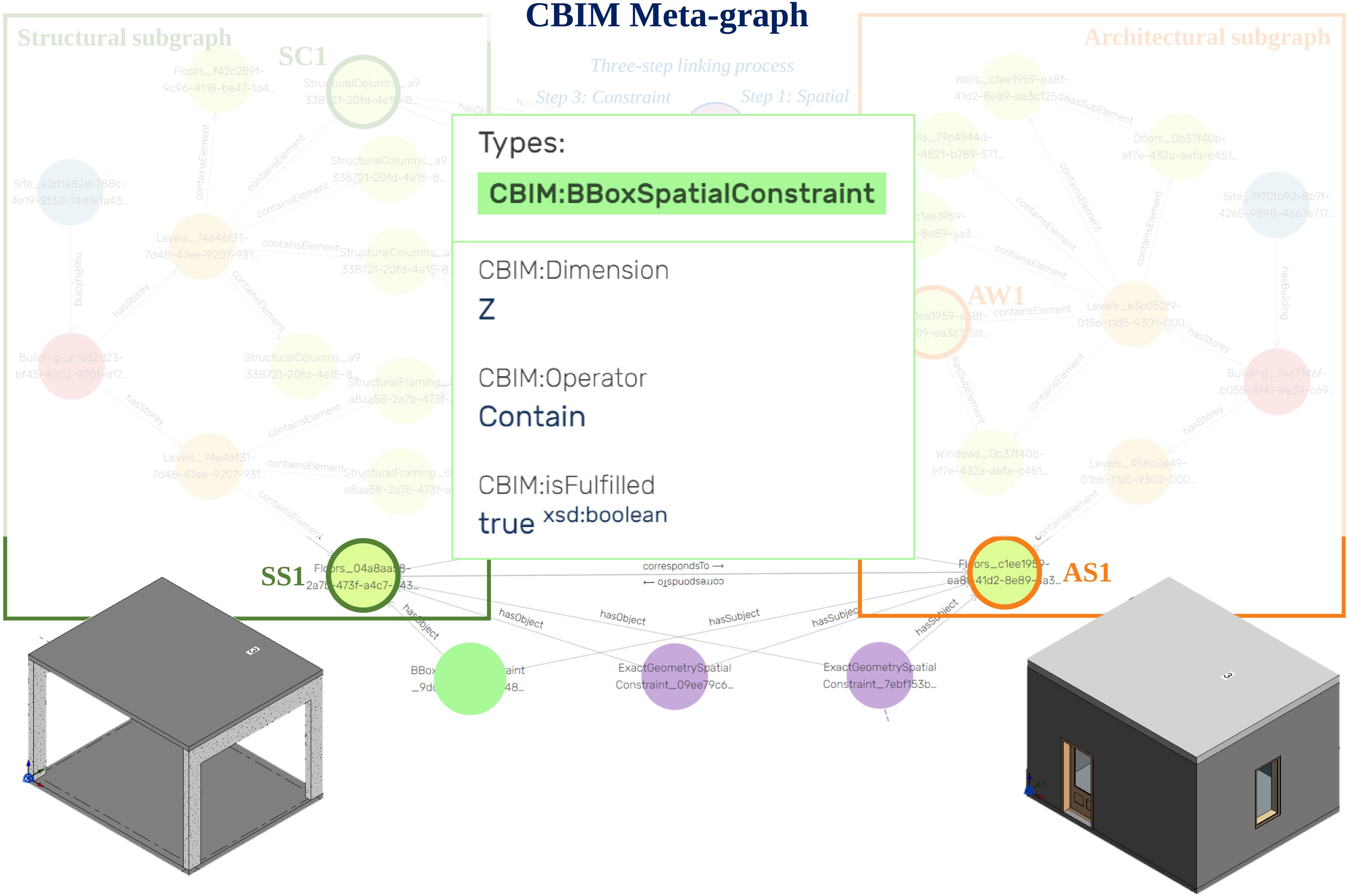
Send to the CBIM server/
Graph representation



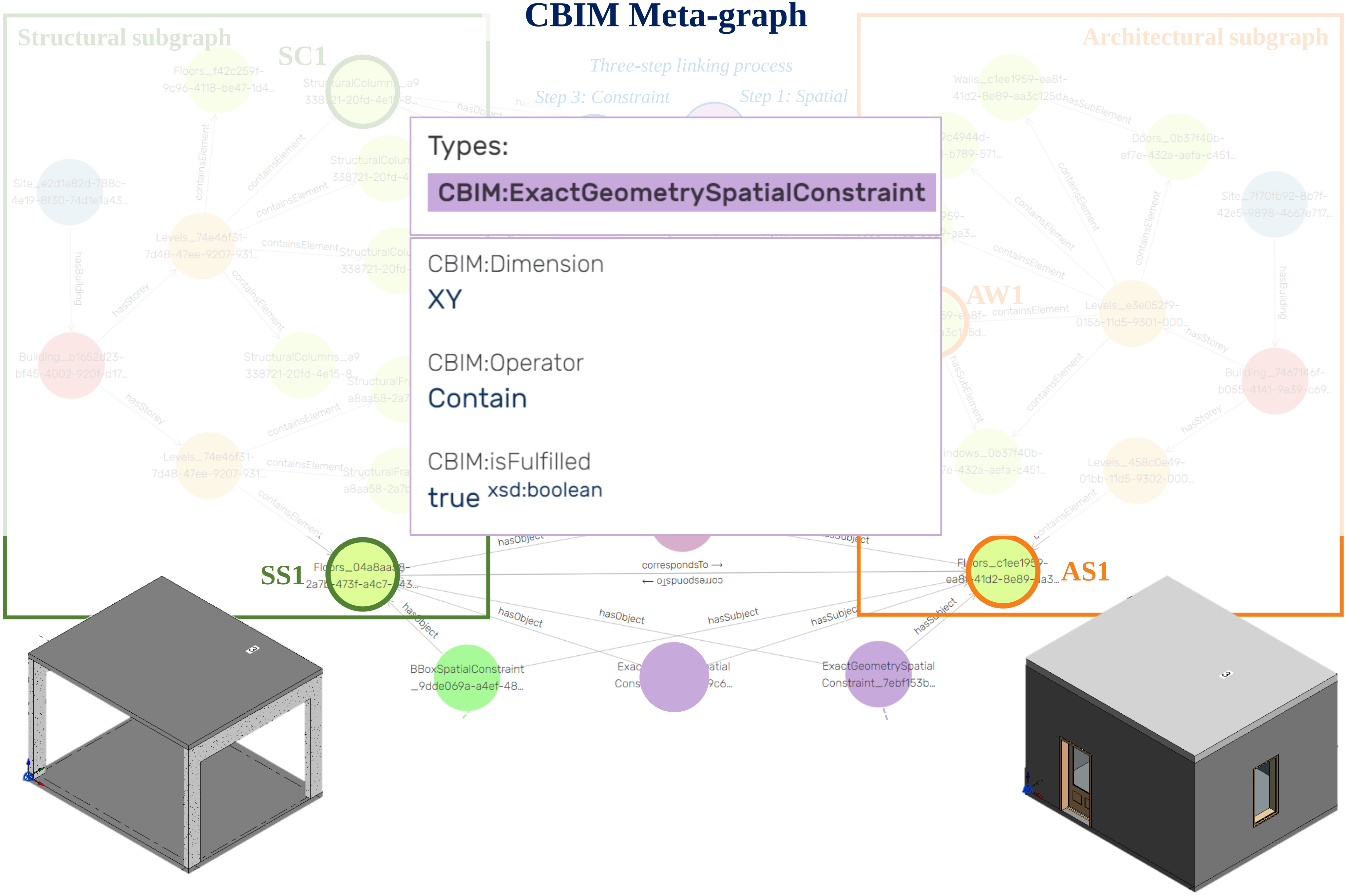
CBIM Meta-graph



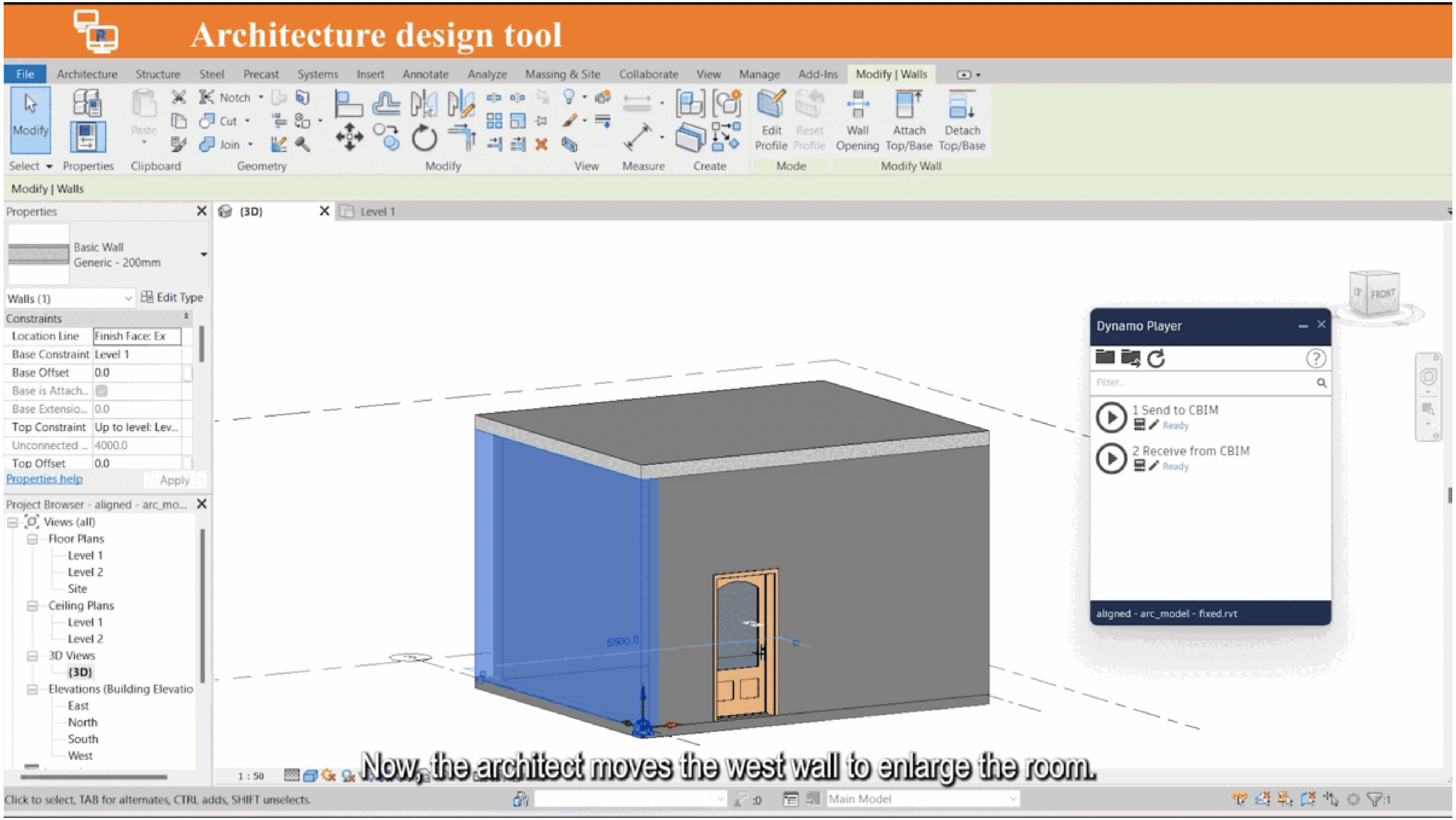
CBIM Meta-graph



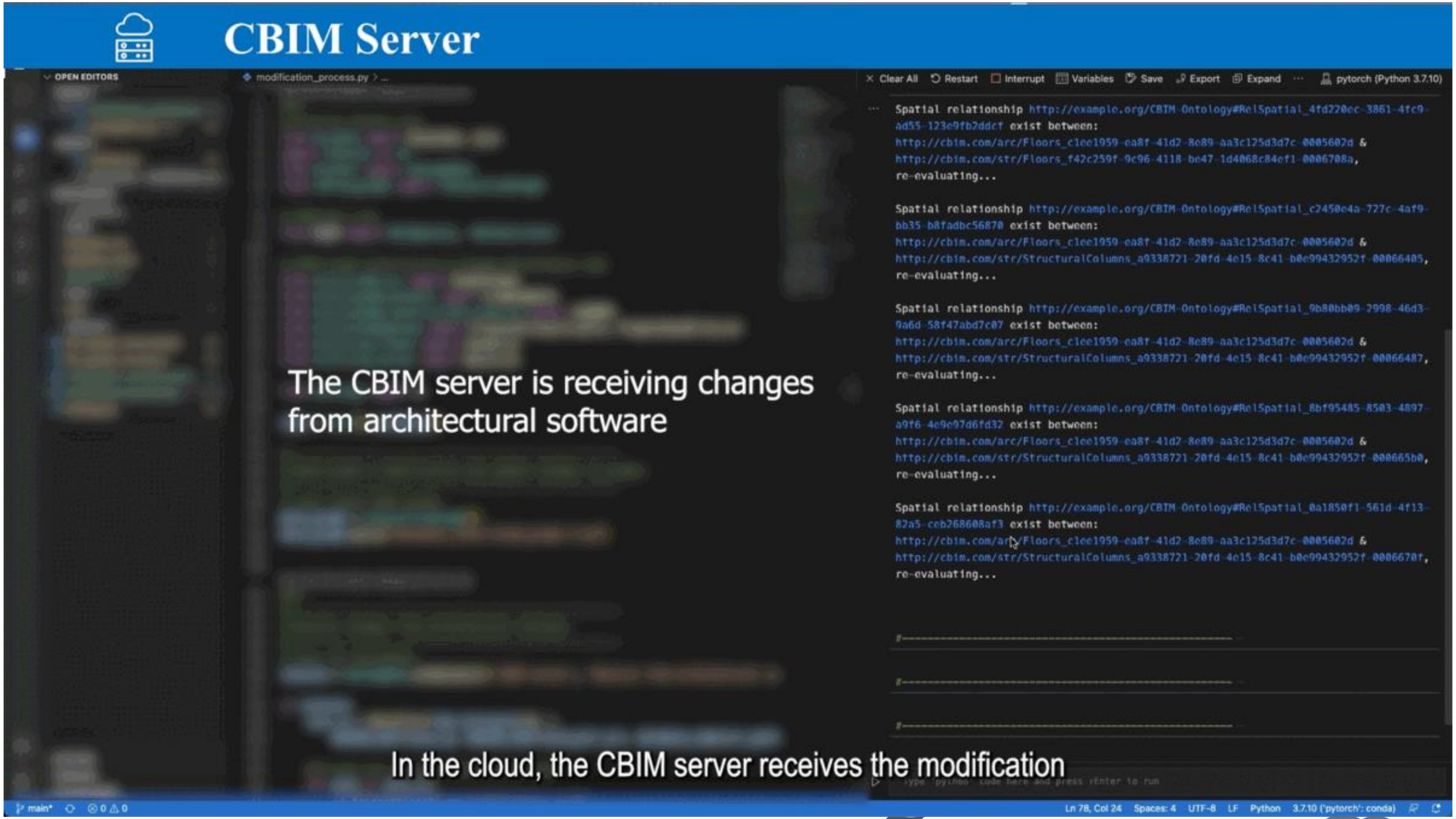
CBIM Meta-graph



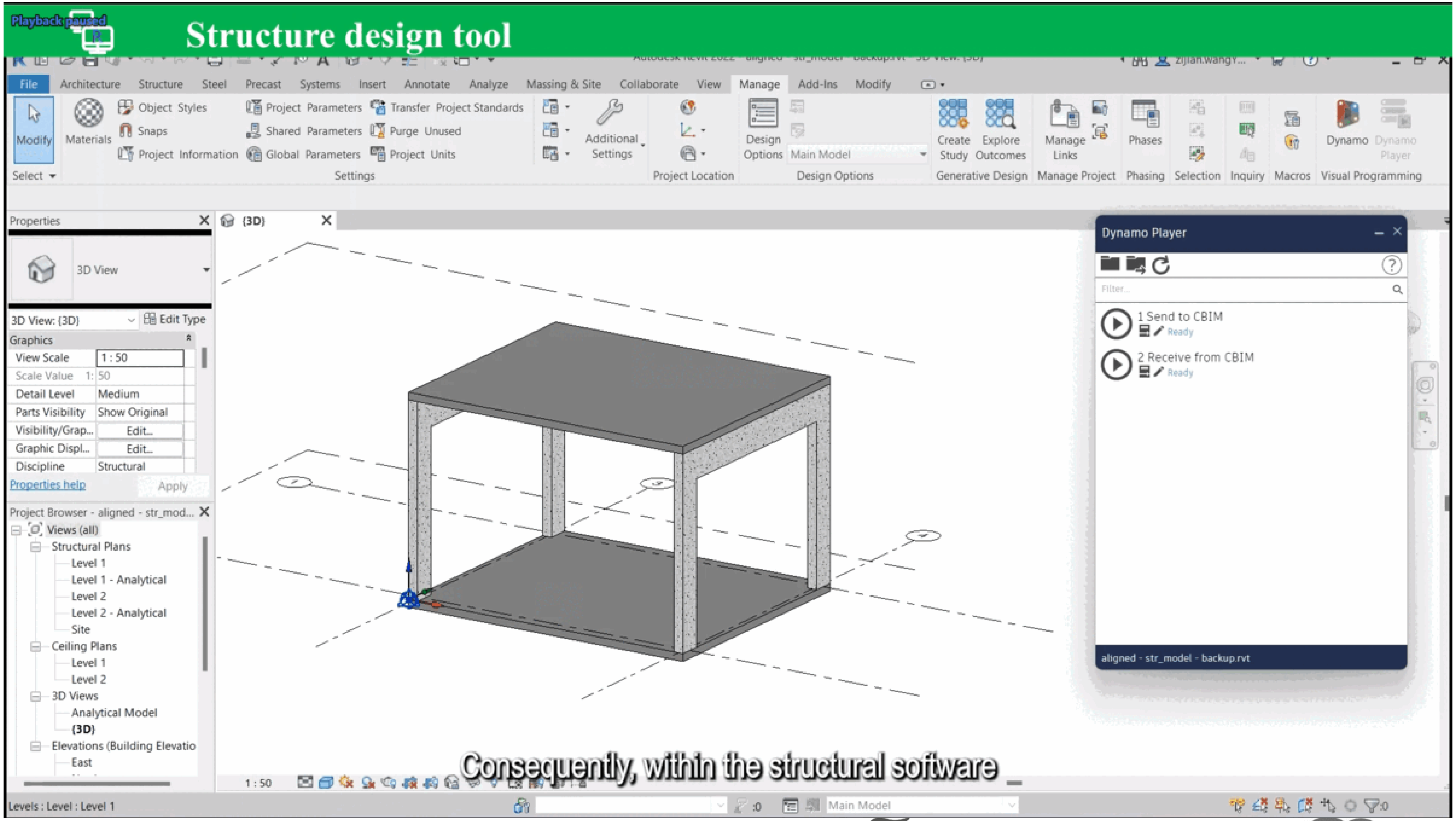
CBIM Prototype, Consistency Maintenance



CBIM Prototype, Consistency Maintenance

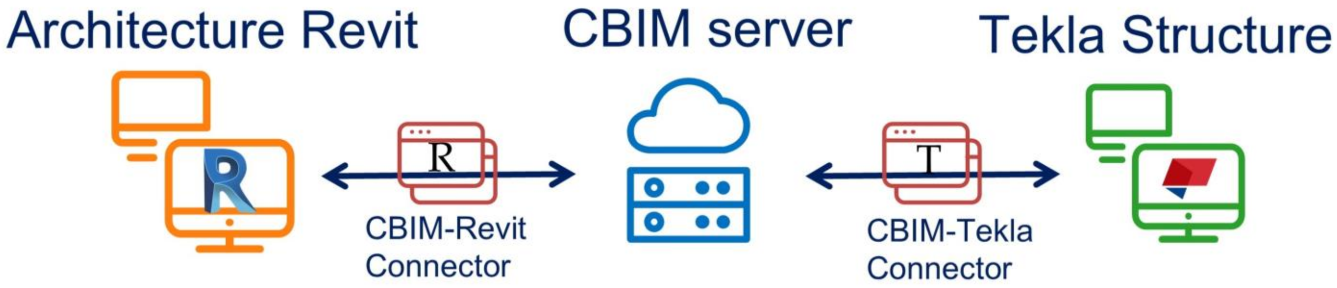


CBIM Prototype, Consistency Maintenance

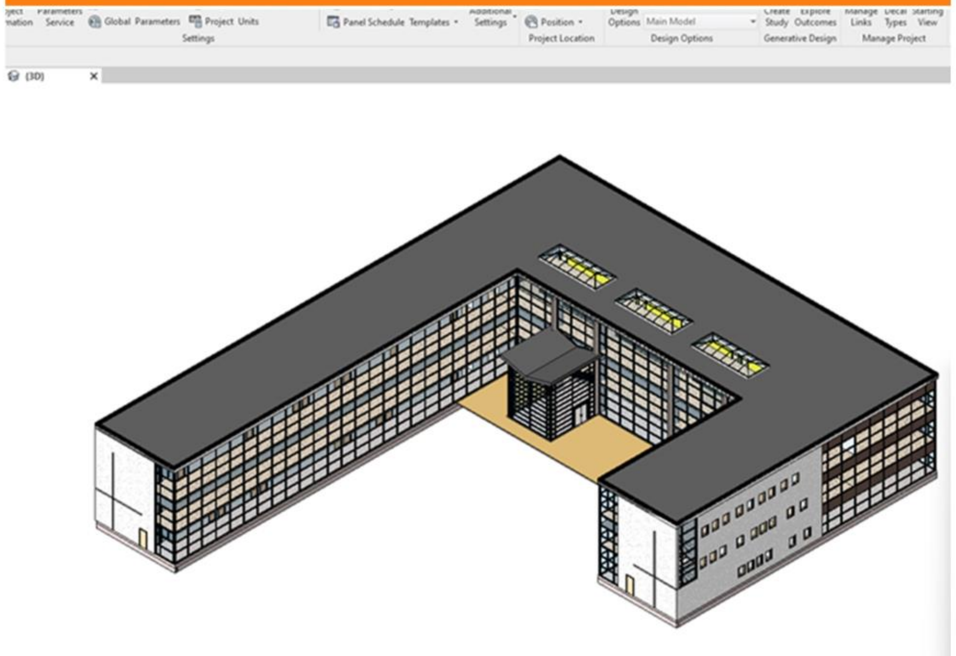


Prototype II: Interoperability & Across BIM Vendors

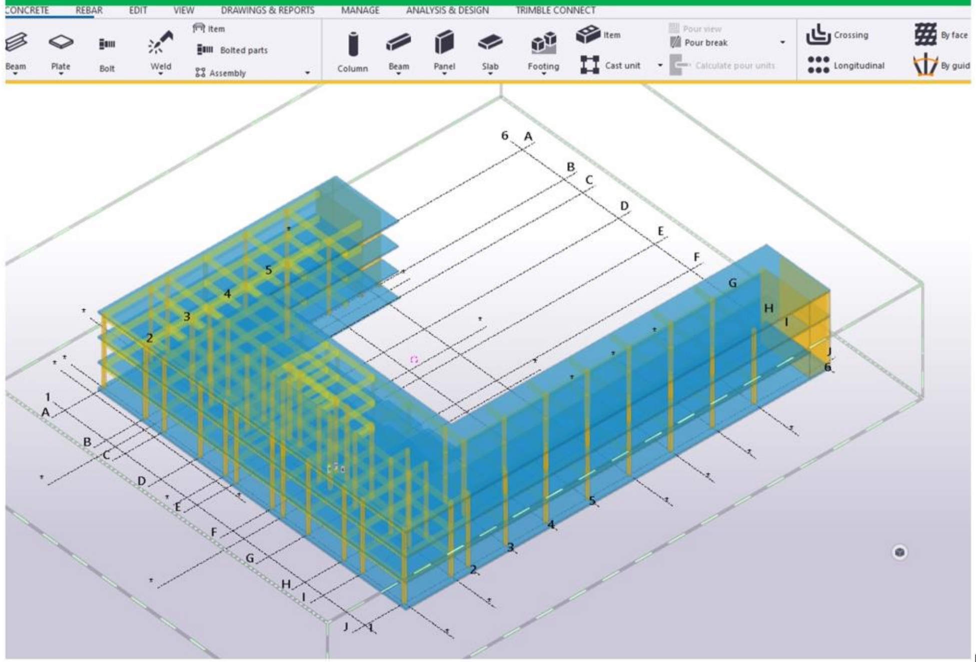
Propagating changes across Revit and Tekla software



(a) Architectural model in Revit

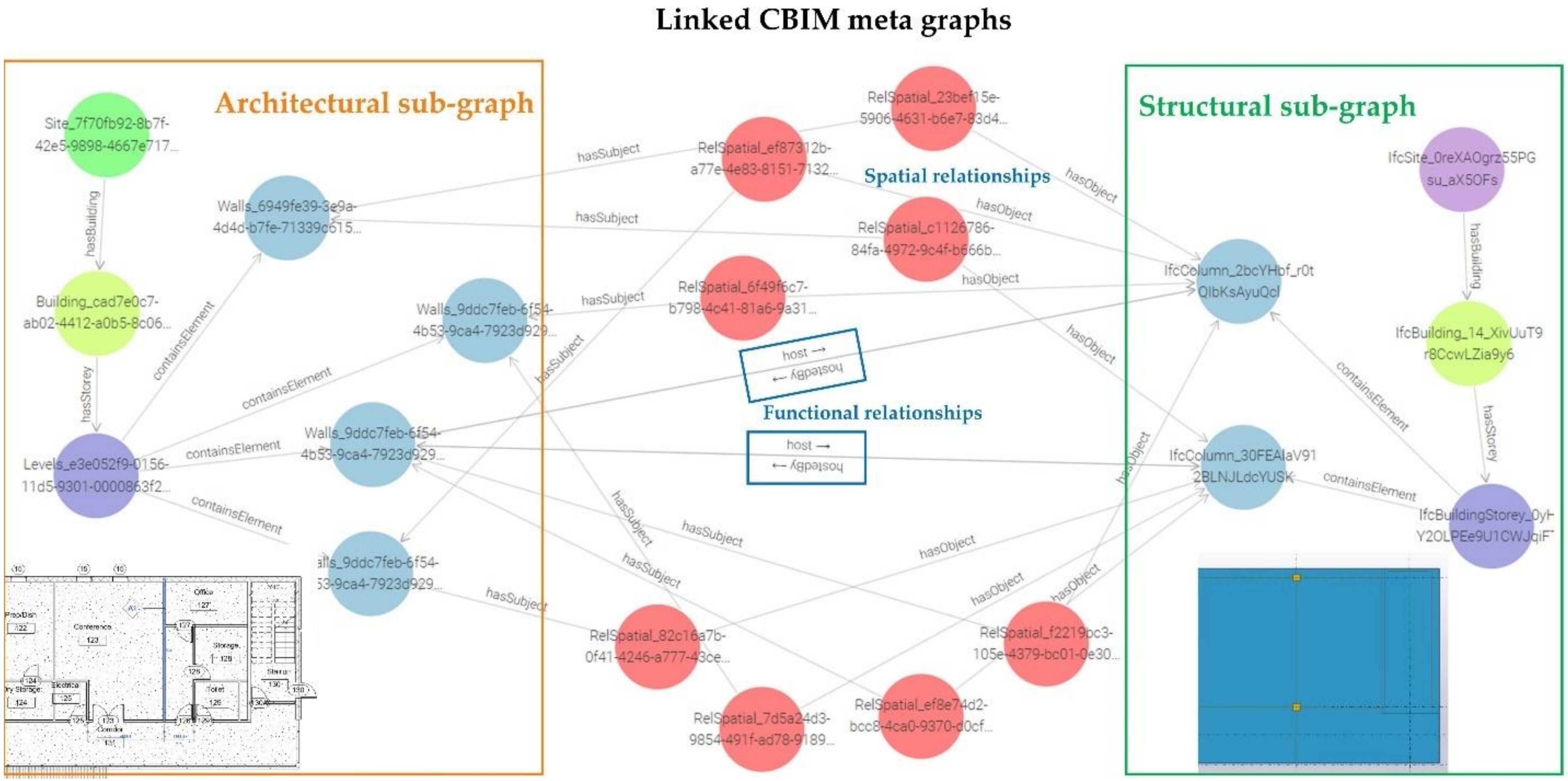


(b) Structural model in Tekla



Prototype II: Interoperability & Across BIM Vendors

Linked architectural and structural graphs on the CBIM cloud server

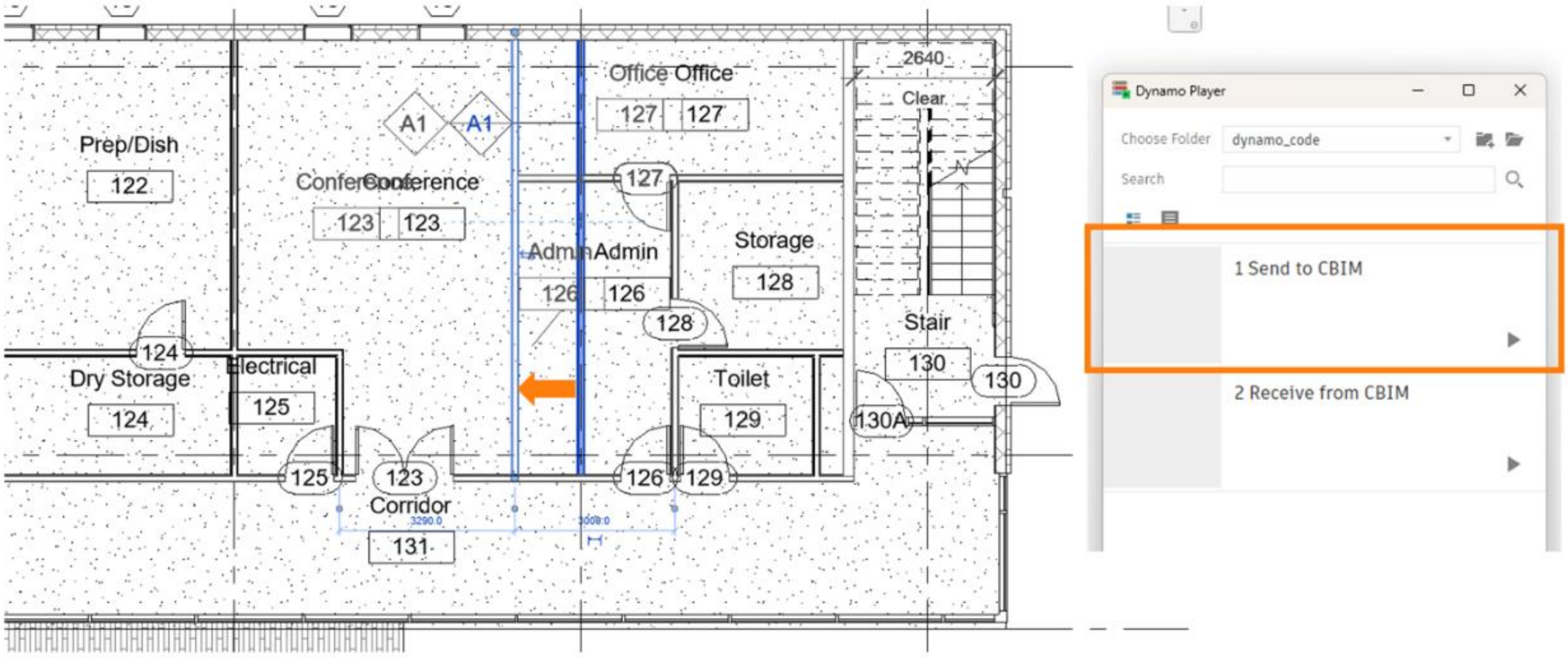


Exp1 Consistency | Exp2 Enrichment | Exp3 GNNs | Discussion Conclusion

TECHNION Israel Institute of Technology | VClab Seskin Virtual Construction Laboratory | CBIM

Prototype II: Interoperability & Across BIM Vendors

Architect adjusts the model and pushes into CBIM

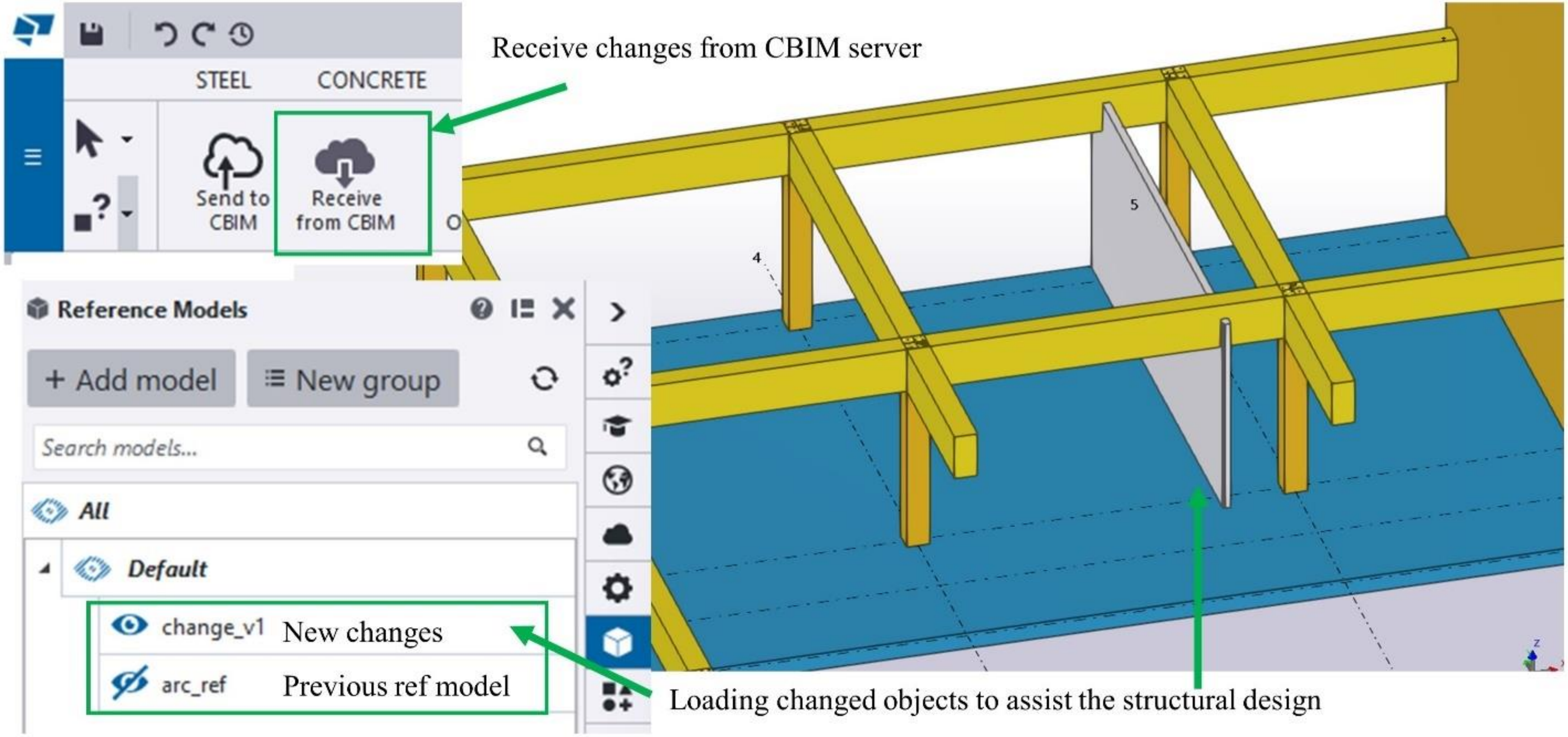


Exp1 Consistency | Exp2 Enrichment | Exp3 GNNs | Discussion Conclusion

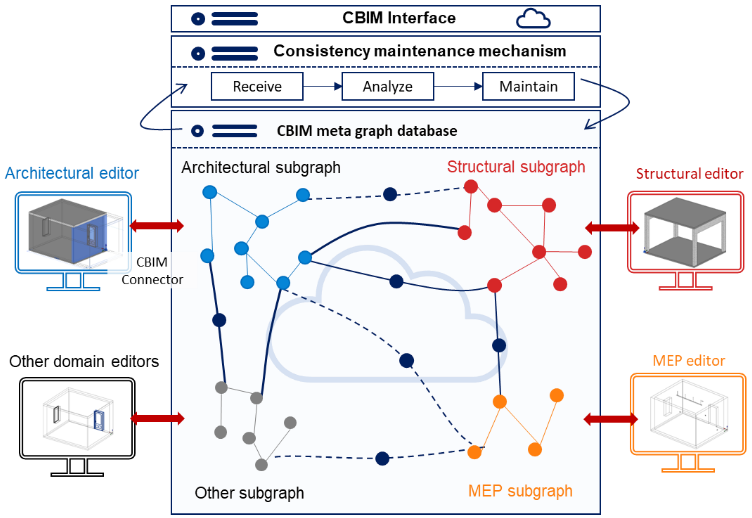
TECHNION Israel Institute of Technology · VClab Seskin Virtual Construction Laboratory · CBIM

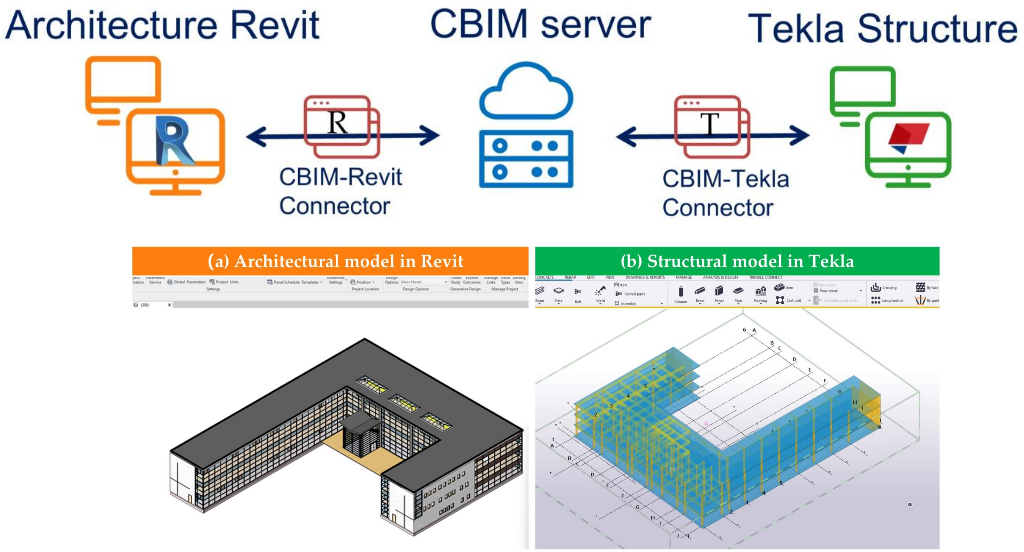
Prototype II: Interoperability & Across BIM Vendors

Structural engineer receives changed object reference from CBIM



Summary of Experiment 1





Graph-based theory of consistency maintenance

Representation of domain-specific graphs as sub-graphs, linking BIM sub-graphs by constraints and other inter-domain relationships, and a maintenance mechanism for identifying and resolving design conflicts.

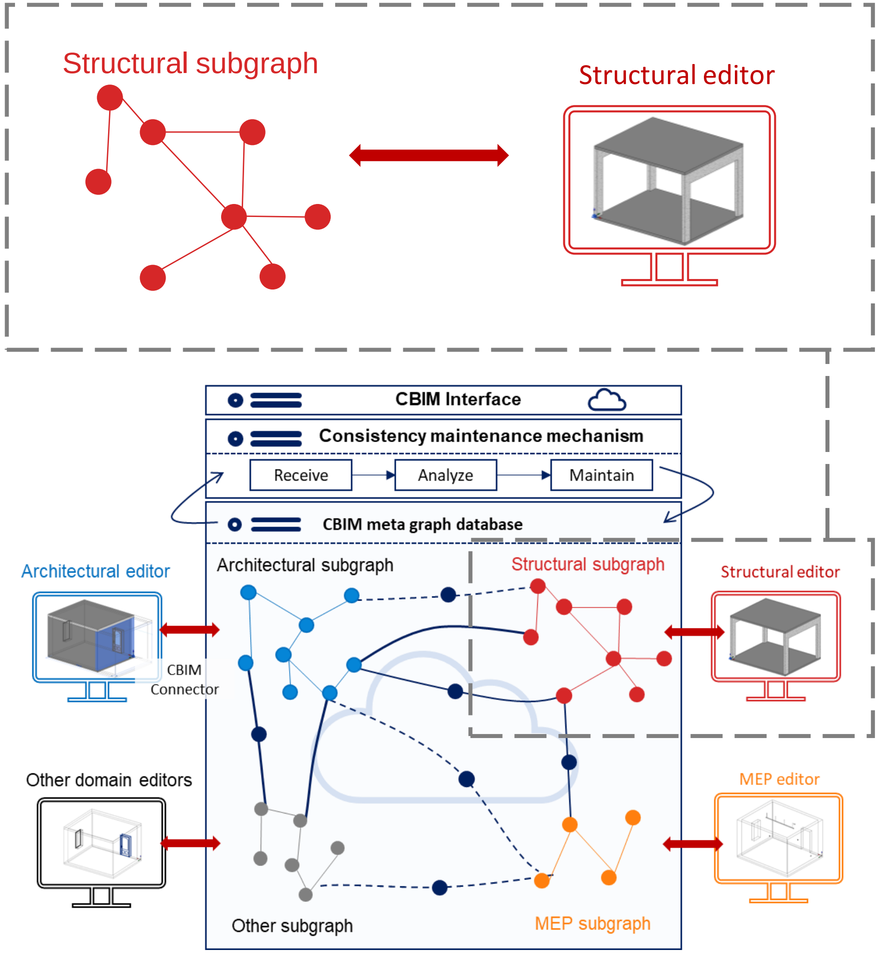
CBIM prototypes

- Involves an architectural, a structural tool and a cloud server
- Resolves transition conflicts automatically
- Offers geometry reference for assisting design

[1] Wang, Z., Ouyang, B. and Sacks, R., 2023. Graph-based inter-domain consistency maintenance for BIM models. Automation in Construction, 154, p.104979.
[2] Sacks, R.,Wang, Z., and Ouyang, B. 2023. Cloud BIM. US Patent (Reviewing).

Generic Semantic Enrichment

Motivation: Reduce the reliance on software and enrich semantics for interoperability



CBIM motivation:

- The platform requires complete and correct building information
- Data could be incomplete and with errors from design software

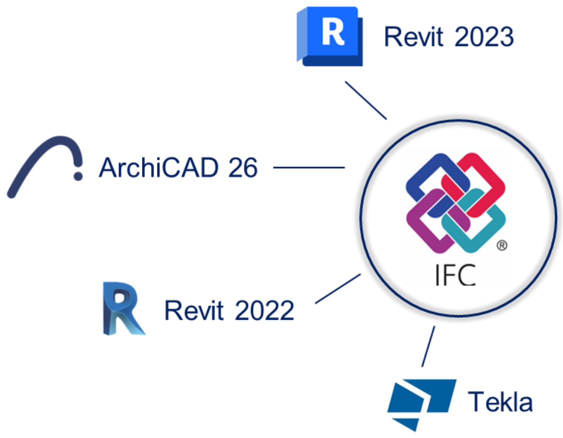
- Check and **ensure data quality** and **reduce the reliance** on software

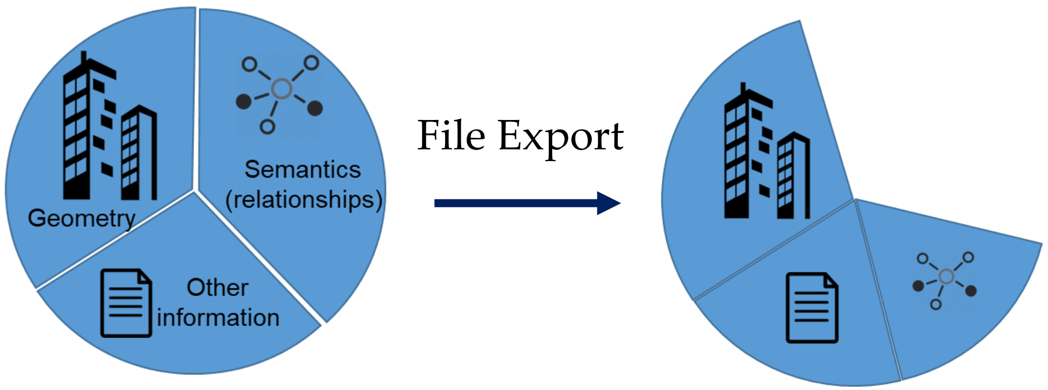
Generic Semantic Enrichment

Motivation: Reduce the reliance on software and enrich semantics for interoperability

Interoperability motivation:

- The file-based approach is the prevailing method for design exchange
- Information loss when exporting models as files





Information in design tools

Information in files

Why loss?

1) Data schemas are not matched
2) Vendors not to share all data

Exp1 Consistency | Exp2 Enrichment | Exp3 GNNs | Discussion Conclusion

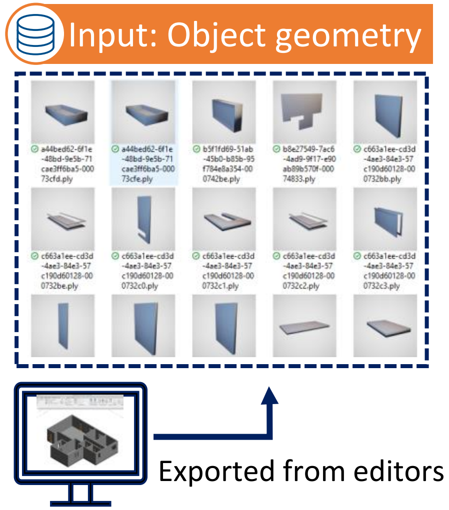
TECHNION Israel Institute of Technology

VClab Seskin Virtual Construction Laboratory

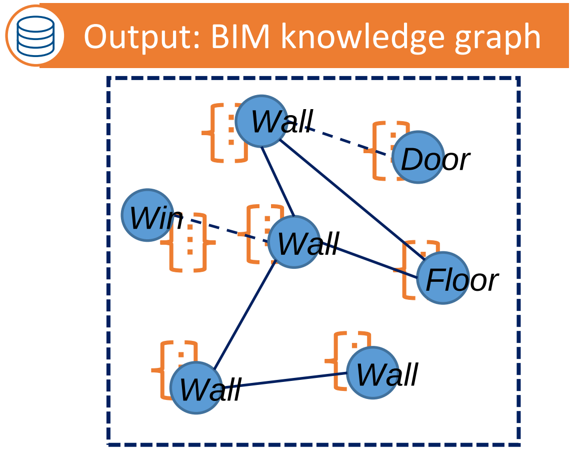
CBIM

Generic Semantic Enrichment

Explore a new approach to enrich semantics from object geometries and organize results into a graph



Semantic Enrichment



Semantic enrichment (SE) aims to infer implicit information based on existing data and supplement the results back to models [1]

Why object geometry?

1) Fundamental data of 3D solid design

2) Tools support export of solid objects into accessible and generic file formats

Why graph representation?

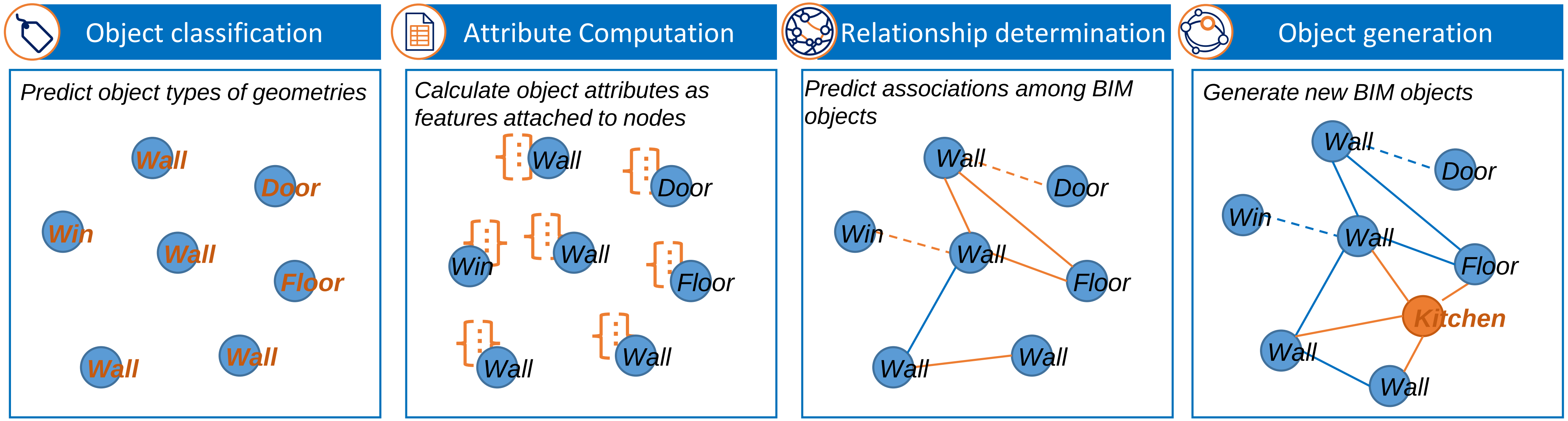
1) Can flexibly represent information, especially for relationships

2) Supports downstream applications

[1] Belsky, M., Sacks, R. and Brilakis, I., 2016. Semantic enrichment for building information modeling. *Computer-Aided Civil and Infrastructure Engineering*, *31*(4), pp.261-274.

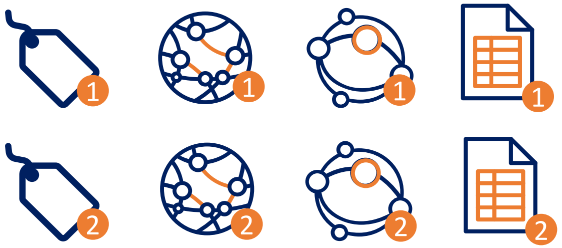
Framework of Generic Semantic Enrichment

(a) Semantic Enrichment Tasks



Toolbox

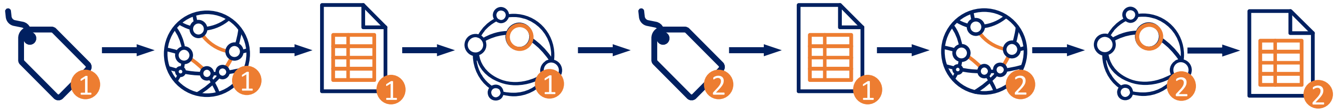
Tools are developed by AI methods for tackling tasks Each task can have many specific tools



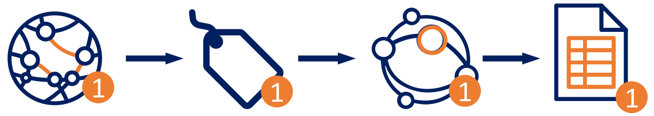
stands for the developed tools ......

(b) Process control Mechanism

Process 1



Process 2 *adopts part of tools to infer necessary required information*

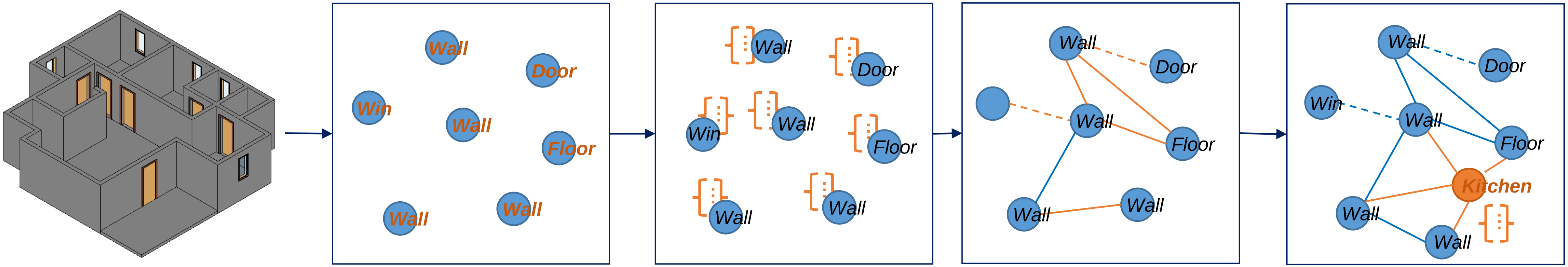


Wang, Z., Sacks, R., Ouyang, B., Ying, H. and Borrmann, A., 2023. A Framework for Generic Semantic Enrichment of BIM models. Journal of Computing in Civil Engineering (In press).

TECHNION Israel Institute of Technology VClab SeskinVirtual Construction Laboratory CBIM

Validation of Generic Semantic Enrichment

Process	Step 1
Task	Object classification
Input	Geometry
Output	Object types: *wall, slab, window, door*
Method	Machine learning



Exp1 Consistency | Exp2 Enrichment | Exp3 GNNs | Discussion Conclusion

TECHNION Israel Institute of Technology
VClab
SeskinVirtual Construction Laboratory
CBIM

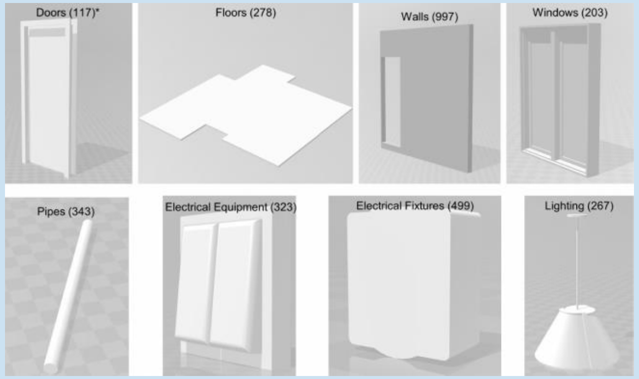
Validation of Generic Semantic Enrichment

ML object classification

Method: Machine learning

Input: Pure object geometry

Output: Eight object types



	Algorithm	Test Acc.
1	Logistic regression	24.02%
2	Support vector machine (SVM)	46.85%
3	K-nearest neighbors (KNN)	88.89%
4	Gaussian naive bayes	81.78%
5	Perceptron	58.56%
6	Linear support vector classification	69.77%
7	Stochastic gradient descent (SGD)	32.23%
8	Decision tree	99.80%
9	Random forest	99.90%

Rule-based relationship determination

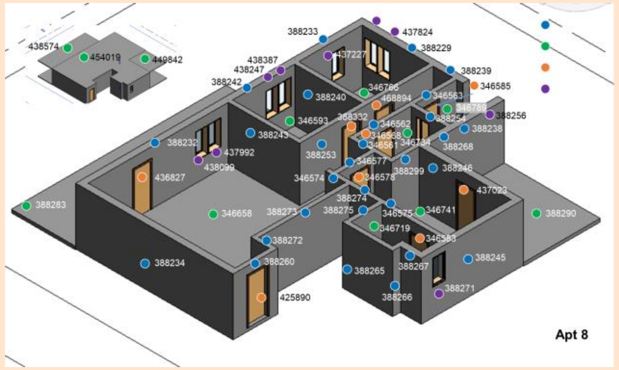
Method: Rule-based algorithm

Input: Pure object geometry

Output: Two object relationships

(cbim:adjacentTo, cbim:hosting/hosted)

Fig. Test apartment design



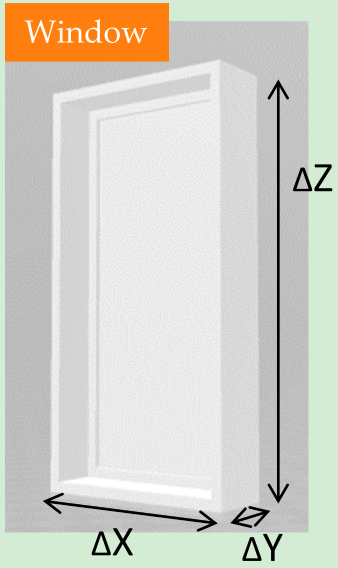
	Evaluation metrics	Value
1	Accuracy	99%
2	Precision	0.97
3	Recall	0.99
4	F1	0.98
5	Processing time (s)	308
6	Num. of relationships	168
7	Time/Rel (s)	1.8

Geometry attribute computation

Method: Geometry computation

Input: 1) Geometry, 2) Object types

Output: Nice attributes (area, volume, height, width, perimeter, thickness, slope, length, and depth)



ΔX ⇨ Length

ΔY ⇨ Width

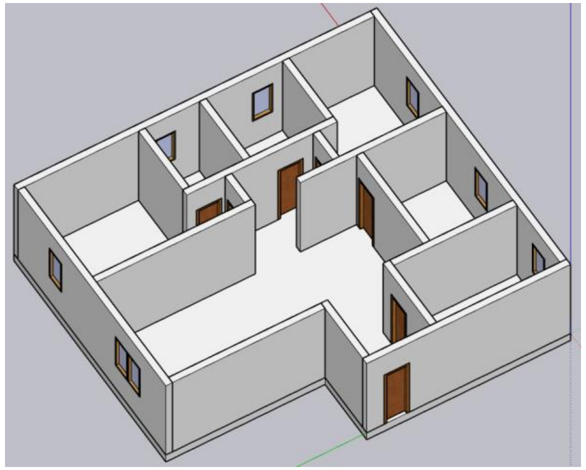
ΔZ ⇨ Height

Validation of Generic Semantic Enrichment

Application 1: Enrich pure geometry into BIM models

3D Geometry Design Software

SketchUp Blender AutoCAD 3D
……



SketchUp 2023

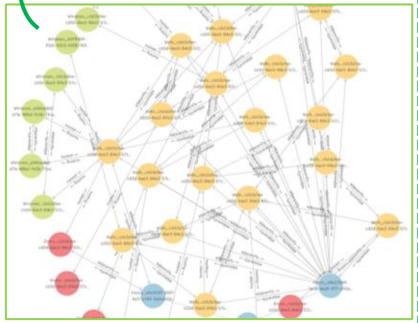
Geometry exporter

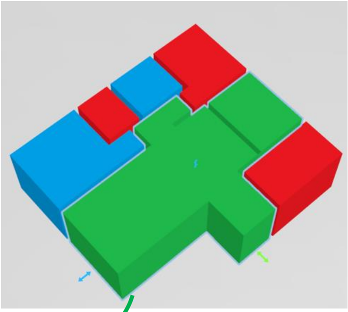
Object Geometries

Semantic Enrichment

Generated Graph-based CDE

Core graph layer:
BIM objects, relationships and attributes





Extension geometry layer:
Generated space geometries, original geometries

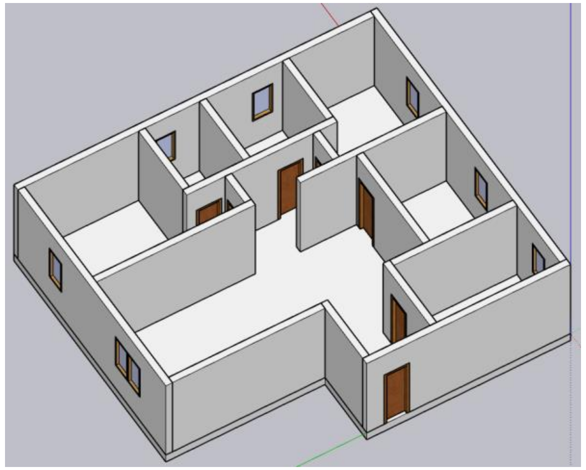
Validation of Generic Semantic Enrichment

Application 1: Enrich pure geometry into BIM models

3D Geometry Design Software

SketchUp Blender AutoCAD 3D

……

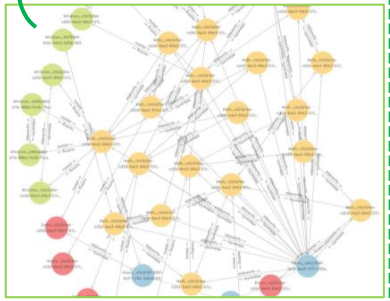


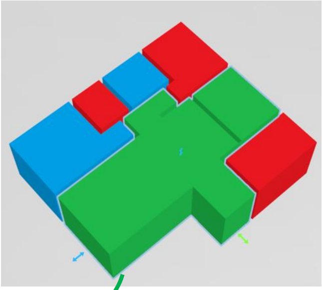
SketchUp 2023

…

Generated Graph-based CDE

Core graph layer:
BIM objects, relationships and attributes



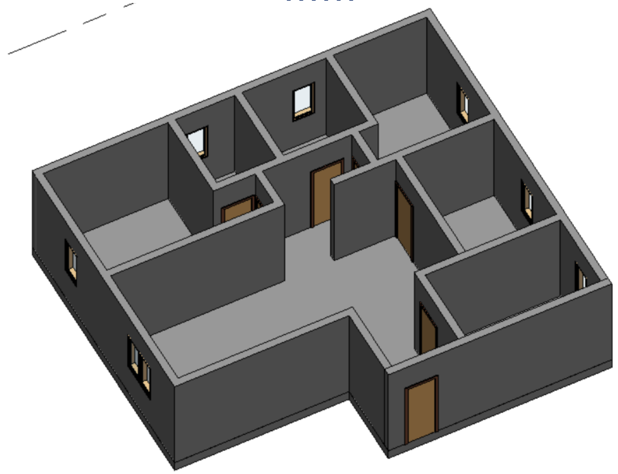


Extension geometry layer:
Generated space geometries, original geometries

BIM Modeling Software

Revit ArchiCAD Tekla

……



Reconstructed BIM model in Revit 2022

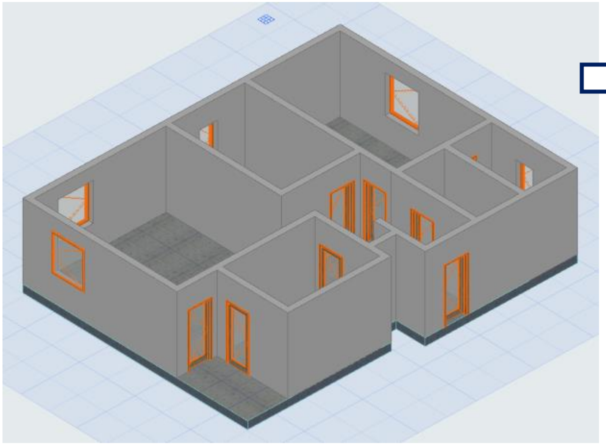
Reconstructor

Validation of Generic Semantic Enrichment

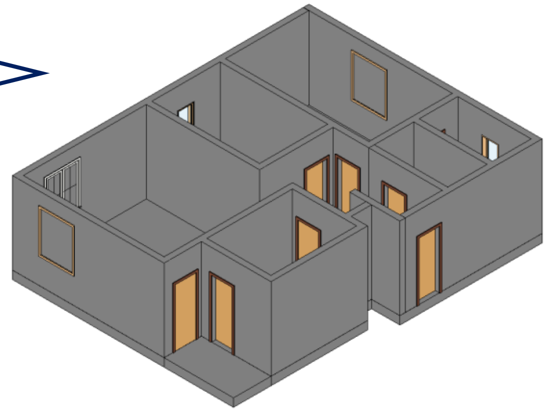
Application 2: Enhance BIM interoperability

BIM tool ***A*** → 1 *Geometry export* → Geometries → 2 *Semantic enrichment* → Graph CDE → 3 *Model reconstruct* → BIM tool ***B***

Original model in ArchiCAD 26



Reconstructed model in Revit 2023



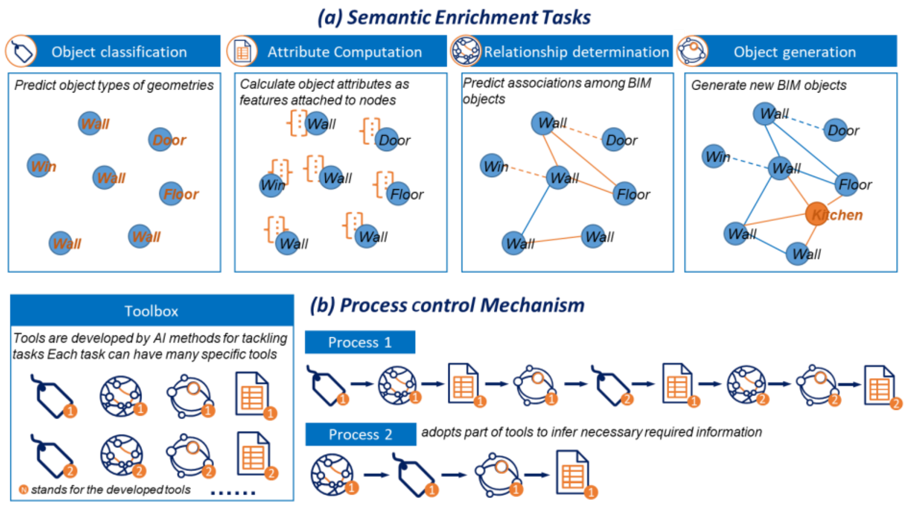
Objects and properties are consistent

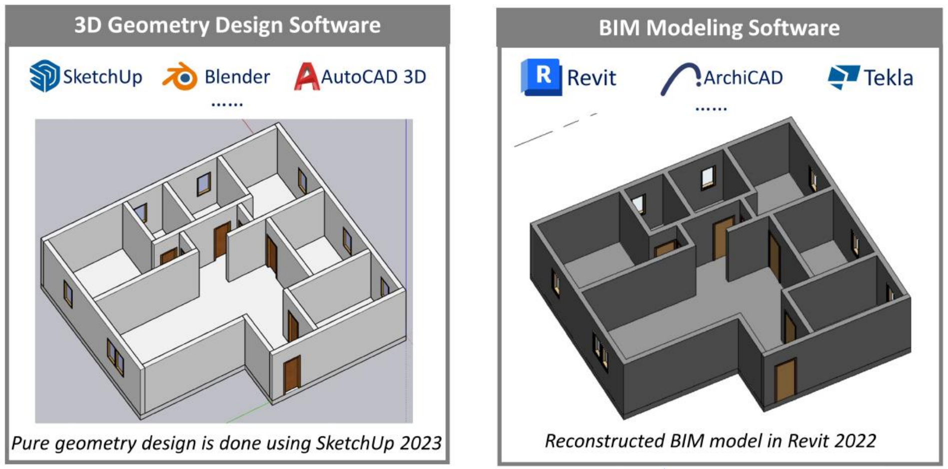
Revit 2023 → Revit 2022

Exp1 Consistency | Exp2 Enrichment | Exp3 GNNs | Discussion Conclusion

TECHNION Israel Institute of Technology | VClab Seskin Virtual Construction Laboratory | CBIM

Summary of Experiment 2





Framework of Generic Semantic enrichment

- Includes four fundamental SE tasks under the context of graphs
- A process control mechanism to execute SE tools in sequence for enrichment

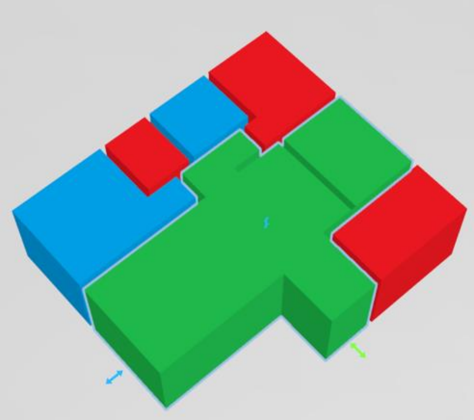
Applications for enrichment and interoperability

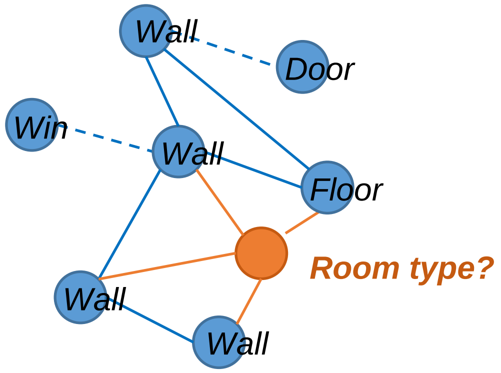
- Take pure geometry as input to enrich BIM models
- Bridge BIM software without the reliance on software proprietary schema

Wang, Z., Sacks, R., Ouyang, B., Ying, H. and Borrmann, A., 2023. A Framework for Generic Semantic Enrichment of BIM models. Journal of Computing in Civil Engineering (In press).

Applying GNNs to BIM graphs

Motivations of adopting GNNs to predict space types





Importance of space types

- Space geometry can be generated by tools and algorithms, while space types still require users to label manually
- Space information is necessary for simulation and quantity take-offs.

Potential of BIM graphs and GNNs

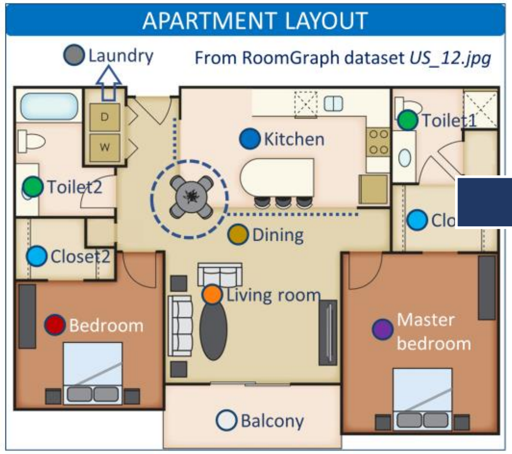
- BIM models are compiled as graphs which capture the object topology relationships
- GNNs have shown potential in other domains, like classifying proteins, recommending friends

Can we apply GNNs to BIM graphs? What is its performance?

Applying GNNs to BIM graphs

Constructed a novel BIM graph dataset

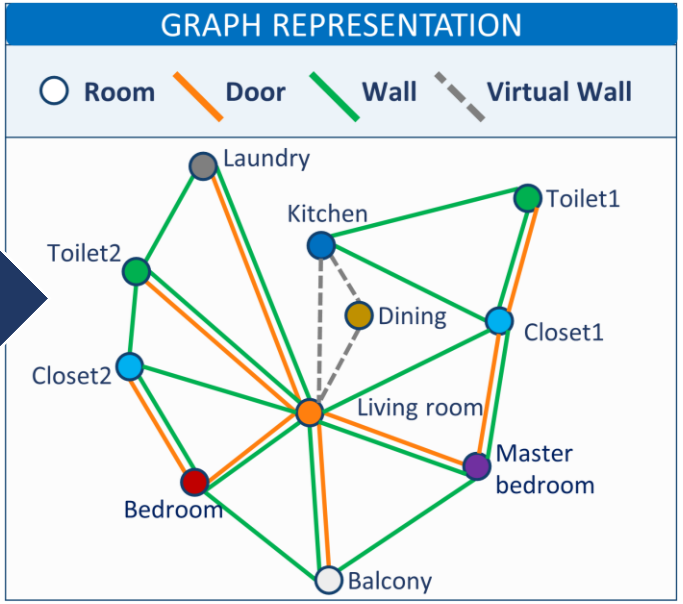
- Collected 224 apartment designs from three countries
- Manually labeled them in a matrix and converted them into graphs
  - Door, wall, virtual wall connections
- Designed both node and edge features based on graph topology



SELF-DESIGNED LABELING MATRIX

From \ To	kitchen	dining	living	bed1	bed2	bed3	masbed	mastoil	toil1	clos1	clos2	bal1	bal2	laun
kitchen	x	3	3	-	-	-	-	2	-	2	-	-	-	-
dining		x	3	-	-	-	-	-	-	-	-	-	-	-
living			x	1	-	-	1	-	1	2	2	1	-	1
bed1				x	-	-	-	-	-	-	1	2	-	-
bed2					x	-	-	-	-	-	-	-	-	-
bed3						x	-	-	-	-	-	-	-	
masbed							x	-	-	3	-	2	-	-
mastoil								x	-	1	-	-	-	-
toil1									x	-	2	-	-	2
clos1										x	-	-	-	-
clos2											x	-	-	-
bal1												x	-	-
bal2													x	-
laun														x

Legend
- x Same room
- \- No connection
- 1 Door connection
- 2 Wall connection
- 3 Virtual wall connection

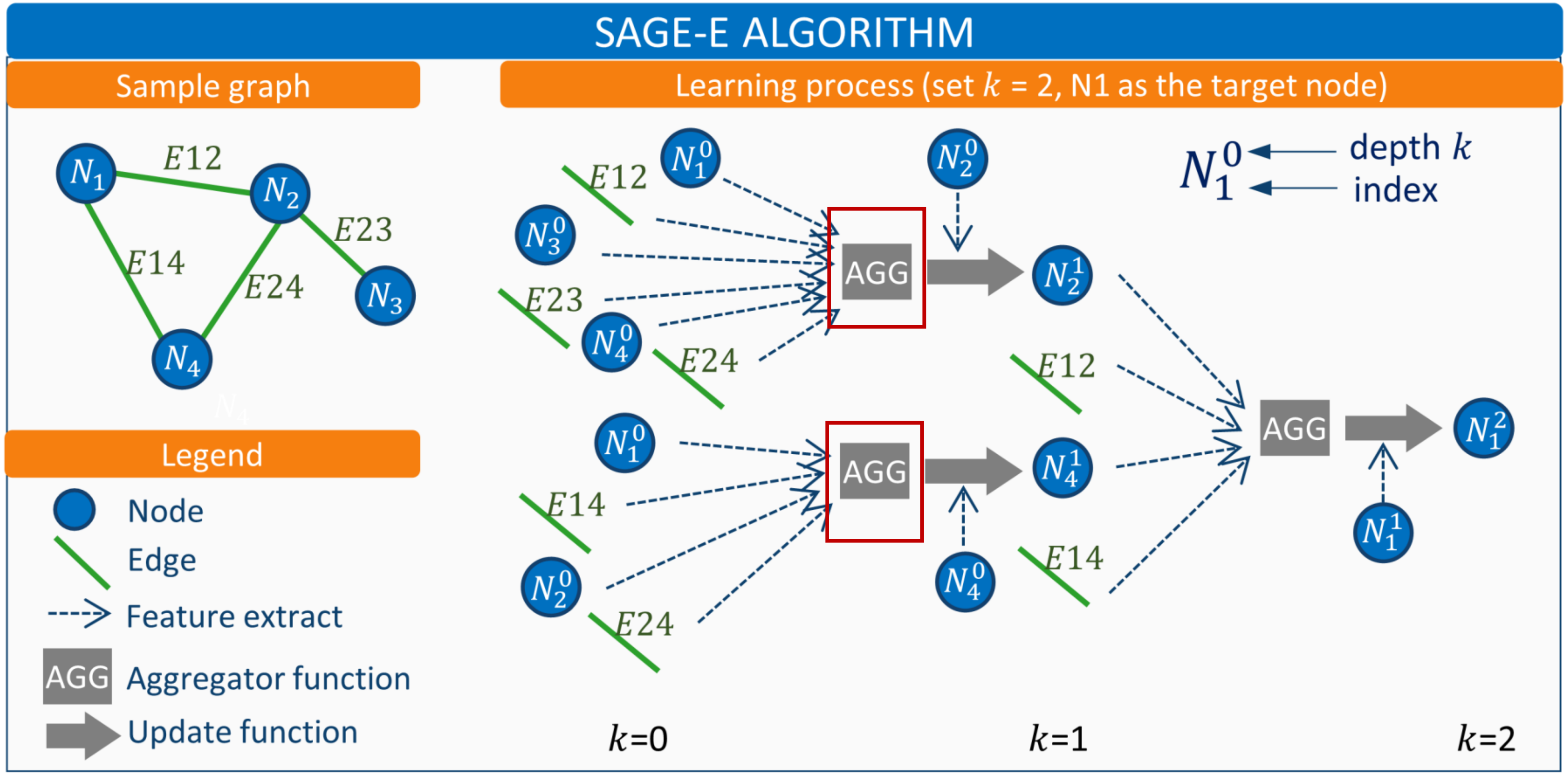


Wang, Z., Sacks, R. and Yeung, T., 2022. Exploring graph neural networks for semantic enrichment: Room type classification. Automation in Construction, 134, p.104039.

Applying GNNs to BIM graphs

Improved a GNN algorithm

- Improved the aggregator function to leverage both node and edge features, named SAGE-E
- Training/validation, test = 80:20



Applying GNNs to BIM graphs

Results show that SAGE-E owns the best performance

Model	GraphSAGE	SAGE-E	Multilayer perceptron (MLP)	Decision tree
Accuracy	70.84%	79.28%	63.46%	65.38%
F1	0.71	0.79	0.61	0.61

Confusion Matrix

GraphSAGE (Actual / Predicted)

	KIV	LIV	DIN	BED	MBE	TOI	CLO	BAL	LAU
KIV	62%	0	31%	2%	0	2%	0	0	0
LIV	0	96%	4%	0	0	0	0	0	0
DIN	20%	0	80%	0	0	0	0	0	0
BED	1%	0	0	72%	9%	16%	0	0	2%
MBE	0	0	0	19%	78%	3%	0	0	0
TOI	0	0	0	31%	1%	53%	9%	0	6%
CLO	4%	0	0	4%	0	59%	33%	0	0
BAL	0	0	0	0	0	0	0	100%	0
LAU	0	0	0	20%	0	20%	0	0	60%

SAGE-E (Actual / Predicted)

	KIV	LIV	DIN	BED	MBE	TOI	CLO	BAL	LAU
KIV	82%	0	13%	0	0	0	0	0	4%
LIV	0	100%	0	0	0	0	0	0	0
DIN	23%	0	77%	0	0	0	0	0	0
BED	0	0	0	86%	11%	1%	1%	0	0
MBE	0	0	0	13%	78%	6%	3%	0	0
TOI	0	0	0	29%	3%	60%	6%	0	3%
CLO	0	0	0	11%	0	26%	63%	0	0
BAL	0	0	0	0	0	0	0	100%	0
LAU	0	0	0	17%	0	20%	3%	0	60%

Multilayer perceptron (MLP) (Actual / Predicted)

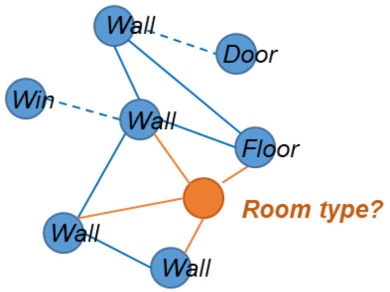
	KIV	LIV	DIN	BED	MBE	TOI	CLO	BAL	LAU
KIV	70%	22%	0	2%	6%	0	0	0	0
LIV	25%	70%	5%	0	0	0	0	0	0
DIN	2%	0	96%	0	2%	0	0	0	0
BED	0	0	0	51%	7%	37%	2%	0	3%
MBE	0	0	0	0	96%	0	0	0	4%
TOI	0	0	0	40%	5%	48%	3%	0	5%
CLO	0	0	0	33%	0	53%	7%	0	7%
BAL	0	0	0	0	2%	0	0	98%	0
LAU	0	0	0	40%	0	37%	3%	0	20%

Decision tree (Actual / Predicted)

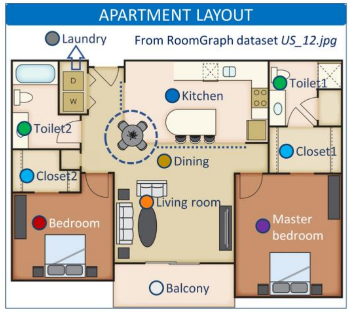
	KIV	LIV	DIN	BED	MBE	TOI	CLO	BAL	LAU
KIV	80%	12%	0	6%	2%	0	0	0	0
LIV	40%	55%	5%	0	0	0	0	0	0
DIN	2%	0	96%	0	2%	0	0	0	0
BED	0	0	0	58%	9%	28%	0	0	5%
MBE	0	0	0	4%	93%	4%	0	0	0
TOI	0	0	0	40%	2%	45%	0	0	14%
CLO	0	0	0	20%	0	67%	0	0	13%
BAL	0	0	0	0	0	0	0	100%	0
LAU	0	0	0	26%	3%	34%	0	0	37%

- SAGE-E has the highest accuracy, 79.28%, and the highest F1 score (0.79)
- SAGE-E has more accurate and balanced prediction ability compared with others

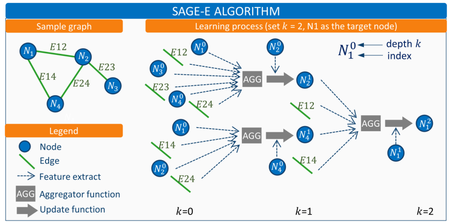
Summary of Experiment 3



- **A novel research approach** that represents BIM models as graphs and applies GNNs to graphs directly for semantic enrichment.



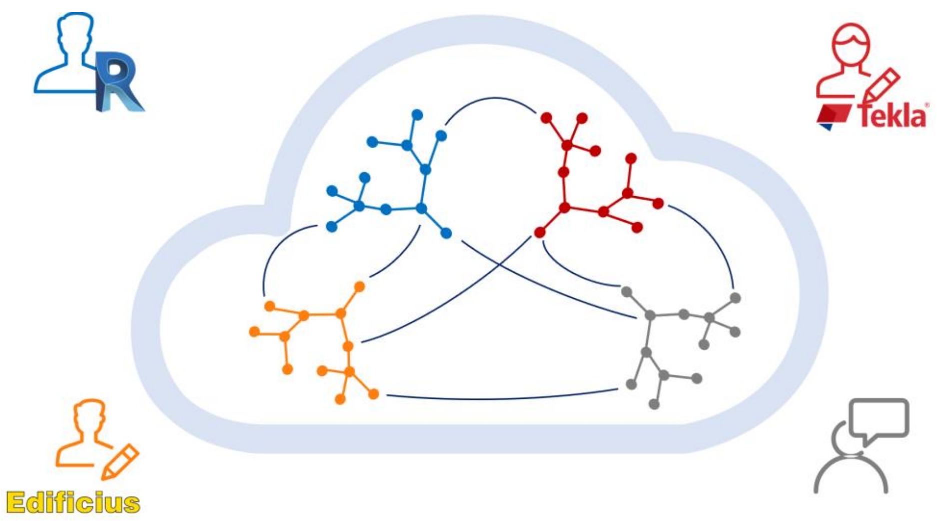
- **A BIM graph dataset**, RoomGraph, for classifying room types in residential apartments.



- **A GNN algorithm** to compute both edge and node features, named SAGE-E. The improved algorithm achieved better accuracy and F1 scores when compared with other state-of-the-art algorithms.

Wang, Z., Sacks, R. and Yeung, T., 2022. Exploring graph neural networks for semantic enrichment: Room type classification. Automation in Construction, 134, p.104039.

Summary



- **Federated** nature of the AEC industry
- Existing **file-based** workflow results in many problems
- The industry desires **close and interoperable collaboration** across disciplines and platforms.

1. Proposed **a graph-based approach** to represent and link building information for supporting intelligent applications.
2. Developed **CBIM prototypes** to validate the feasibility of the graph concept.
3. Designed a **generic semantic enrichment** framework to enhance BIM semantics and improve interoperability.
4. Explored **GNNs on BIM graphs** to leverage topology for semantic enrichment.

Comparison with the-state-of-the-art

The graph-based approach and the CBIM prototype

- In contrast to commercial BIM cloud platforms, we illustrate the functionality of maintaining design conflicts on linked BIM graphs rather than files.
- It facilitates coordination among participants and provides suggestions to improve designs, promoting a more collaborative, efficient, and intelligent workflow.
- Compared to existing research, we propose the framework and architecture of the CBIM platform. This research stands as a pioneering effort in developing prototypes to validate the BIM graph idea.

Generic semantic enrichment and GNNs

- Distinguishing from existing research, we define the fundamental tasks of graph semantic enrichment and illustrate the feasibility of accomplishing these tasks by constructing AI tools.
- We present a novel approach to address the interoperability challenge by employing pure object geometries.
- We construct a BIM graph dataset and improve the GNN algorithm to leverage edge features with better performance, open for public use [1]

[1] https://github.com/ZijianWang-ZW/SAGE-E

Limitations

The graph-based approach and the CBIM prototype

- The across-domain consistency maintenance illustrates only one possible application on the linked BIM graphs.
- The CBIM prototype can only resolve the transition conflicts, and the scope of automatic maintenance is narrow.
- The CBIM prototype develops only one BIM software plug-in and a local server.

Generic semantic enrichment and GNNs

- The developed tools of generic semantic enrichment are limited to the residential apartment. The scope of these tools is narrow and should be extended to wider scenarios.
- The performance of the developed tools of generic semantic enrichment can be further improved from the perspectives of accuracy, efficiency, and robustness.
- In the GNN experiment, the graph generation process is manual.
- The GNN experiment takes only the graph topology features and achieves an accuracy of 79%. More features should be considered and better performance is expected.

Contribution to knowledge

Learn from experiments

- Linking BIM graphs with design intent constraints enables intelligent BIM applications.
- Generic semantic enrichment can resolve the interoperability issues.
- Graph neural networks can be applied to BIM graphs for enriching semantics.

Learn about graphs

- Graphs are suitable to host and integrate object-based heterogeneous built environment data, representing object relationships explicitly.
- Graphs can enable graph learning for both generating new semantics and supporting intelligent applications.

Future work

Industry

- Implement CBIM plug-ins for common BIM design tools, such as Revit, Rhino, Tekla, etc.
- Deploy CBIM servers in commercial cloud graph platforms

Research

△ • Investigate the potential of designing the CBIM ontology to encapsulate design intent and constraint relationships of objects within and across domains

△ • Examine the feasibility and performance of using graph learning to generate multi-class across-domain relationships

- Study learning-based algorithms to propose solutions for resolving conflicts automatically
- Expanding the scope and the scenario of generic semantic enrichment to develop more accurate and robust enrichment tools and methods
- Explore the usage of BIM graphs, and develop more intelligent applications on the linked BIM graphs, especially integrating large natural language processing (NLP) models to communicate with users directly and execute actions automatically

Conclusion

This is exploratory research – validating the feasibility and possibility

The start of the beginning

Publication records

Journal Papers

1. **Wang, Z.**, Sacks, R. and Yeung, T., 2022. Exploring graph neural networks for semantic enrichment: Room type classification. Automation in Construction, 134, p.104039.

2. **Wang, Z.**, Ouyang, B. and Sacks, R., 2023. Graph-Based Inter-domain Consistency Maintenance for BIM Models. Automation in Construction, 154, p.104979.

3. **Wang, Z.**, Sacks, R., Ouyang, B., Ying, H. and Borrmann, A., 2024. A Framework for Generic Semantic Enrichment of BIM Models. Journal of Computing in Civil Engineering, 38(1), p.04023038.

4. Sacks, R., **Wang, Z.**, Ouyang, B., Utkucu, D. and Chen, S., 2022. Toward artificially intelligent cloud-based building information modelling for collaborative multidisciplinary design. Advanced Engineering Informatics, 53, p.101711.

Conference Papers

5. **Wang, Z.**, Yeung, T., Sacks, R. and Su, Z., 2021, October. Room Type Classification for Semantic Enrichment of Building Information Modeling Using Graph Neural Networks. In Proc. of the Conference CIB W78 (Vol. 2021, pp. 11-15).

6. **Wang, Z.**, Ying, H., Sacks, R. and Borrmann, A., 2023. CBIM: A Graph-based Approach to Enhance Interoperability Using Semantic Enrichment. In EG-ICE 2023 (In press).

7. **Wang, Z.**, Ouyang, B. and Sacks, R., 2023. CBIM: object-level cloud collaboration platform for supporting across-domain asynchronous design. In EC3 & CIB W78 2023 (In press).

8. Ouyang, B., **Wang, Z.** and Sacks, R., 2023. Semantic enrichment of object associations across federated BIM semantic graphs in a common data environment. In ECPPM 2022-eWork and eBusiness in Architecture, Engineering and Construction 2022 (pp. 591-598).

Patents

9. Sacks, R., **Wang, Z.**, and Ouyang, B. 2023. Cloud BIM. US Patent (Provisional - Under Review).

Thank you

Q & A

https://zijianwang-zw.github.io/

Acknowledgement

The work is part of the Cloud-based Building Information Modelling (CBIM) project, a European Training Network. The CBIM project receives funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant with agreement No 860555.