Enhancing Collaborative Practices in AEC through Multi-Scalar Modelling Methodologies

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InnoChain ETN Network
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Design-to-Production (Switzerland): Fabian Scheurer

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Robert Otani - Principal & Chief Technology Officer, Thornton Tomasetti, New York, USA
Daniel Lee - Associate Professor, Institute of Architecture and Technology, KADK

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- Reading material (thesis abstract & pre-defence version)
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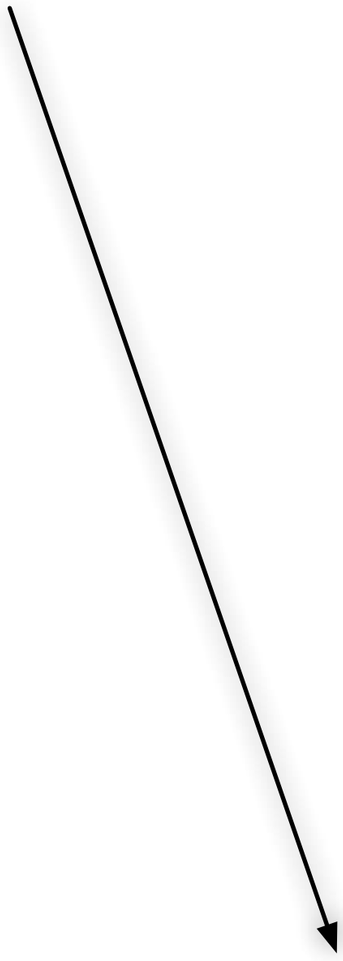

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1. Introduction & Research Questions

Research Framework

Research program / funding

European Union's Horizon 2020:
Research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642877

Academia

Academic research:
- Computational design
- Design research

Industrial partner

Engineering practice (UK):
- Consultancy
- Structural engineering

Industrial partner

Engineering practice (Switzerland):
- Consultancy
- Generation of precise and complex geometries for production
- Expertise in Free-form timber structures

Multi Scalar Modelling for Building Design (ESR 6)

PhD thematics:
- Multi-Scalar Modelling
- Free-form timber structures (as a design probe)
- Design workflows strategies

Aim & Research Objectives

1. Validating whether or not the Multi-Scalar Modelling framework existing in academia can be transferred into the realm of the AEC industry.

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1. Validating whether or not the Multi-Scalar Modelling framework existing in academia can be transferred into the realm of the AEC industry.

2. Establishing new means of simulating and communicating complex data sets throughout the whole digital chain of the building process.

3. Creating a theoretical framework, acting as a larger software platform or infrastructure, that could host the multiple custom prototypical software applications developed throughout the thesis work.

Research Questions

1. *How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?*

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Research Questions

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2. *How can we keep track, add and modify data within a common directory structure until completion of the building?*

3. *How would an ideal multi-scalar parametric AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which UI and UX concepts would be needed?*

2. State of the Art in Applied Parametric Modelling in AEC

Digital Workflows in AEC - Precedents

Rick Smith - *Technical Notes in using Parametric and BIM architectural software* - 2007

*"The concept of **creating a fully parametric digital model of an entire project** to accommodate variable changes is just not efficient at this time with the current state of technology. This is **theory and hyperbole**, especially when trying to accomplish such an all encompassing function on a 32-bit PC."*

Rick Smith, 2007

Digital Workflows in AEC - Precedents

Rick Smith - *Technical Notes in using Parametric and BIM architectural software* - 2007

1. Parametric models require a high degree of front-loading.

2. Anticipating flexibility can be diffcult.

3. Major changes break parametric models.

4. Changes can be hard to see visually.

5. Reusing and sharing models is problematic.

Separation Of Concerns

Edsger W. Dijkstra - *Separation Of Concerns* - 1974

> *"It is what I sometimes have called "the **separation of concerns**" [...]. This is what I mean by "focussing one's attention upon some aspect": **it does not mean ignoring the other aspects, it is just doing justice to the fact that from this aspect's point of view, the other is irrelevant**. It is being one- and multiple-track minded simultaneously."*
>
> Dijkstra, 1974

Separation Of Concerns

Alexander Peña de León - Automation vs. Direct Modelling - 2014

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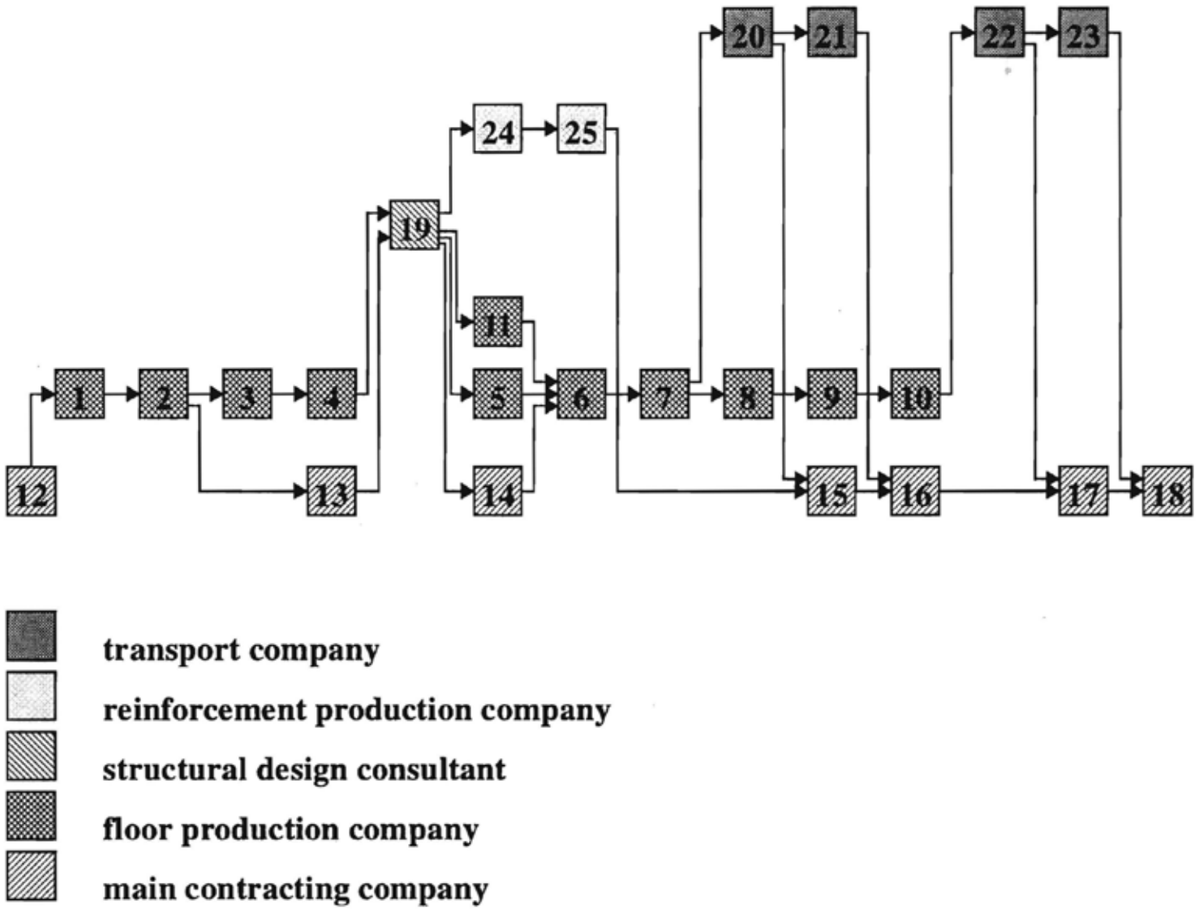
> Dijkstra, 1974

> *"[...] a paradox between the need for more automated ways of modelling with the need for more "Direct Modelling" ways of interacting with models. They are contradictory because automation aims at reducing "Direct Modelling" interaction. [...] **we need better ways to integrate automation in design modelling while simultaneously we need more tacit interaction through "Direct Modelling" with our models in order to achieve a greater flexibility in design modelling**."*
>
> Peña de León, 2014

Digital Workflows in AEC - Precedents

Bauke de Vries - *Communication in the building industry: a strategy for implementing electronic information exchange* - 1995



The activity network modelled as a PERT (Program Evaluation and Review Technique) network by Bauke de Vries

Digital Workflows in AEC - Precedents

Oliver Tessman - *Collaborative Design Procedures for Architects and Engineers* - 2007

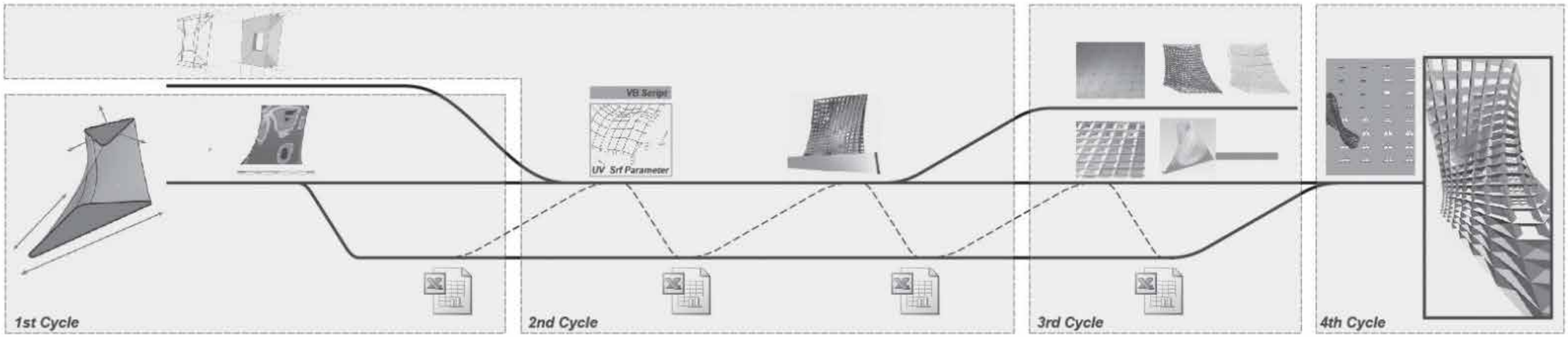


Diagram showing the development cycles and collaborative dependencies during the design of the augmentedFRAME project, a competition entry by Oliver Tessmann with Mirco Becker, Asko Fromm and Gregor Zimmermann.

Digital Workflows in AEC - Precedents

Design-to-Production - Centre Pompidou Metz - 2010

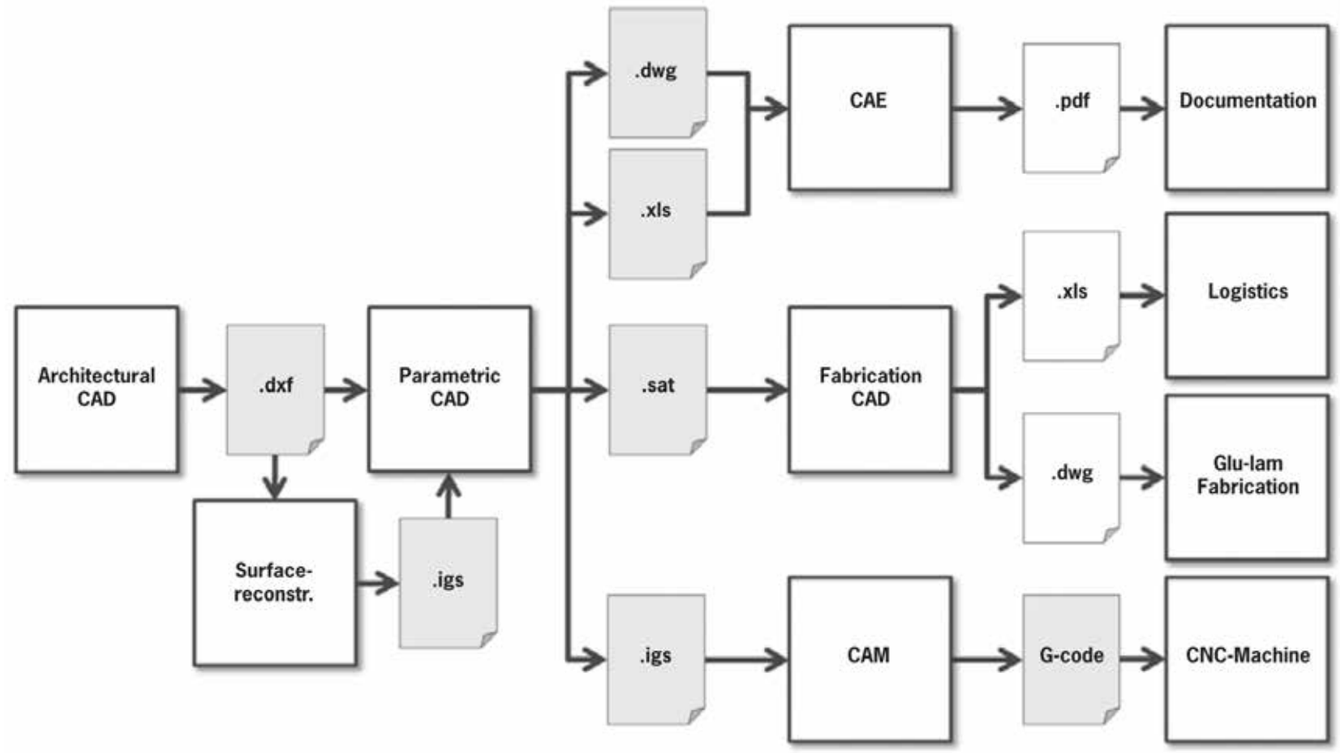
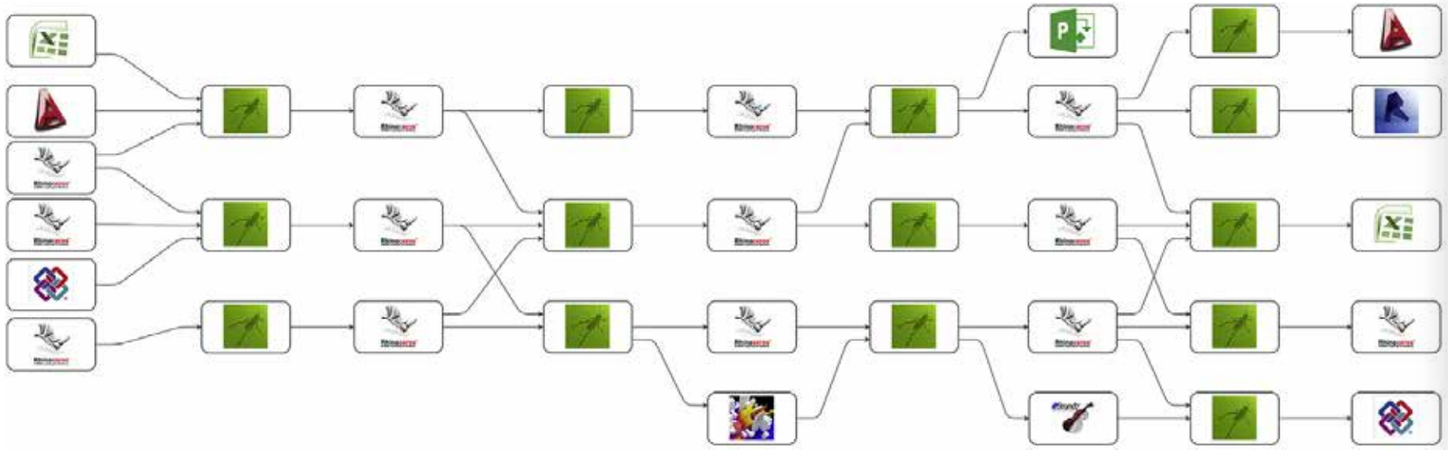


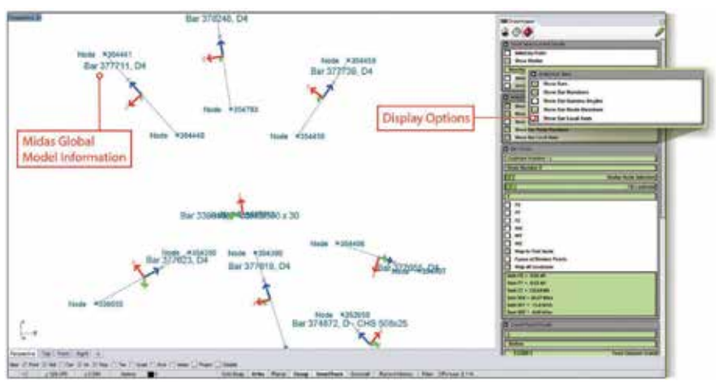
Diagram showing the flow of information between the various software programs used for planning and fabricating the timber roof structure of the Centre Pompidou-Metz by Shigeru Ban and Jean de Gastines.

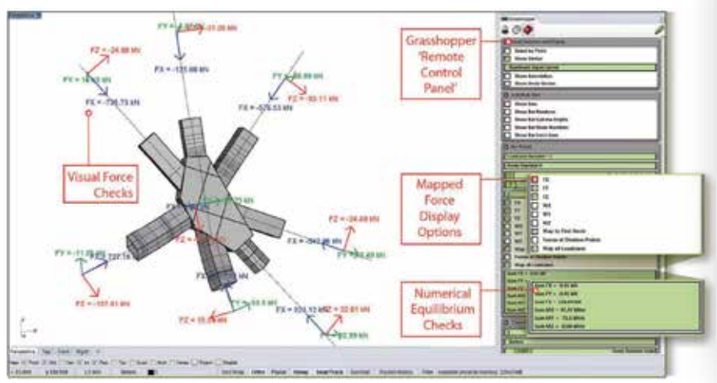
Centre Pompidou - Metz (France, 2010)
Architects: Shigeru Ban and Jean de Gastines

Digital Workflows in AEC - Precedents

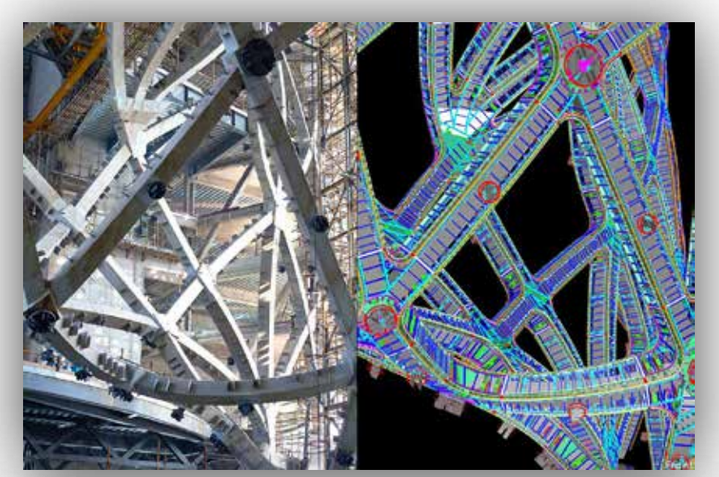
Front Inc. / BuroHappold Engineering - Morpheus Hotel (Zaha Hadid Architects) - 2015

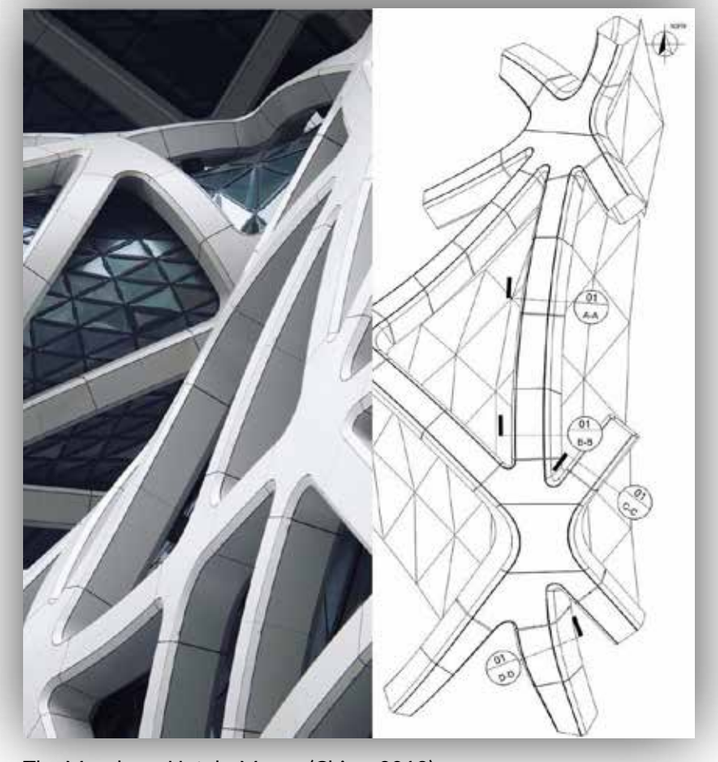






Top: Project ecosystem of staged models and generating logic (Front Inc.)
Bottom: Modelling methodologies and workflows employed by the structural design team at BuroHappold during the conception and realization of the City of Dreams architectural project designed by Zaha Hadid Architects.

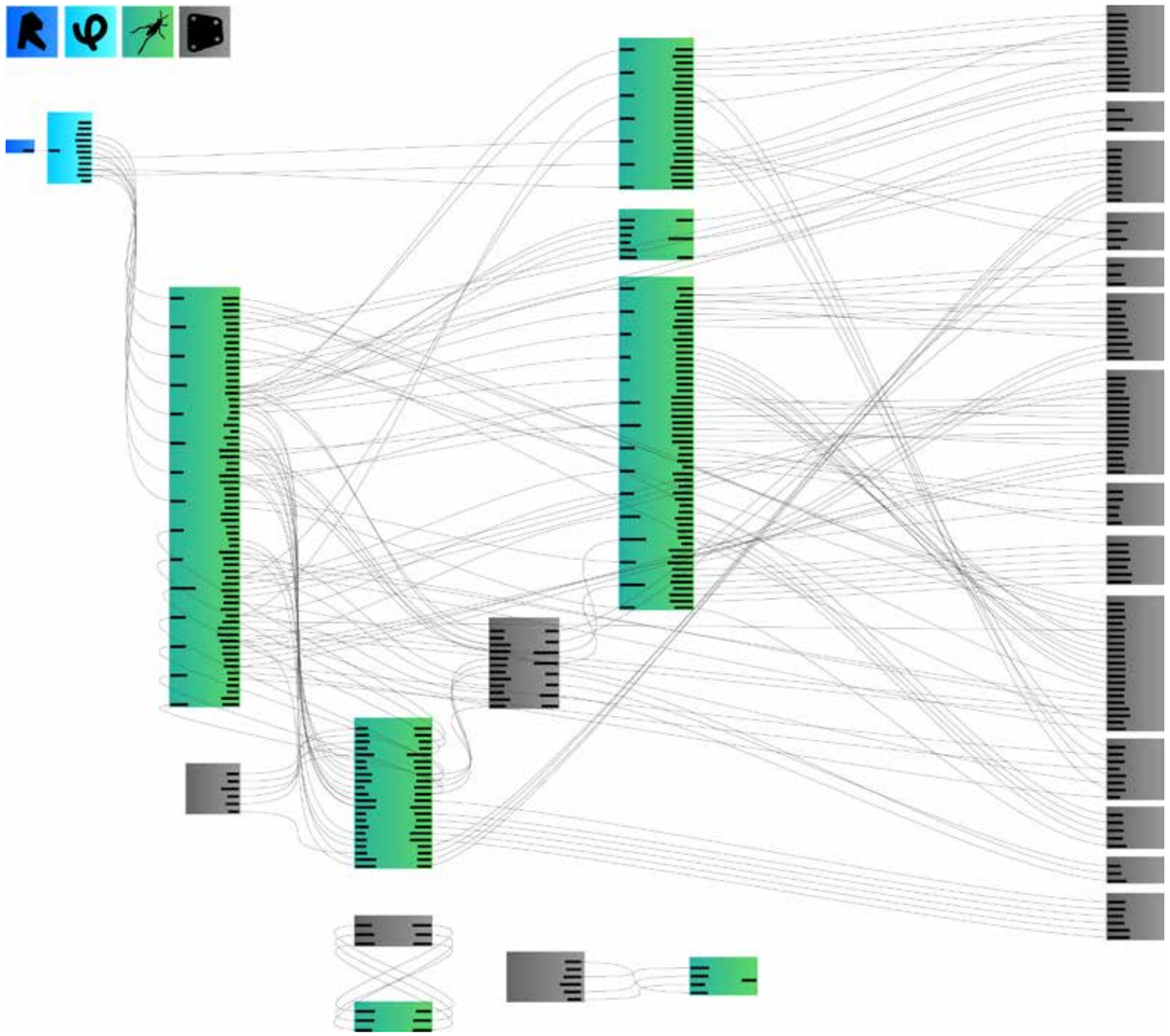




The Morpheus Hotel - Macau (China, 2018)
Architect: Zaha Hadid Architects

Digital Workflows in AEC - Precedents

Woods Bagot - The Eleventh (Bjarke Ingels Group) - 2017

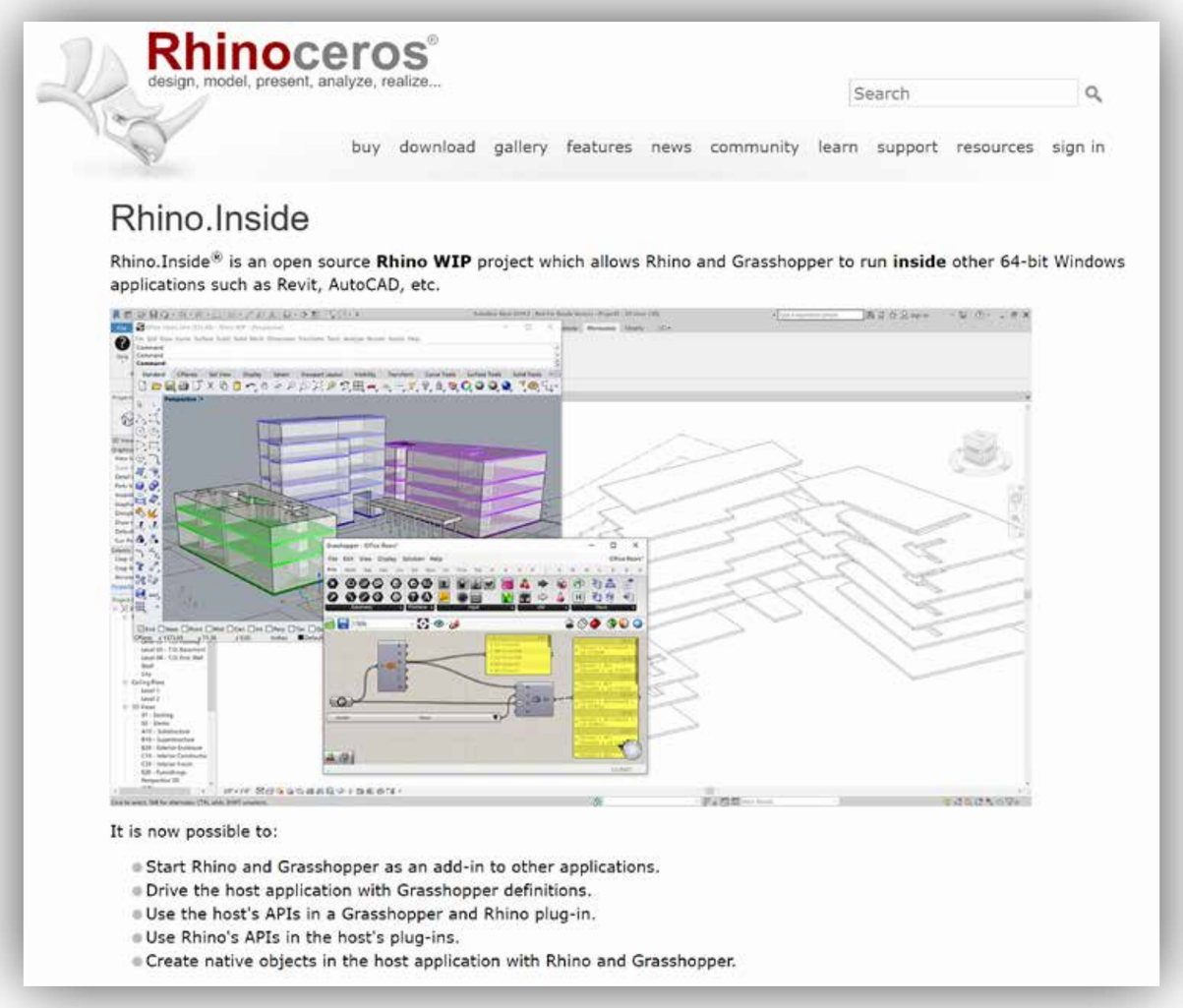


The Metagraph developed by Woods Bagot represents data key relationships among different scripts from different software platforms, using the Grasshopper canvas with its parameters and wire connections. (Ringley, 2017)

The Eleventh - New York City (United States of America, under construction)
Architect: Bjarke Ingels Group & Woods Bagot

Enhancing Interoperability in AEC through Software Development

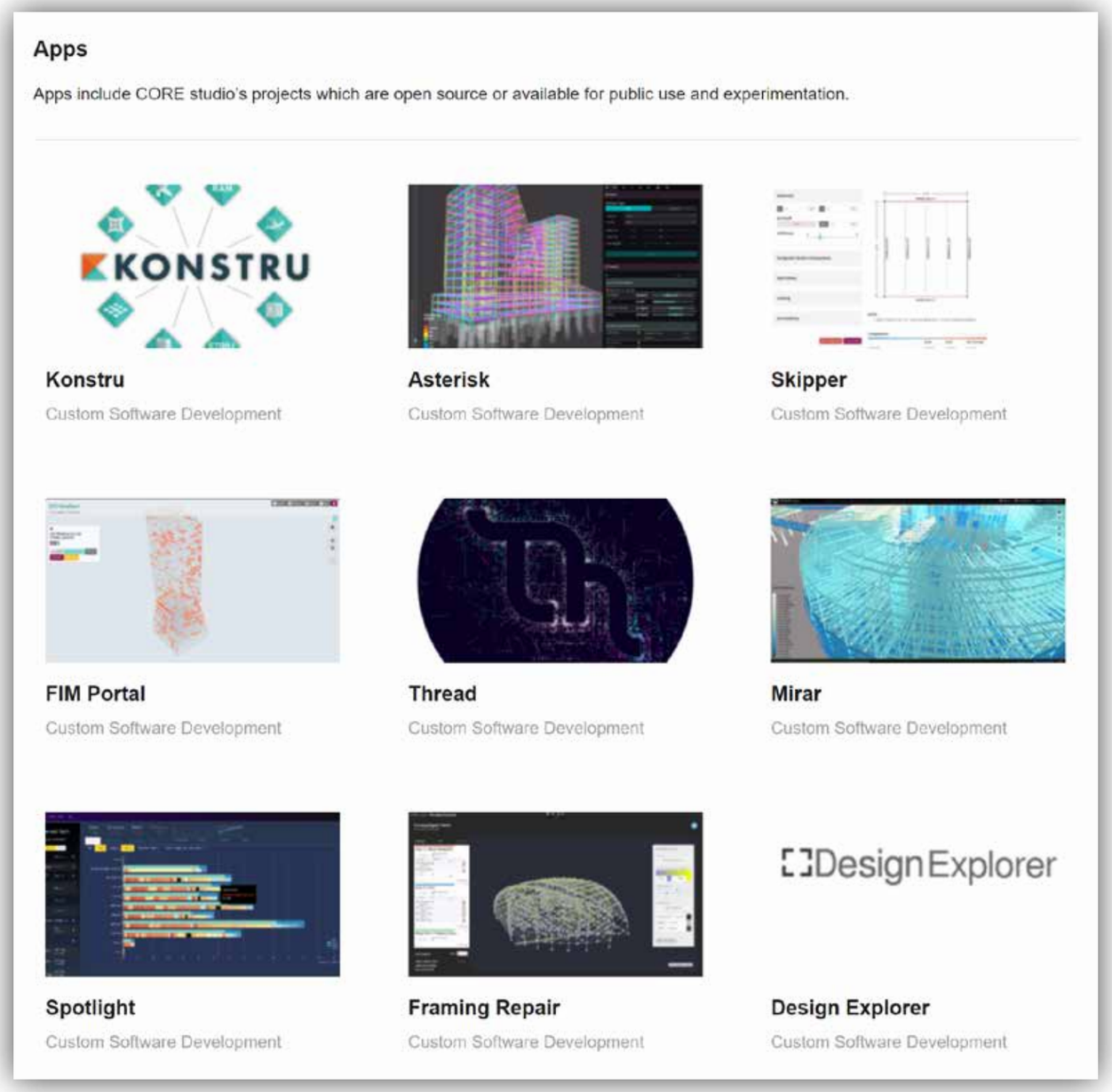
Rhino.Inside® + Rhino Compute ™



Enhancing Interoperability in AEC through Software Development

Proving Ground: Conveyor + Semantic | TT Core Apps

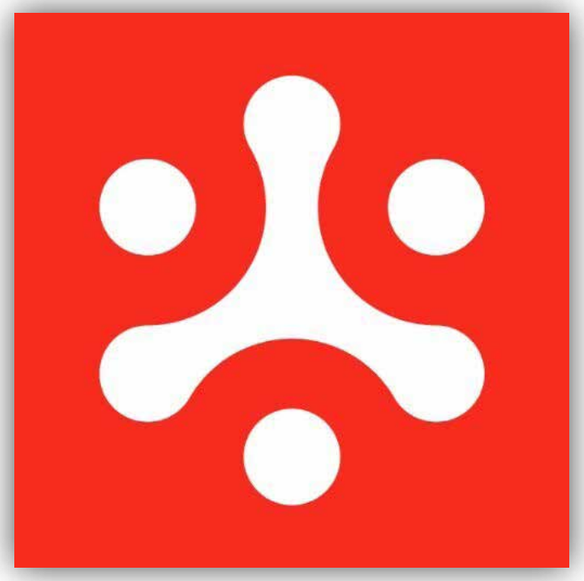
Proving Ground - Conveyor



Thornton Tomasetti - TT Core Apps

Data Platforms for AEC

Flux Data Inc.



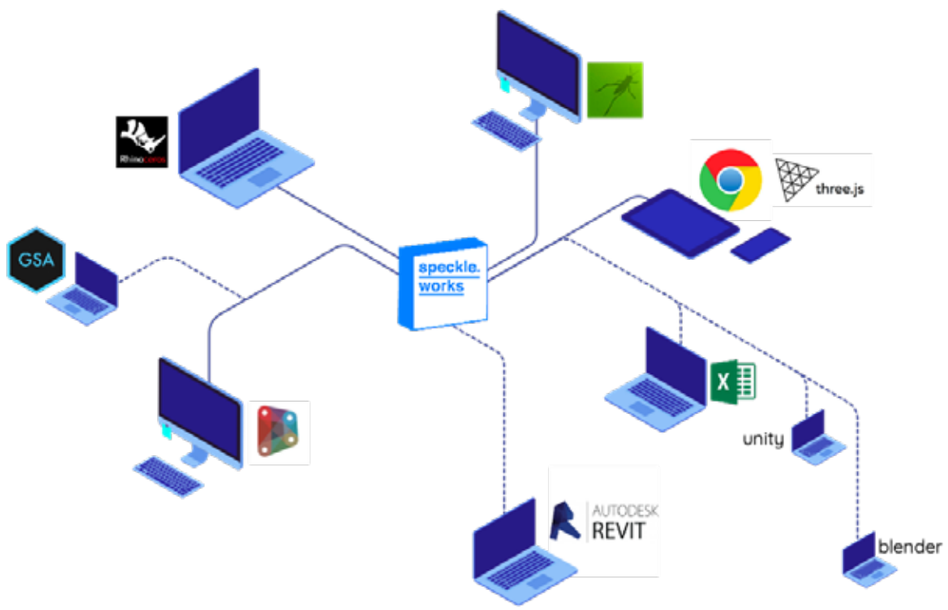
Flux Data Inc. was an interoperability platform which paved the way to transfer seamlessly building data across different software platforms. It became popular within the AEC community and was largely used by many architects, engineers, and consultants before it ceased software development on the 31st of March 2018.

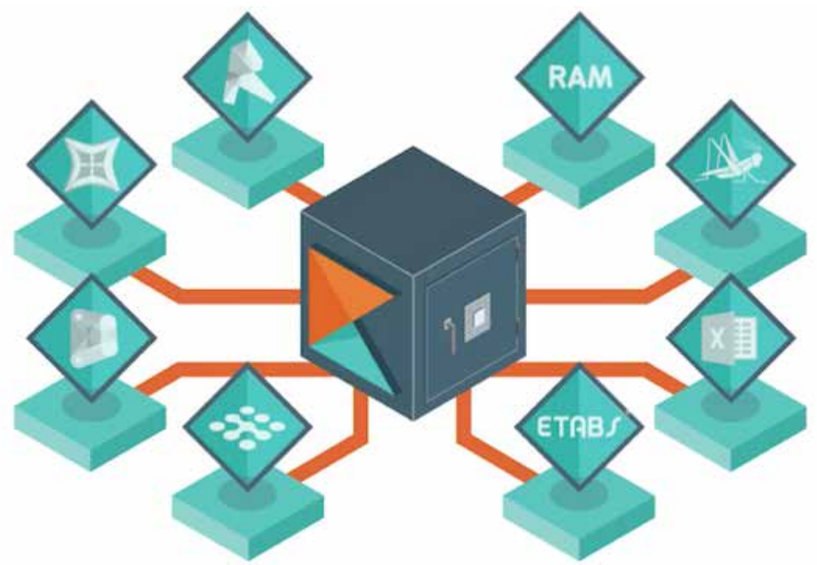
“flux.io is used by more than 6,200 companies in 151 countries and relied upon by Computational Designers, Engineers and sophisticated BIM professionals at Frank Gehry Partners, BIG, SHOP, Arup, BuroHappold Engineering, Thornton Tomasetti and more.”

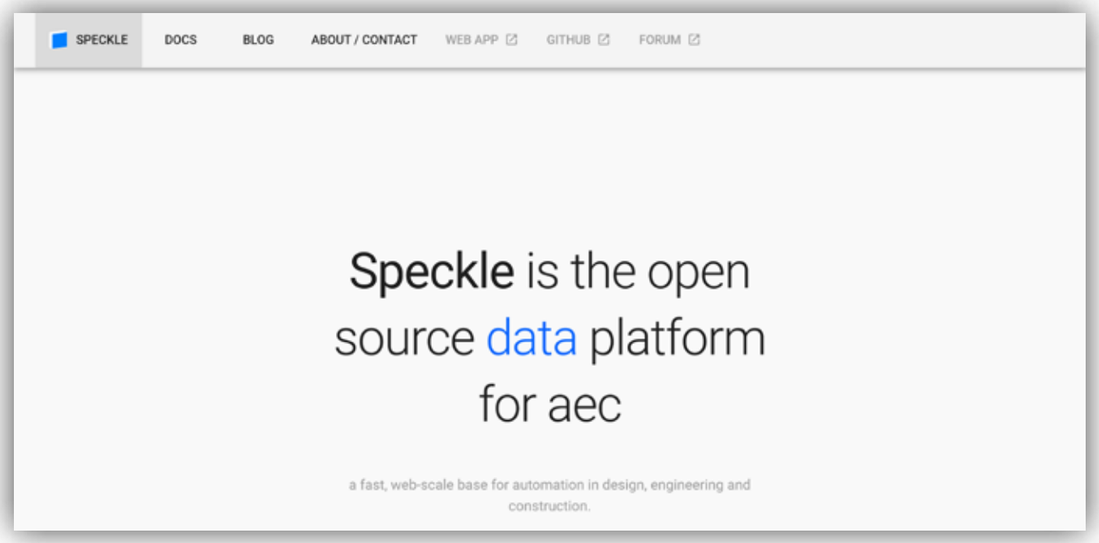
http://flux.io/ (accessed before the 31st of March 2018)

Data Platforms for AEC

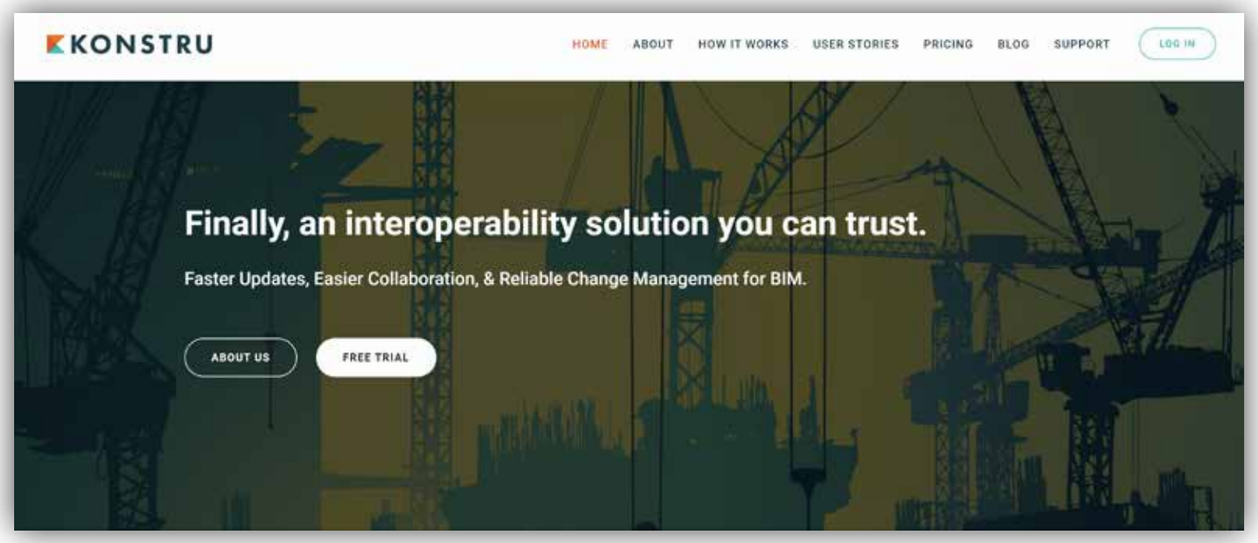
Speckle / Konstru





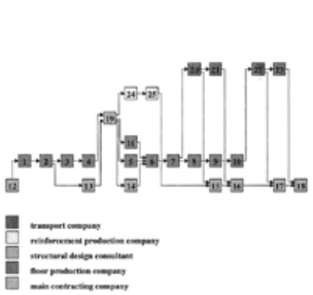


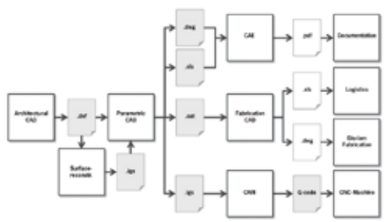
Open-source Data Platform
https://speckle.systems/

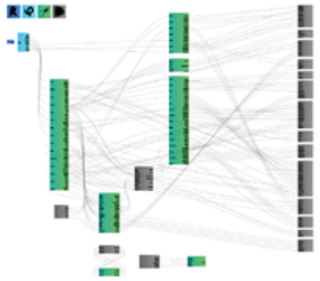


Change Management Platform
https://konstru.com/

State of the Art in Digital Workflows - Overview







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apps.provingground.io

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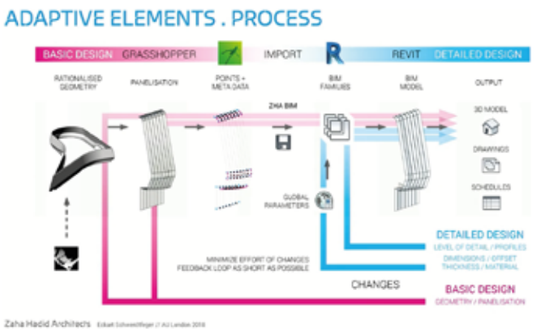

2019
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2013-Today
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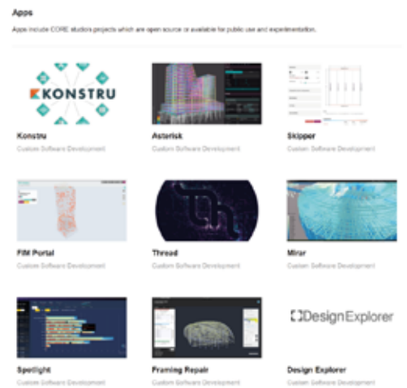

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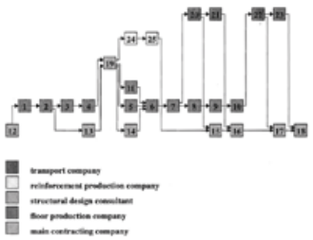

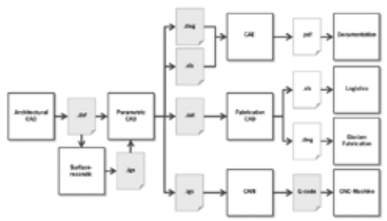

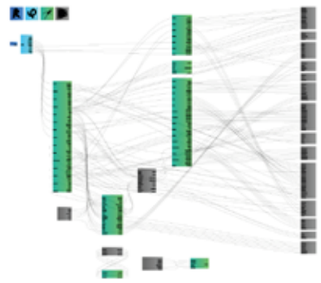

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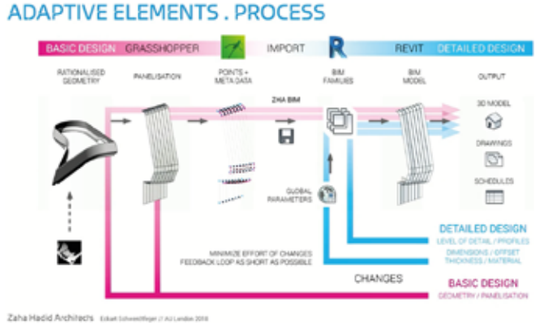

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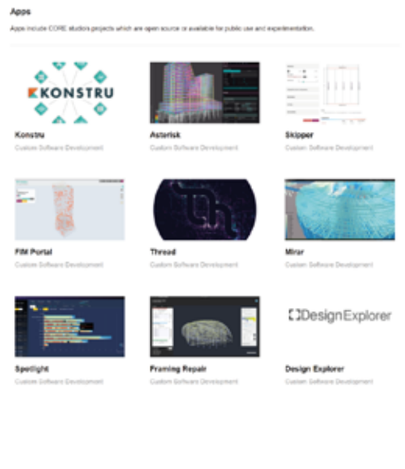

Digital Workflows in AEC - Convergence of Concepts

1. General trend in developing neutral and open-source custom tools and frameworks to “break the silos”.

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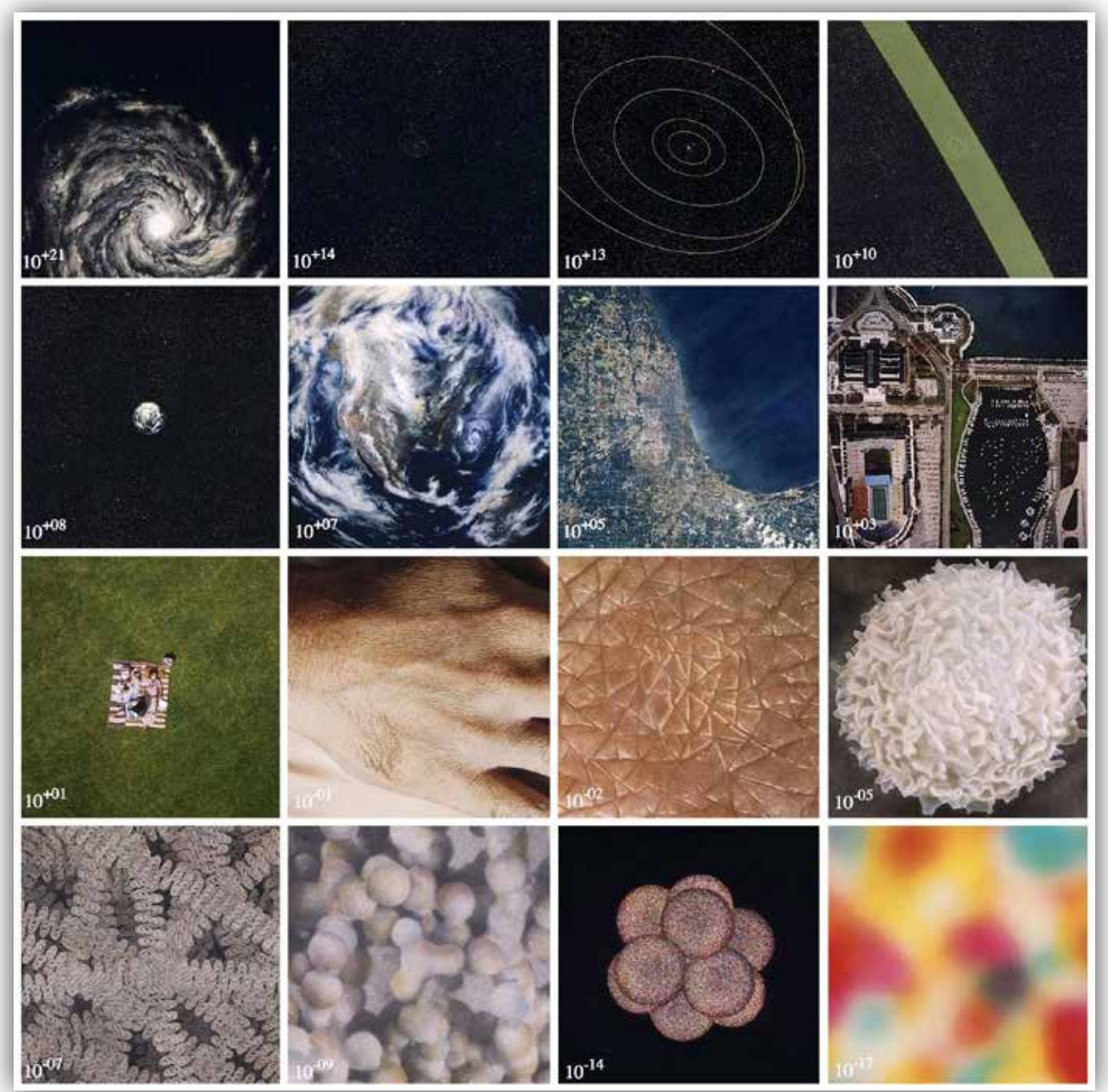
4. Segregating the different levels of modelling, from design to fabrication (“Separating the Concerns”)

3. Towards Multi-Scalar Modelling for Building Design: A Theoretical Framework and Research Methodology

Multi-Scalar Modelling

A cross-disciplinary concept



Powers of Ten Charles and Ray Eames, 1977

It is recognized that the conceptual development of Multi-Scalar Modelling comes from the realization that the full behavior of a system cannot be represented within one single model since the level of detail differs from one scale to another. Maintaining full detailed resolution through all the levels of the system becomes most of the time inefficient and computationally expensive.

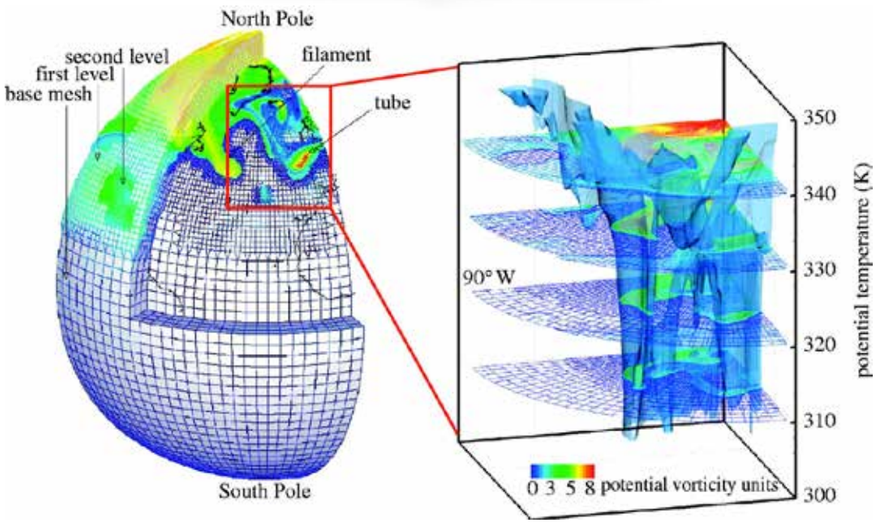
*"[...] It offers a more unified view to modeling, by **focusing more on the different levels** of physical laws and the **relations between them**, with the specific applications as examples."*

- Weinan E, *Principles of MultiScale Modeling*, 2011

Multi-Scalar Modelling

A cross-disciplinary concept

Meteorological events

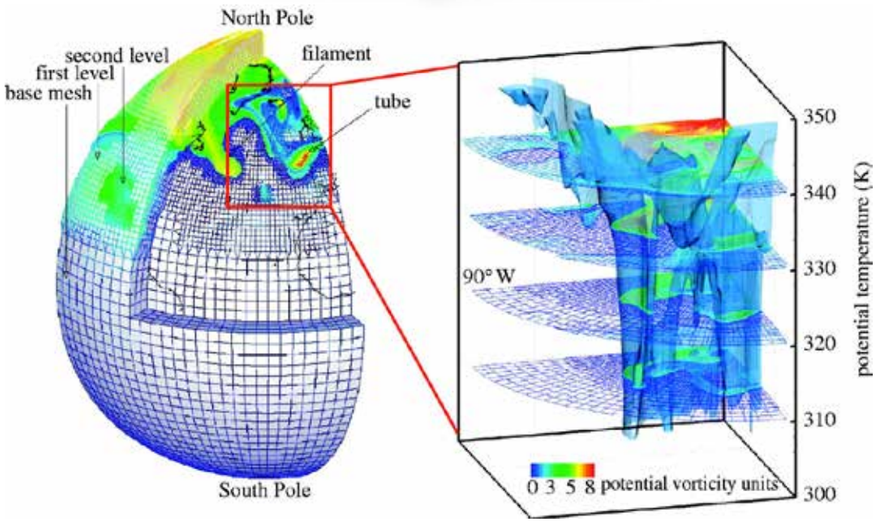


Example of an off-line simulation of a tropopause-folding event (June 1996) using structured hierarchical Adaptive Meshing Refinement and Multi-Scalar Modelling on a regular longitude–latitude spherical grid.

Multi-Scalar Modelling

A cross-disciplinary concept

Meteorological events



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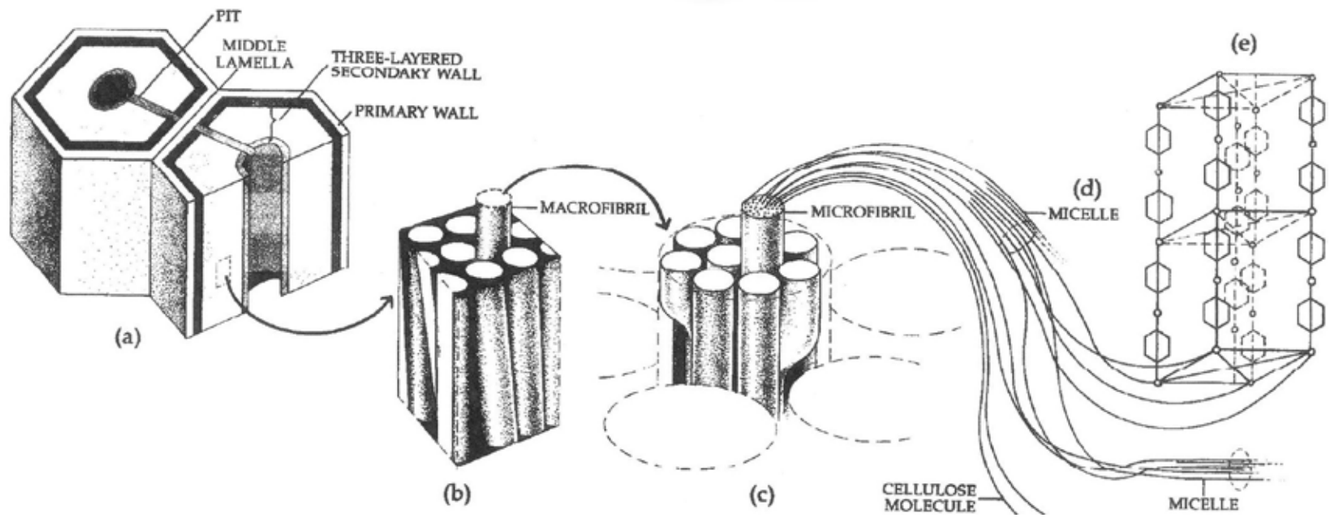
Material organization

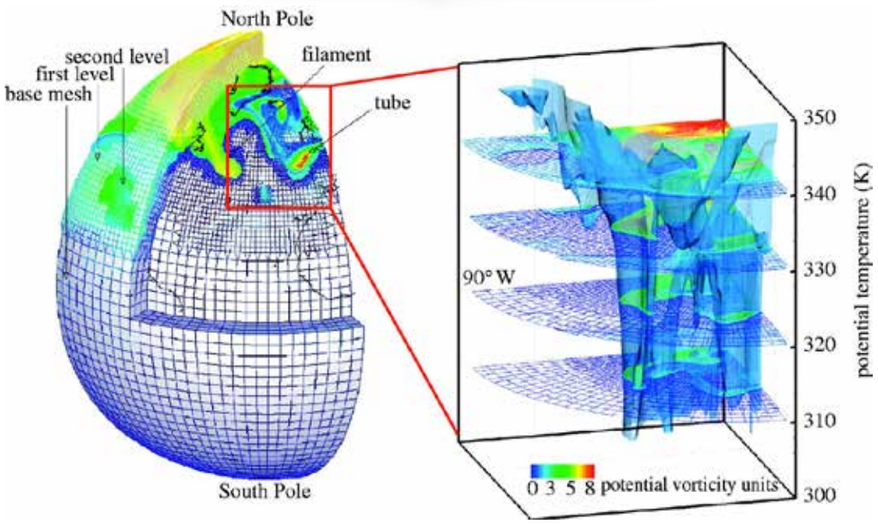


Structure of the cell wall: A: a strand of fibre cells. B: a layer of primary wall and three layers of secondary wall. C: a fragment of middle layer of secondary wall showing macrofibrils (white) cellulose and spaces between the macrofibrils (black). D: a fragment of macrofibril showing microfibrils (white). E: structure of microfibrils. In some parts called micelles there are chain-like molecules of cellulose orderly arranged. F: a fragment of a micelle showing parts of chain-like cellulose molecules.

Multi-Scalar Modelling

A cross-disciplinary concept

Meteorological events



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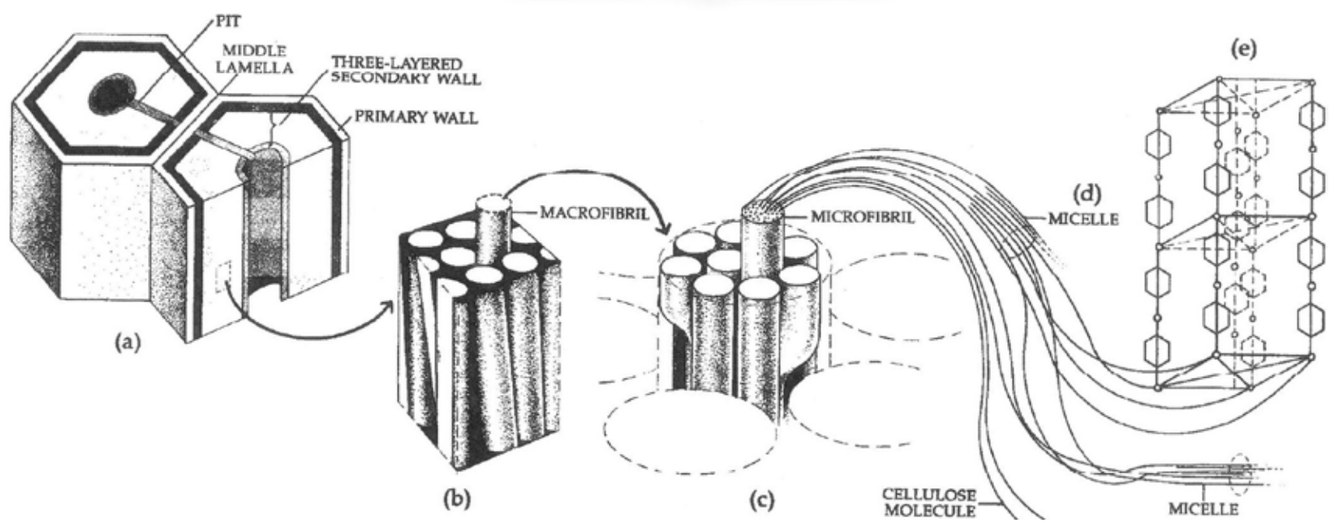
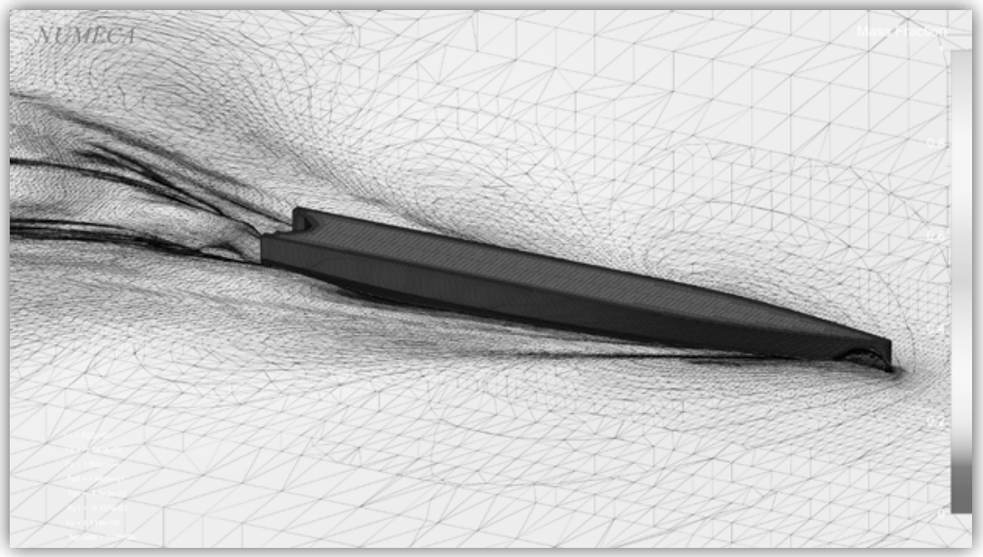
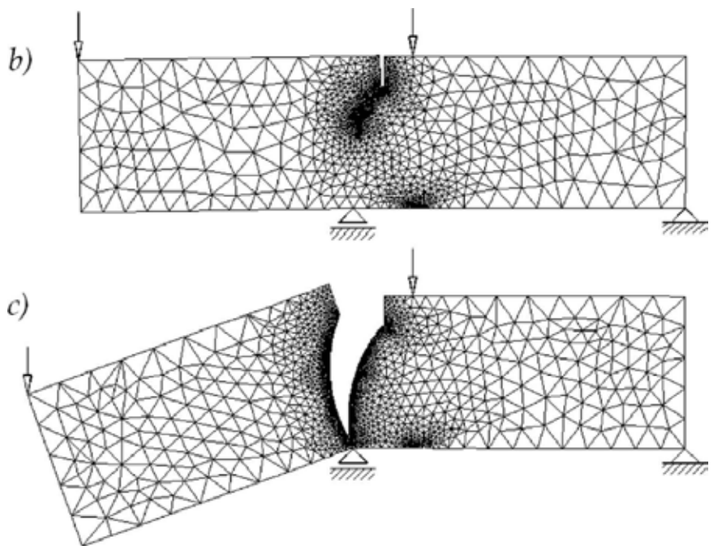


Structure of the cell wall: A: a strand of fibre cells. B: a layer of primary wall and three layers of secondary wall. C: a fragment of middle layer of secondary wall showing macrofibrils (white) cellulose and spaces between the macrofibrils (black). D: a fragment of macrofibril showing microfibrils (white). E: structure of microfibrils. In some parts called micelles there are chain-like molecules of cellulose orderly arranged. F: a fragment of a micelle showing parts of chain-like cellulose molecules.

Computational Fluid Dynamics and strucural behaviour simulation



Visualization of the Adaptive Mesh Refinement algorithm from Numeca's Fine/Marine software using ISIS-CFD RANS solver.



Adaptive Mesh Refinement in the evolutionary problem of crack propagation in a cohesive material. As the image shows, the algorithm uses high resolution grids only at the physical locations and times where they are required.

Multi-Scalar Modelling in Architectural Design Research

ICD/ITKE - The Landesgartenschau Exhibition Hall - 2014 | CITA - Stressed Skins - 2016

Coarsening / Uncoarsening

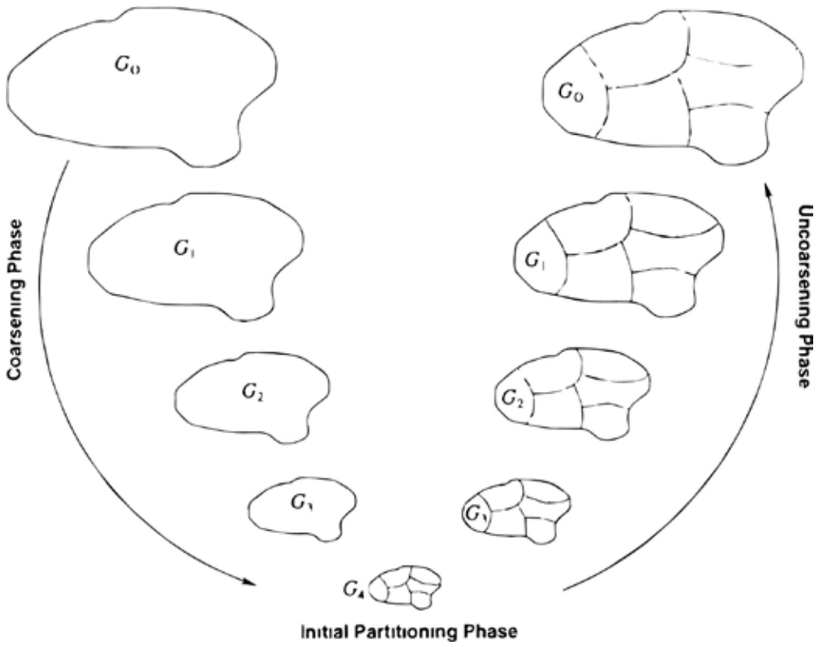
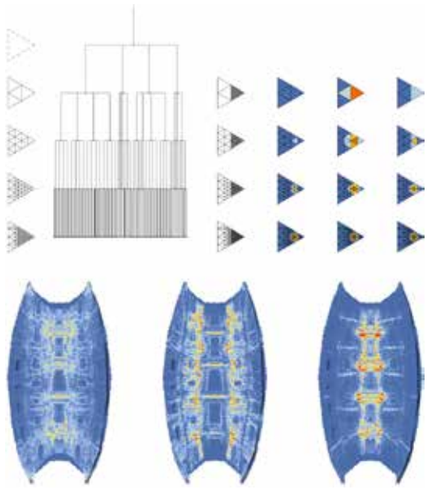
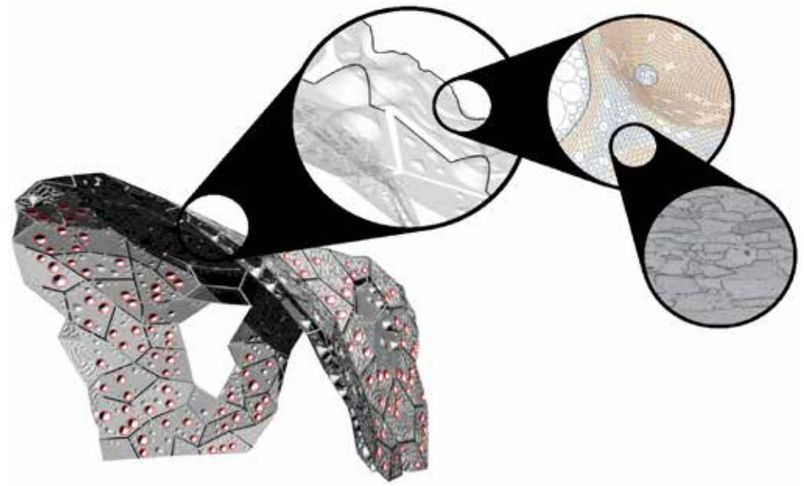


Diagram representing the Coarsening and Uncoarsening Phases, where a graph is partitioned at high-level before passing the obtained and informed data at low-level.

CITA - Stressed Skins (2016) / A Bridge Too Far (2017)

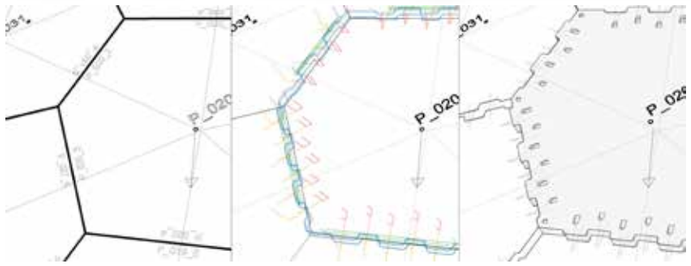


Bi-directional data propagation between low and high resolution during the modelling process of the research project *The Bridge Too Far* (Nicholas, 2016)

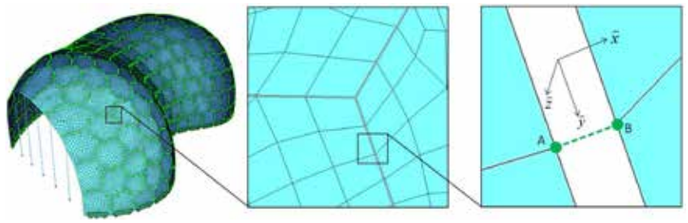


Stressed Skins - Copenhagen (Denmark, 2014), Architect: CITA

ICD/ITKE - The Landesgartenschau Exhibition Hall (2014)



The toolpaths for the robotic fabrication of a plate are generated from the topology analysis of a surface model - ICD/ITKE/IIGS - University of Stuttgart 2014.



The global FE model of the pavilion. Right: Spring elements act on two nodes, A and B, situated at the two opposite sides of neighboring panels. Axes x, y, and z are the directions of the axial force, the in-plane shear, and the out-of- plane shear, respectively. Axis y is also the axis of bending resistance.

Landesgartenschau Exhibition Hall - Landesgartenschau Schwäbisch Gmünd (Germany, 2014), Architects: ICD/ITKE/IIGS University of Stuttgart

Multi-Scalar Modelling in Architectural Design Research
Exsiting Methodologies

1. Defining the coarsening and uncoarsening strategies to navigate across multiple levels and resolutions.

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Discrepancy between Academia and Practice

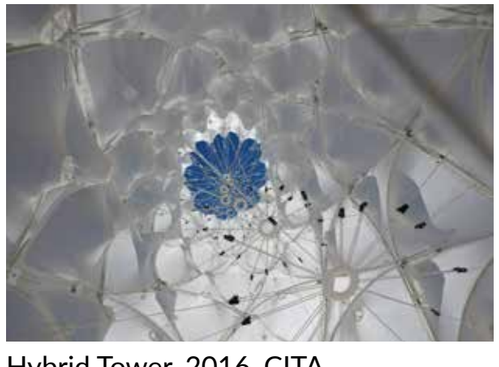
The Demonstrators/Pavilions in Academia
Material specific, seamless design


Panikkar, 2014, CODA


ICD/ITKE Research Pavilion 2013-14

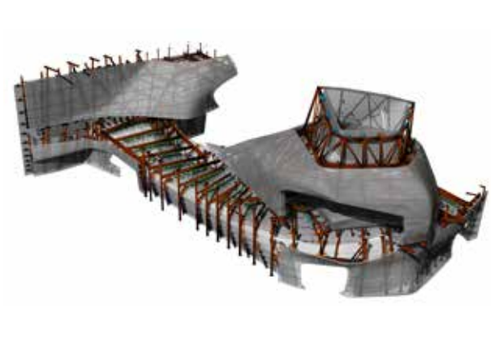

A Bridge Too Far, 2016, CITA

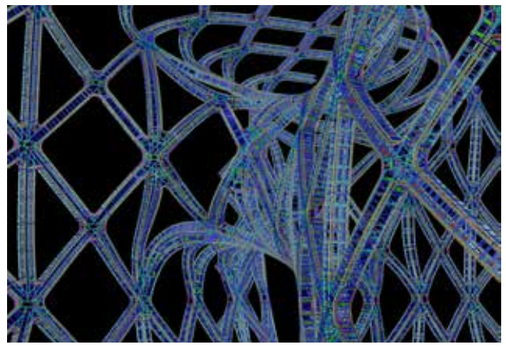

ICD/ITKE Research Pavilion 2014-15

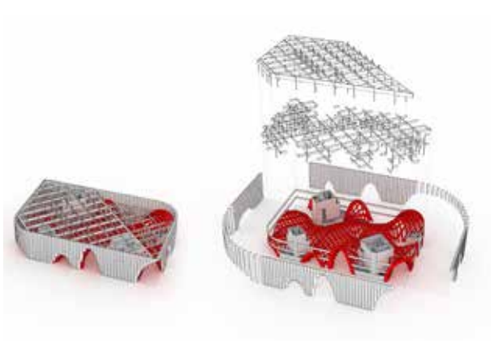

Hybrid Tower, 2016, CITA

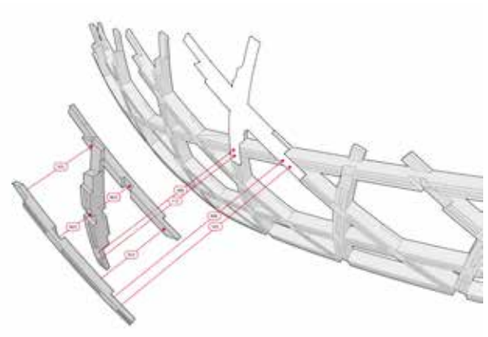

ICD/ITKE Research Pavilion 2015-16

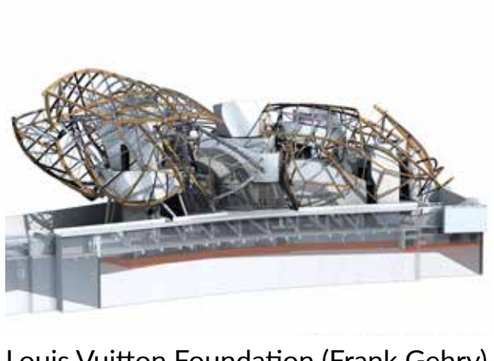
The Building Industry
Large diversity of materials, clashes between elements

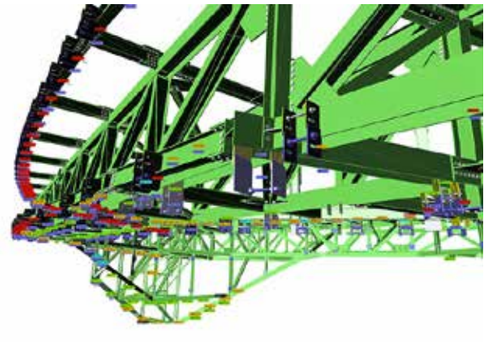

Louisiana State Sports Hall Of Fame


City of Dreams (Zaha Hadid Architects)

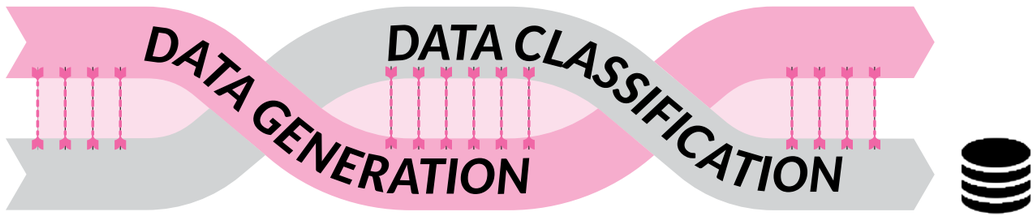

French Pavilion at the Expo 2015


Cité Musicale (Shigeru Ban, 2017)


Louis Vuitton Foundation (Frank Gehry).


Barclays Center (ShoP Architects, 2012)

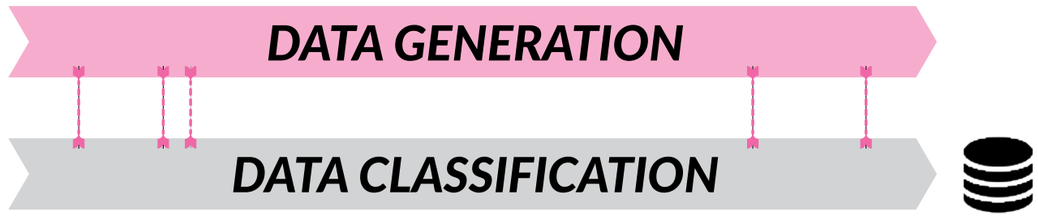
Discrepancy between Academia and Practice



- **The generation of data** and its **classification** are **highly intertwined** and **integrated**: the **generation of data leads directly to its classification**.

- **The user can't or can hardly operate any changes on the data classification** itself, **without affecting the generative design process**.

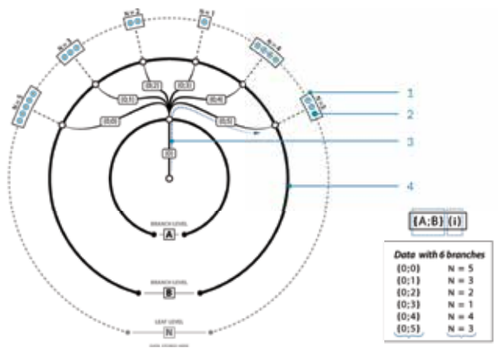
- **Hardly sustainable** at late design stages.



- **The generation of data** and its **classification** are **independent from each other**: **they can be** (but are not necesseraly) **intertwined**.

- **The user is free to operate classification changes whenever he/she wants during the design process**. **Classification features** (such as names and attributes) **can be introduced/developed/refined before, during and after the generation of data**.

- **Proved to be sustainable** at late design stages.



The "dynamic" DataTree

The "static" LayerTable

Redefining/Expanding Multi-Scalar Modelling Methodologies for Building Design

Multi-Scalar Modelling
in Architectural Design Research

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Digital Design Workflows in the AEC industry

1. General trend in developing neutral and open-source custom tools and frameworks to “break the silos”.

2. Improving interoperability through custom software development, enabling the transfer of data-rich and complex geometrical objects.

3. Keeping geometrical objects as lightweight as possible for serialization and further reconstruction & using extensible neutral formats to facilitate both object customization (nesting of data-rich information) and interoperability.

4. Segregating the different levels of modelling, from design to fabrication (“Separating the Concerns”)

Research Methodology
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Research through Design
Physical Prototyping

"*[...] a materially-led investigation allowing exploratory testing, of craft and material behaviour. The prototype answers and develops the design criteria of the design probe.*"

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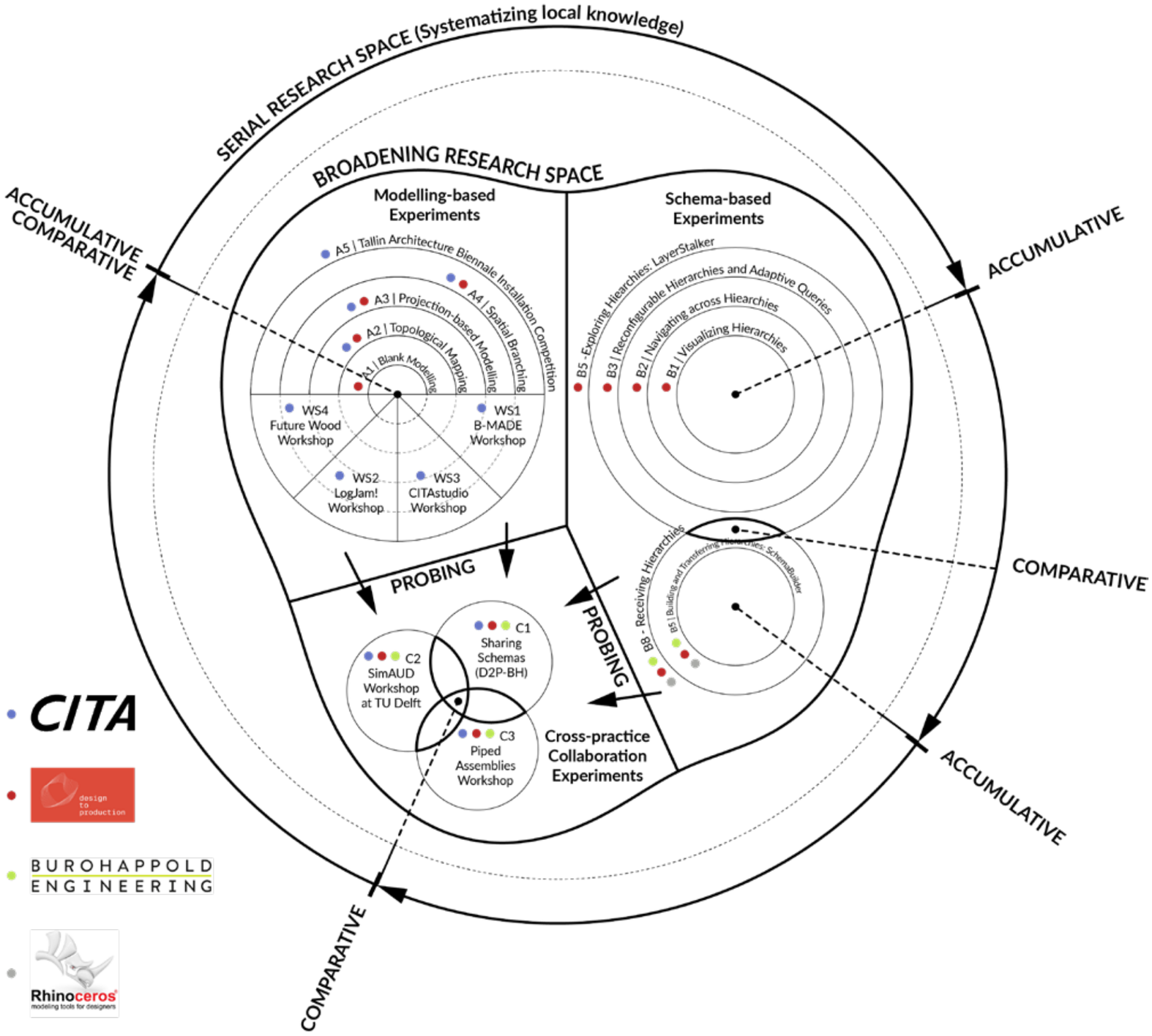
Evaluation & Stress testing

The experiments are not evaluated against their usability. They are instead prototypical applications which are tested against different models:

- Stress testing the model's (in)flexibility.
- Stress testing prototypical applications against multiple source models.
- Stress testing prototypical design tools and methodologies against speculative collaborative practices and workflows.

Mapping the Experiments

Overview



Mapping the Experiments
Different Categories of Experiments

Early Design Stages

Modelling-based Experiments (Free-form Timber Structures as Case Study)

- A1 - BlankMachine: Propagating the Blanks
- A2 - Topological Mapping: Modelling Lap Joints
- A3 - Topological Mapping: Surface/Projection-based Modelling
- A4 - Topological Mapping: Spatial Branching
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- B2 - Navigating across Hierarchies: LayerExplorer
- B3 - Reconfigurable Hierarchies
- B4 - Adaptive Queries
- B5 - Exploring Hierarchies: LayerStalker
- B6 - Building and Transferring Hierarchies
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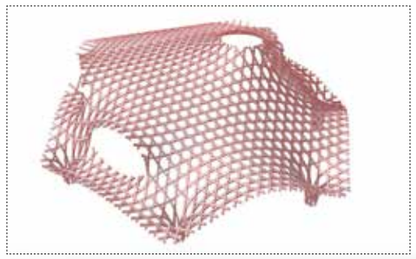
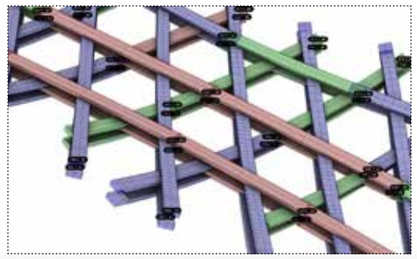
4. Modelling-based Experiments:
Free-form Timber Structures as a Series of Case-studies

Free-form Timber Structures - Design Probe & State of the Art

Design-To-Production is a consultancy practice that mostly intervenes during the post-tender phase of architectural projects. The office has been involved in the modelling process of a large variety of free-form timber structures.

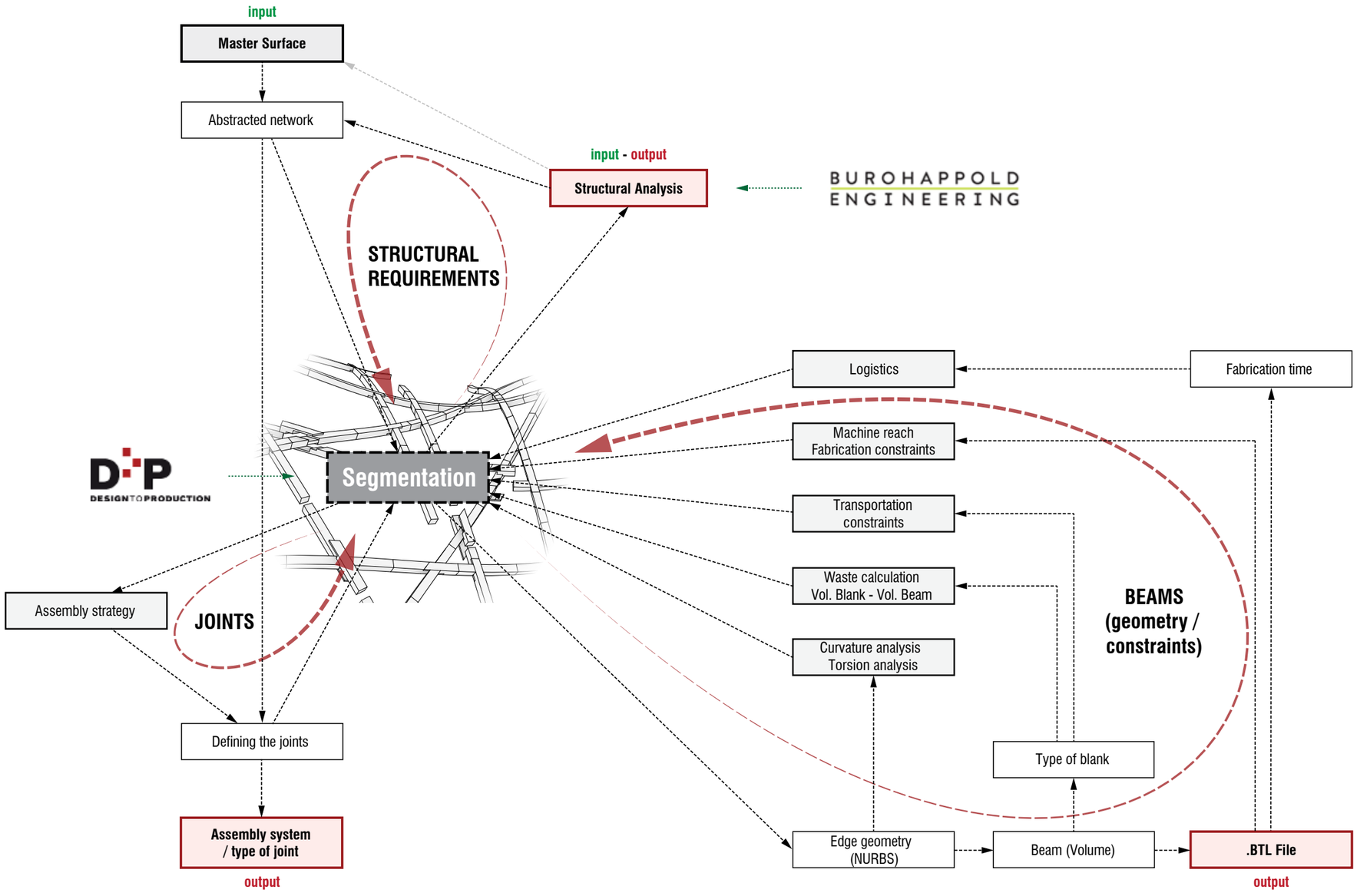




Centre Pompidou - Metz (France, 2009)
Architect: Shigeru Ban Architects & Jean de Gastines

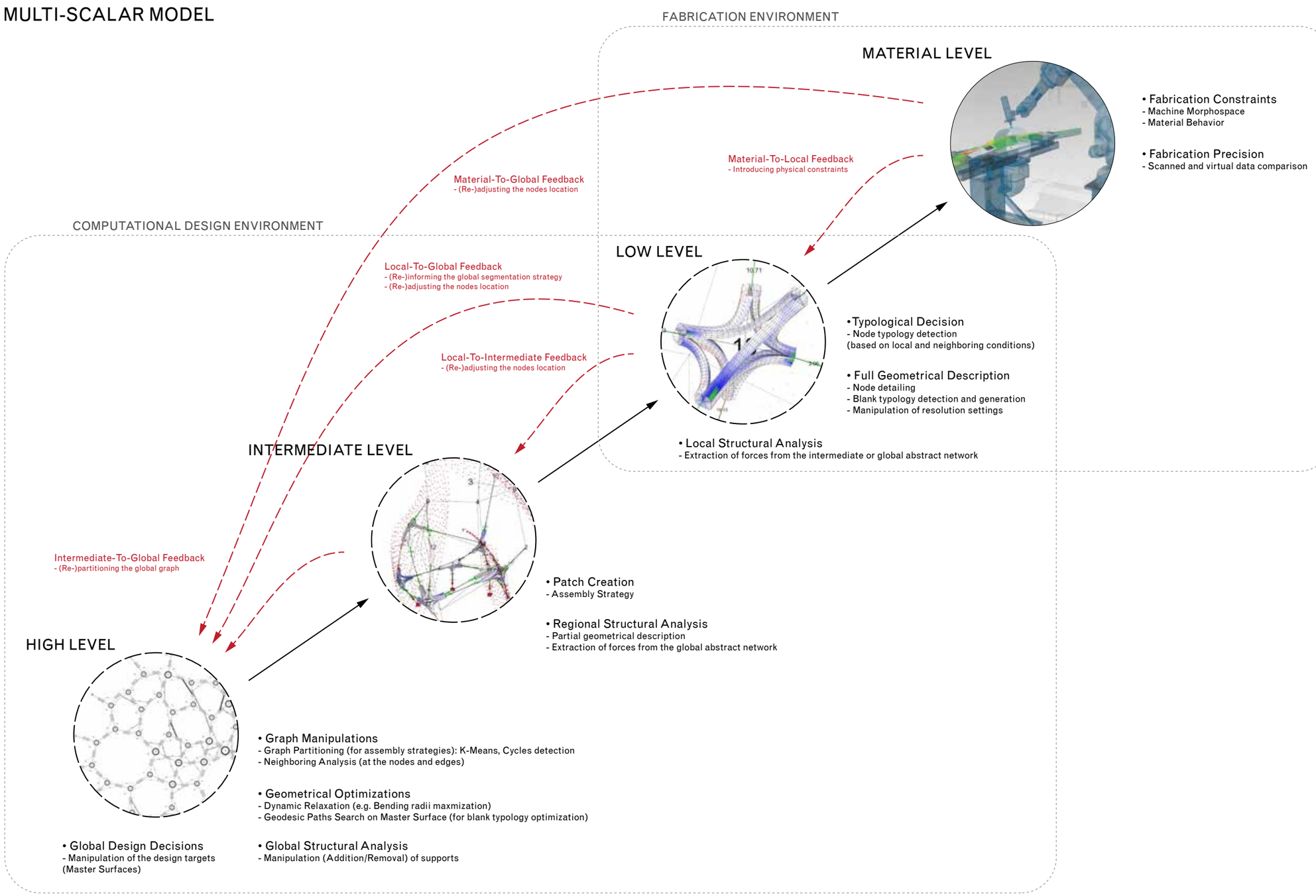
Free-form Timber Structures - Design Probe & State of the Art

The segmentation strategy is seen here as the crucial point in the design of the timber structure.



Multi-Scalar Modelling for Free-form Timber Structures

A design framework for the early design stages - concept development



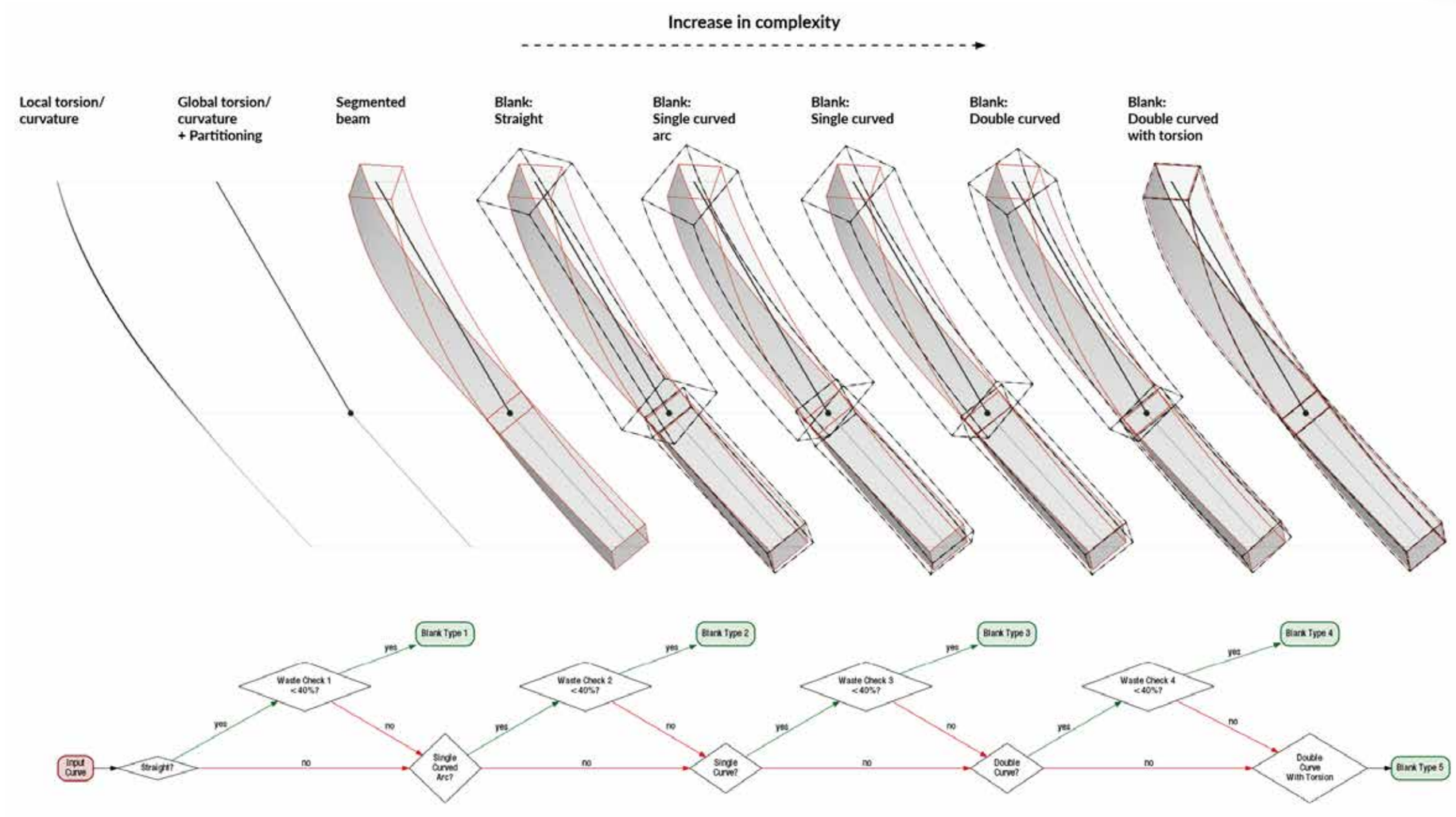
Multi-Scalar Modelling for Free-form Timber Structures

A1 - BlankMachine: Propagating the Blanks

Key question:
"How can early stage data be leveraged to improve late stage design decisions?"

Blank, definition:
*"Once the beam segmentation is set, blanks are created. The term "blank" refers to the **raw glue-laminated timber piece, which is milled down to the final shape of the segment**. In free form projects, single curved or doubly curved blanks approximate the final piece's curvature. They are produced by bending and gluing raw lamellas on a set of pre-shaped supports."*

- Usai & Stehling, 2017



Multi-Scalar Modelling for Free-form Timber Structures

A1 - BlankMachine: Propagating the Blanks

Key question:
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VIDEO PLACEHOLDER

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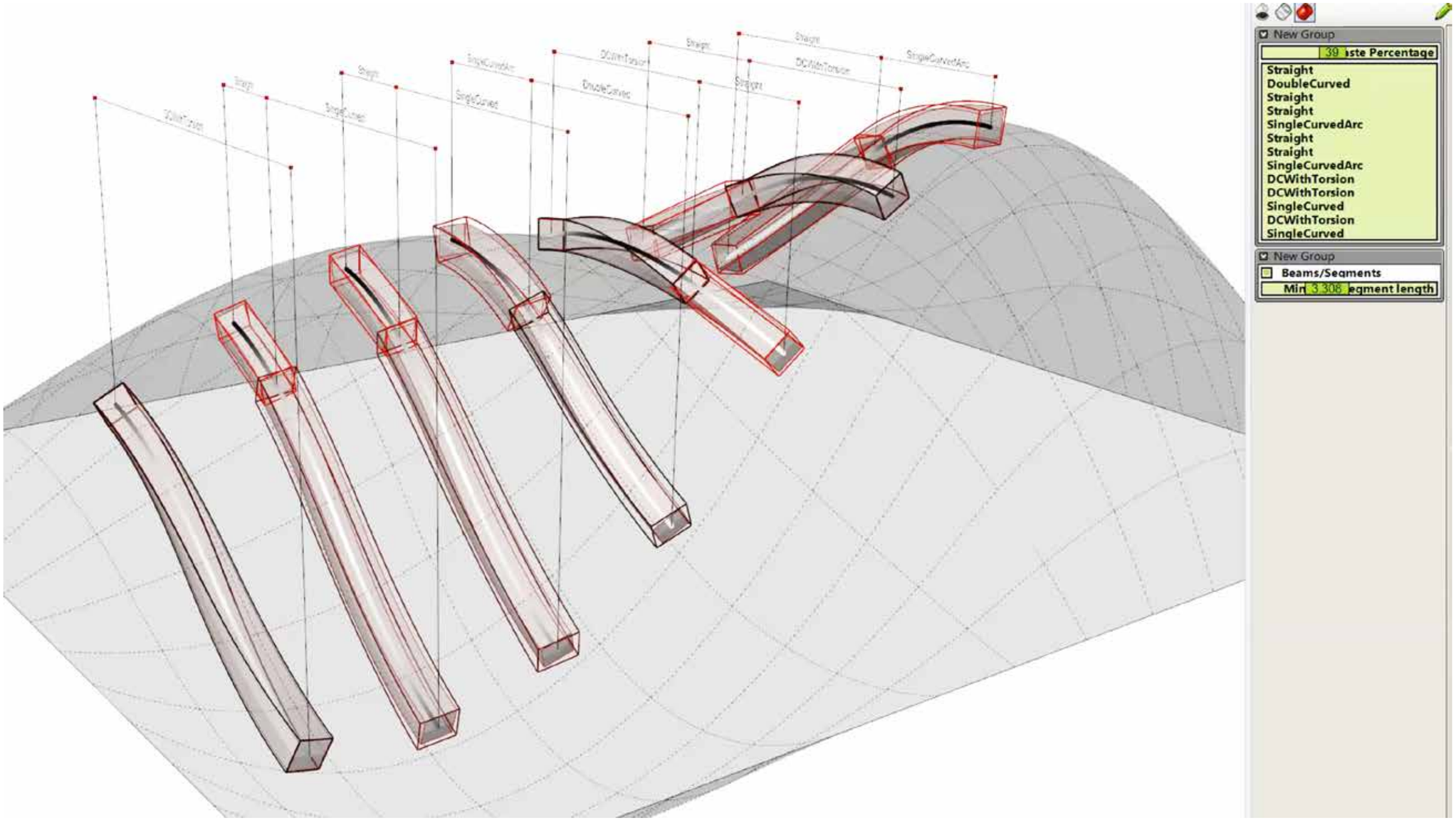


Multi-Scalar Modelling for Free-form Timber Structures

A1 - BlankMachine: Propagating the Blanks

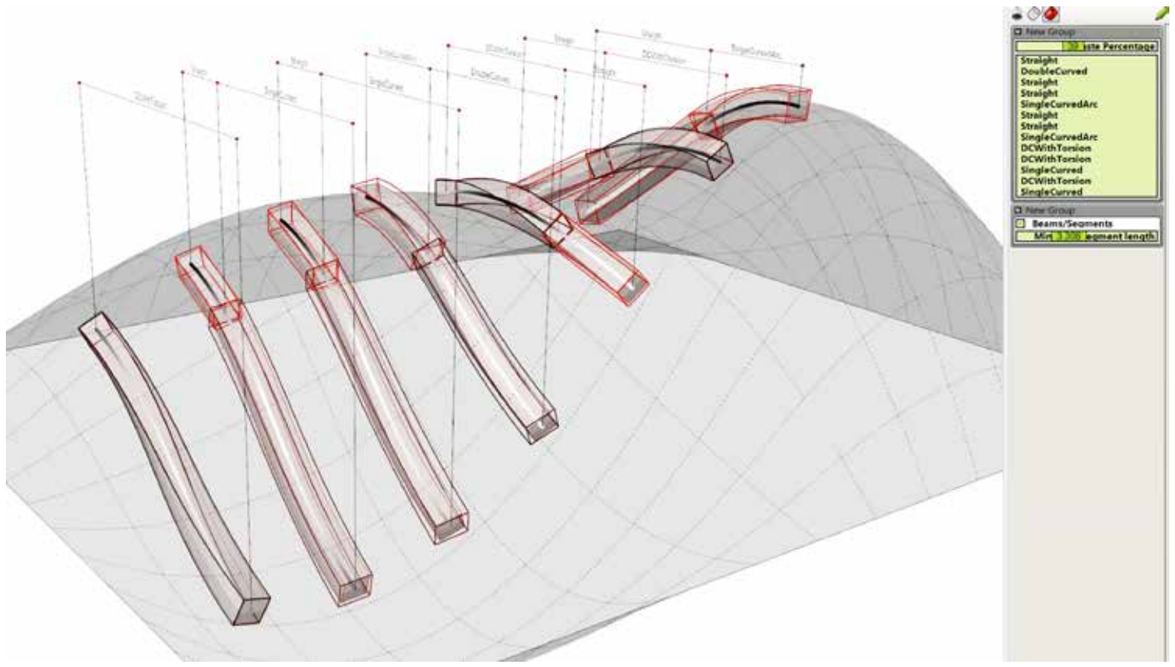
Key question:
“How can early stage data be leveraged to improve late stage design decisions?”

Result

Through several stress-tests against different glue-laminated timber beam models, this prototypical tool proved to be **useful to generate blanks, steer their geometries at high resolution by manipulating low level parameters**.

Limitations / link to the next experiment

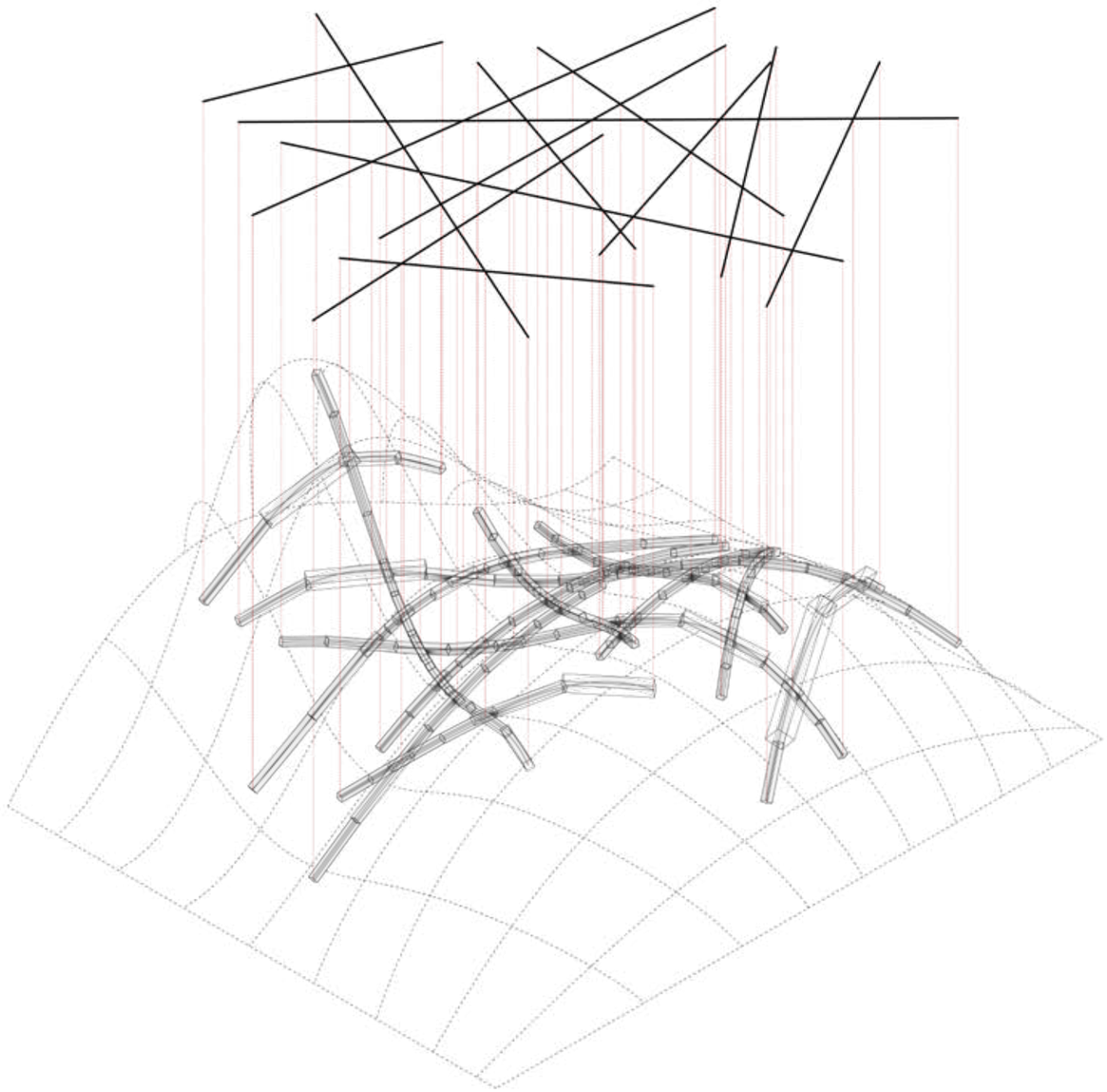
This experiment did not focus on the modelling of joints between elements. The next experiment **will focus this time on a higher level, through the modelling of a large network of interconnected glue-laminated timber beams**.



Multi-Scalar Modelling for Free-form Timber Structures

A2 - Topological Mapping: Modelling Lap Joints

Key question:
"How can the computational designer be able to navigate more easily between different scales during the design process?"



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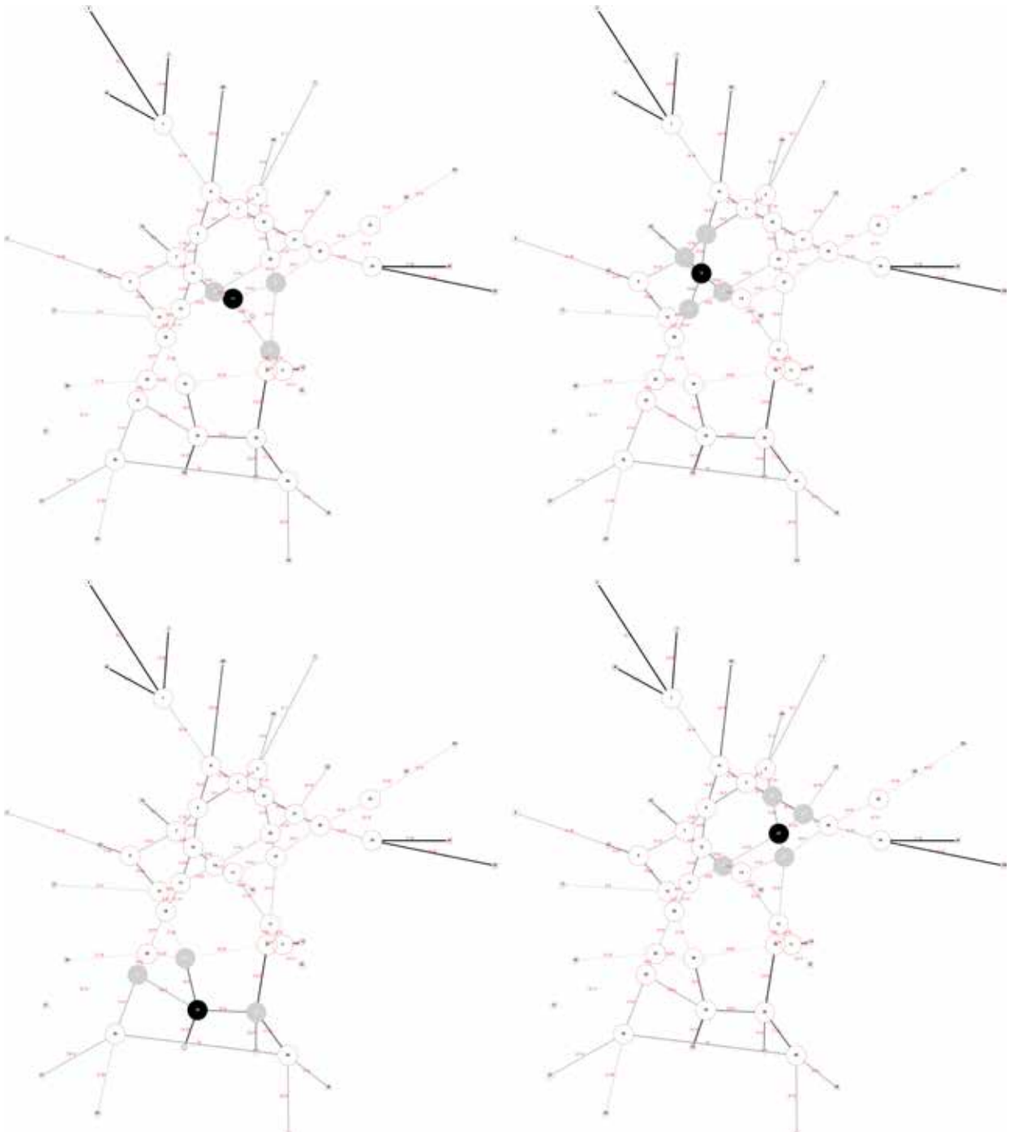

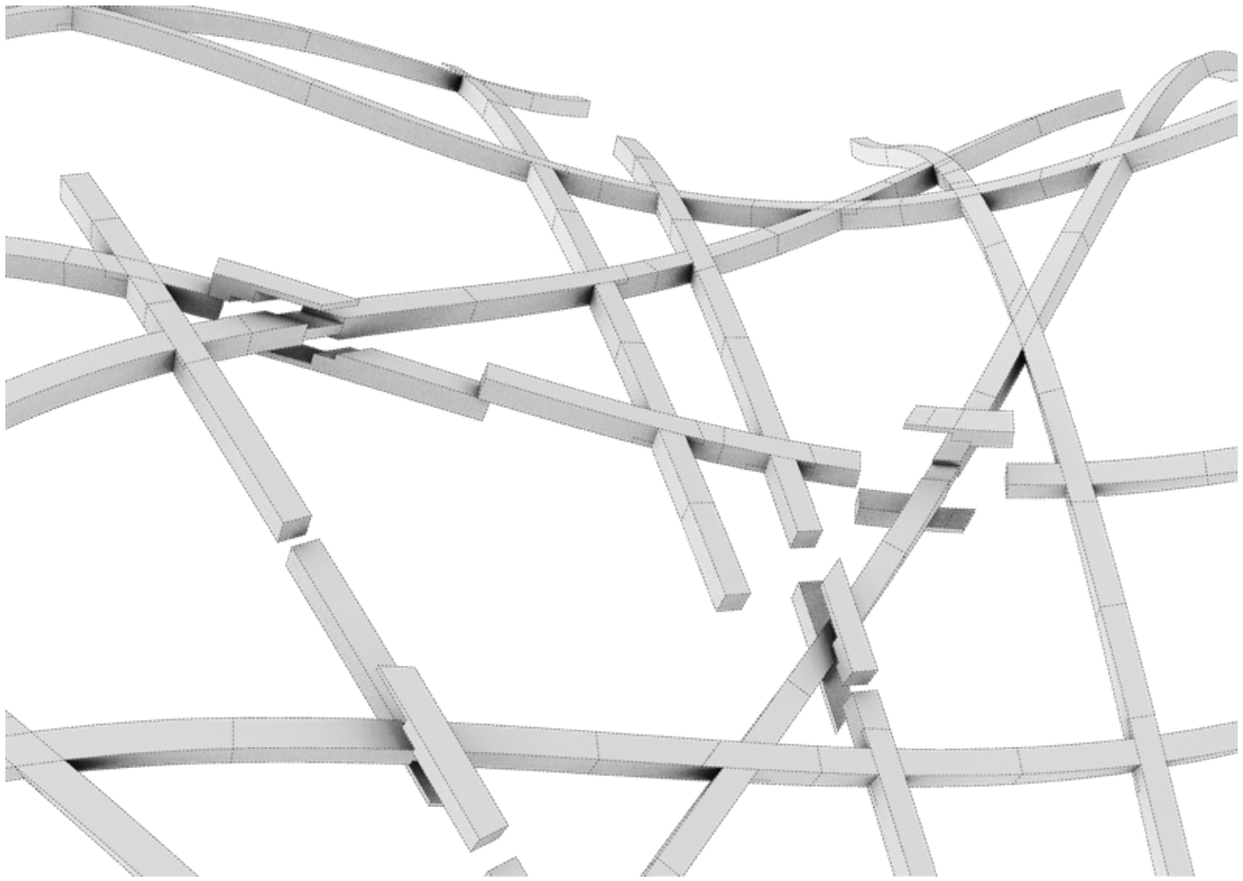

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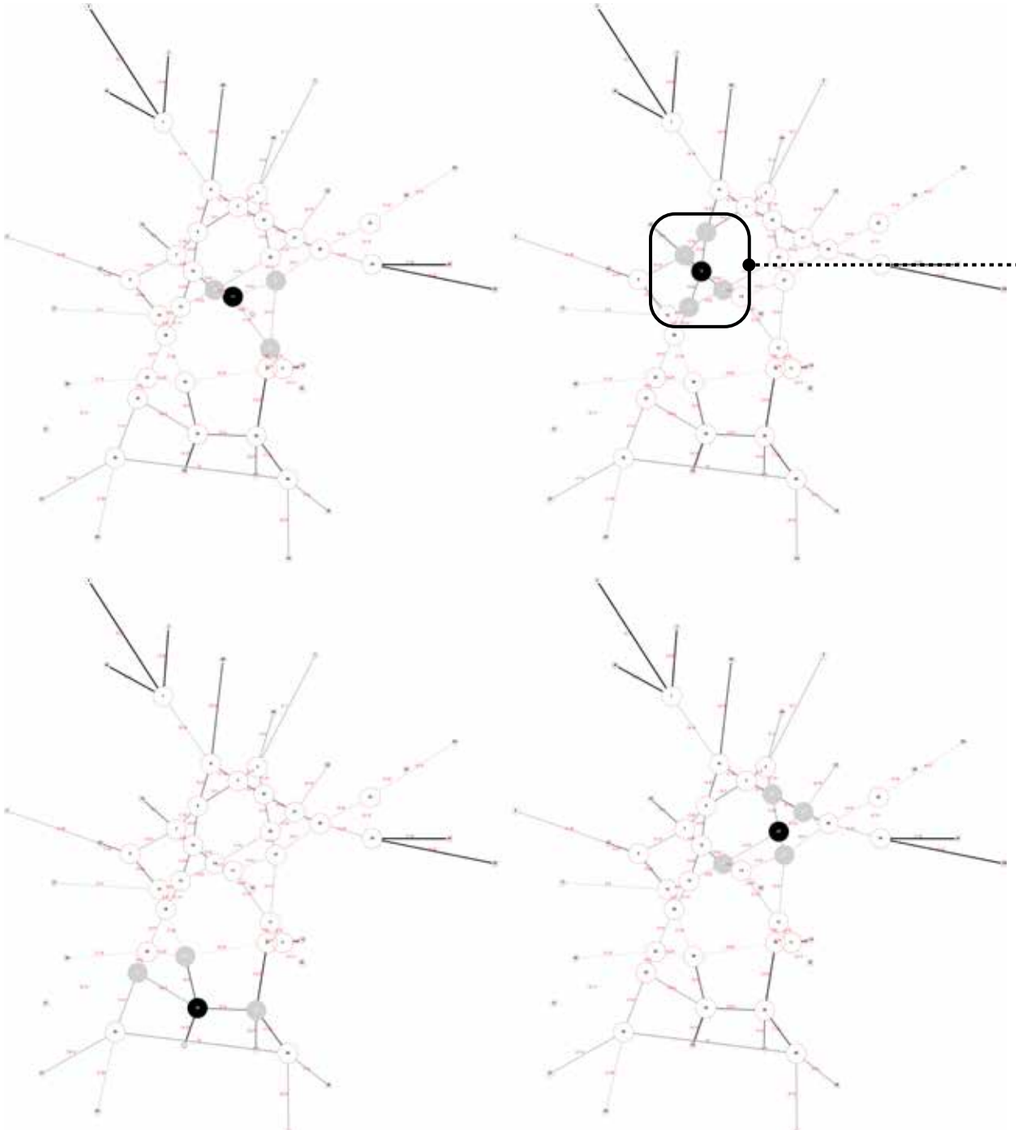

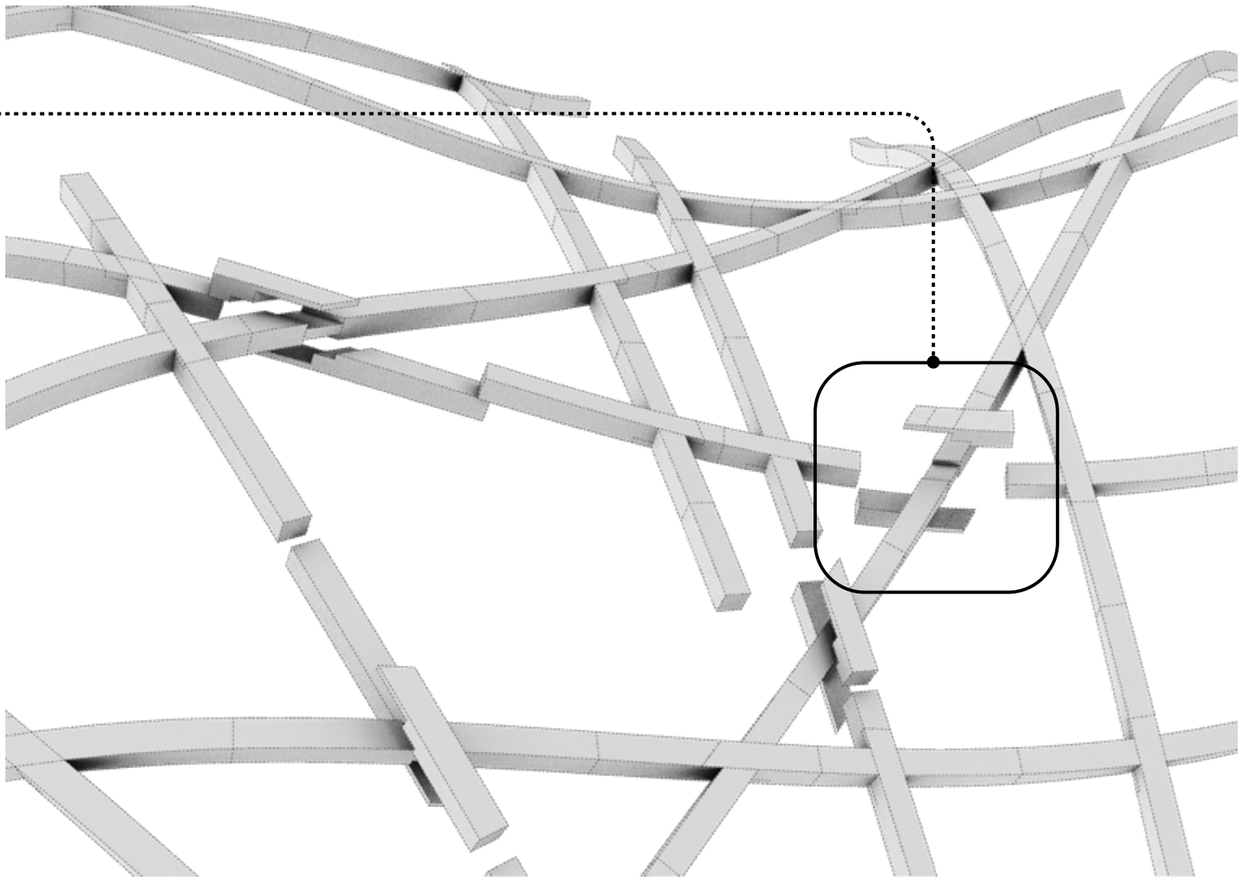

Multi-Scalar Modelling for Free-form Timber Structures

A2 - Topological Mapping: Modelling Lap Joints

Key question:
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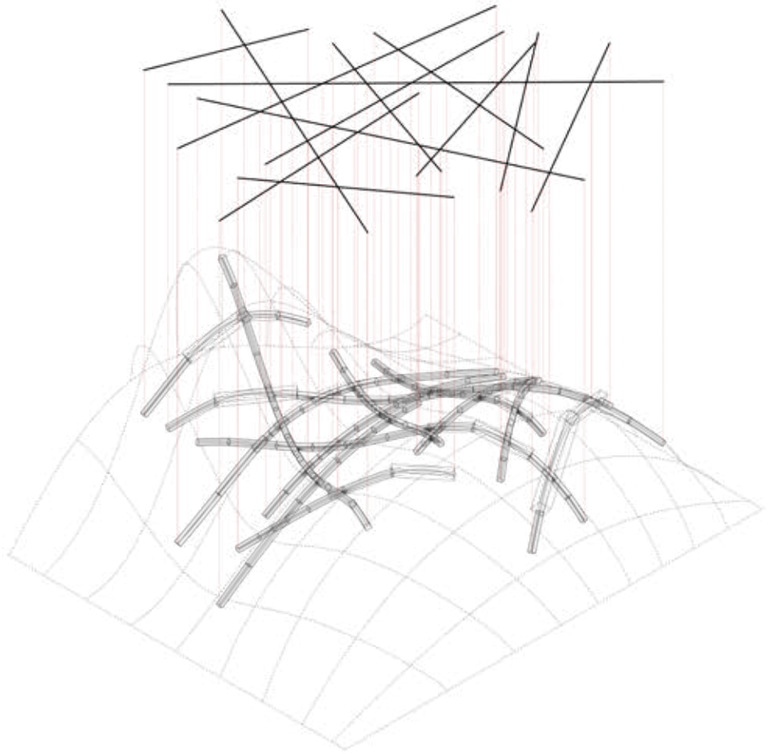
Result

The different features implemented within the present modelling experiment allowed the user to **visualize complexity, search and query the model in a more intuitive manner than through the more traditional Direct Modelling method**.



Limitations / link to the next experiment

The present computational pipeline solved a very particular design problem by allowing only two beams to intersect into one particular lap joint type. Therefore, the next modelling experiments will attempt to demonstrate that the same **graph modelling methodologies** employed within the present experiment can be further deployed and stress-tested against more intricate joint typologies and modelling frameworks.

Multi-Scalar Modelling for Free-form Timber Structures

A3-A4 - Topological Mapping: Projection-based Modelling | Spatial Branching

Key question:
"How can the computational designer be able to navigate more easily between different scales during the design process?"

VIDEO PLACEHOLDER

Multi-Scalar Modelling for Free-form Timber Structures

A3-A4 - Topological Mapping: Projection-based Modelling | Spatial Branching

Key question:
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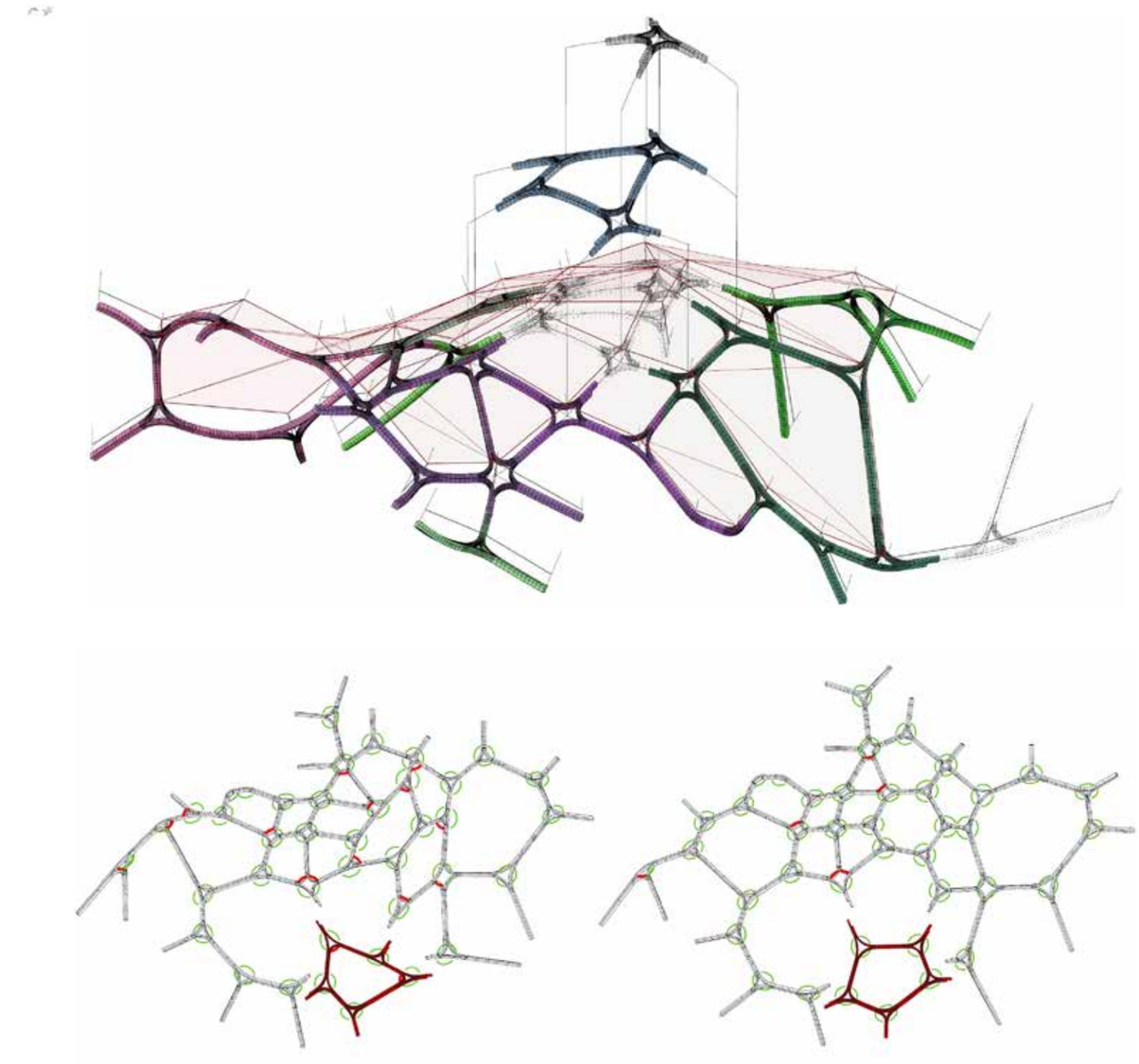
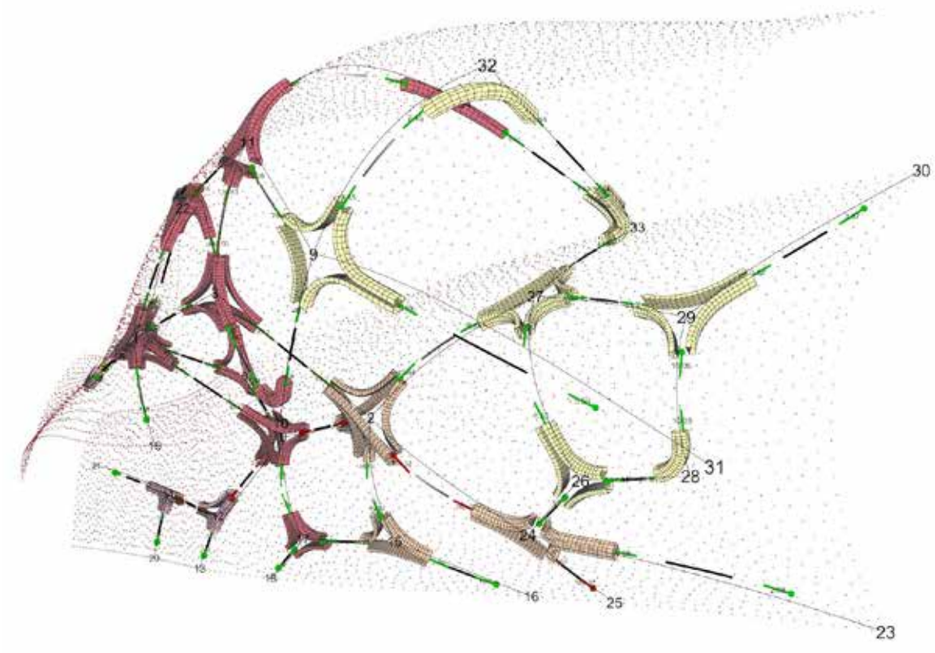
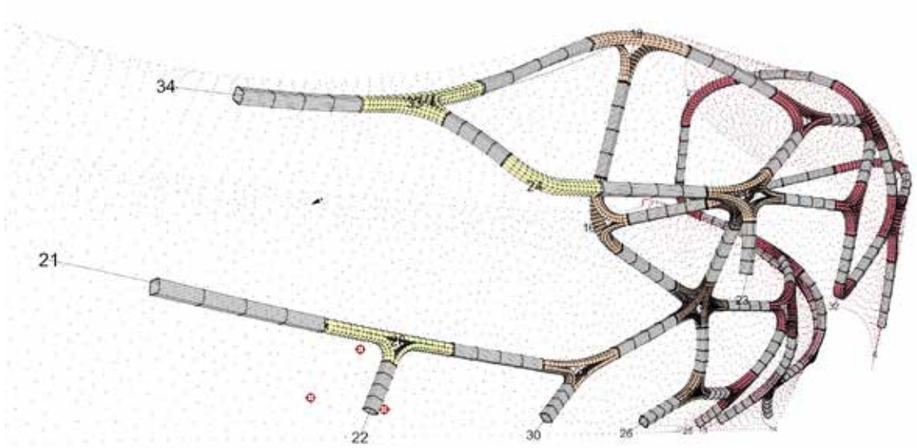






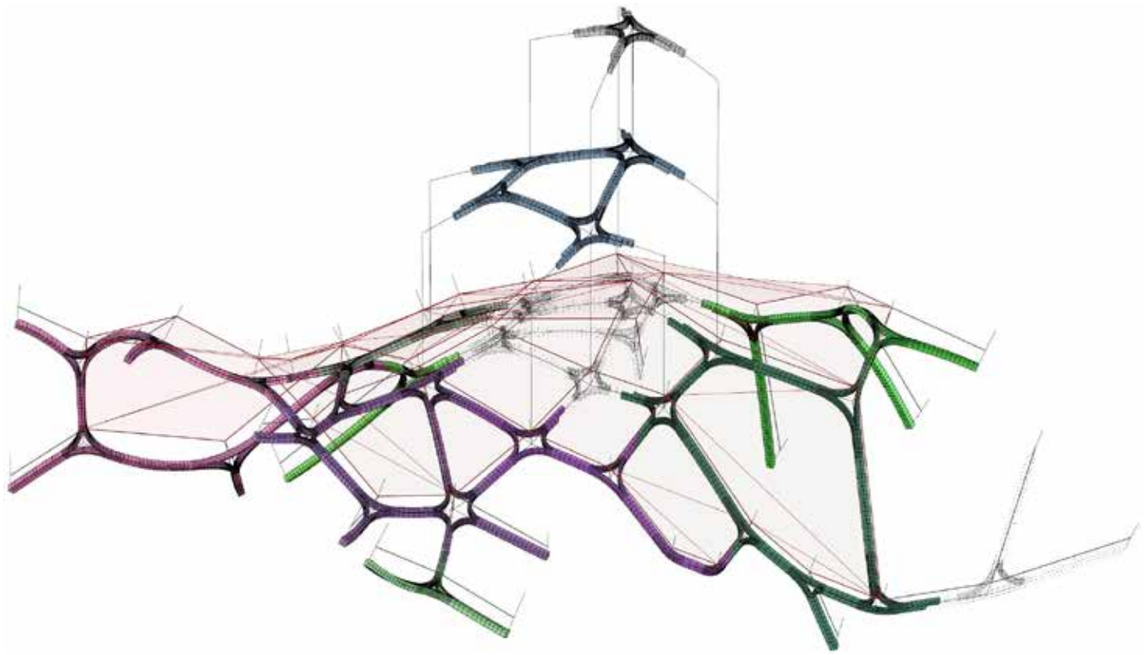
Multi-Scalar Modelling for Free-form Timber Structures

A3-A4 - Topological Mapping: Projection-based Modelling | Spatial Branching

Key question:
"How can the computational designer be able to navigate more easily between different scales during the design process?"

Result

Through multiple stress-tests against different source models, free-form surfaces and complex joint types, the present experiment also demonstrated a **frictionless user experience during the design process, while navigating between the different scales**.



Limitations / link to the next experiment

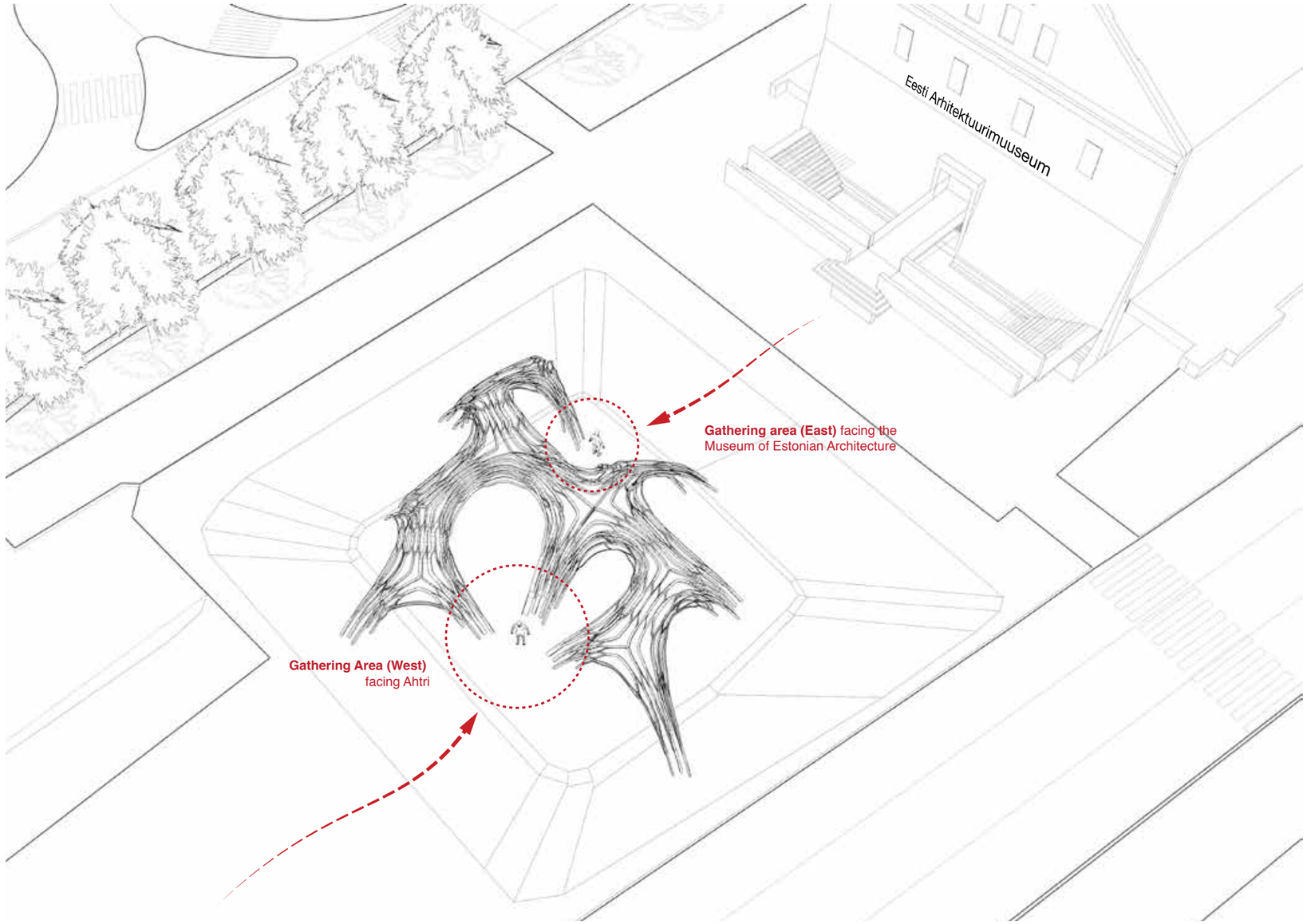
This modelling experiment was very useful to investigate practically the benefits of the Separation of Concerns within computational design pipelines and workflows. Although some of the methods applied here proved to be **useful to improve data access**, search and user experience during the design process, it was quite **challenging to craft every single design exception in the design process**, so that the node typologies could adapt to any particular situation (tangency to a master surface, high valence number, etc.).

The Multi-Scalar Modelling methods developed so far during the previous experiments have been tested and deployed through multiple external research activities, such as the next experiment: A5 - The Tallinn Architecture Biennale Installation Competition (2017)

Multi-Scalar Modelling for Free-form Timber Structures

A5 - The Tallinn Architecture Biennale Installation Competition (2017)

Key question:
"How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?"



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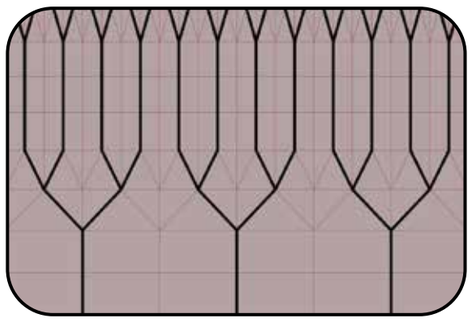
Abstract Network



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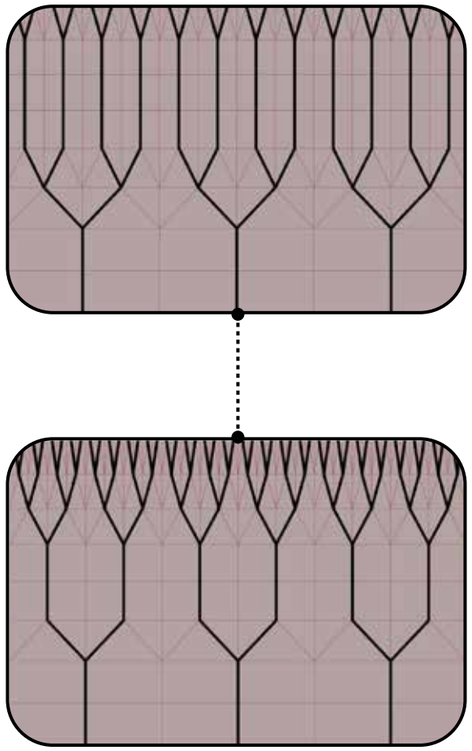

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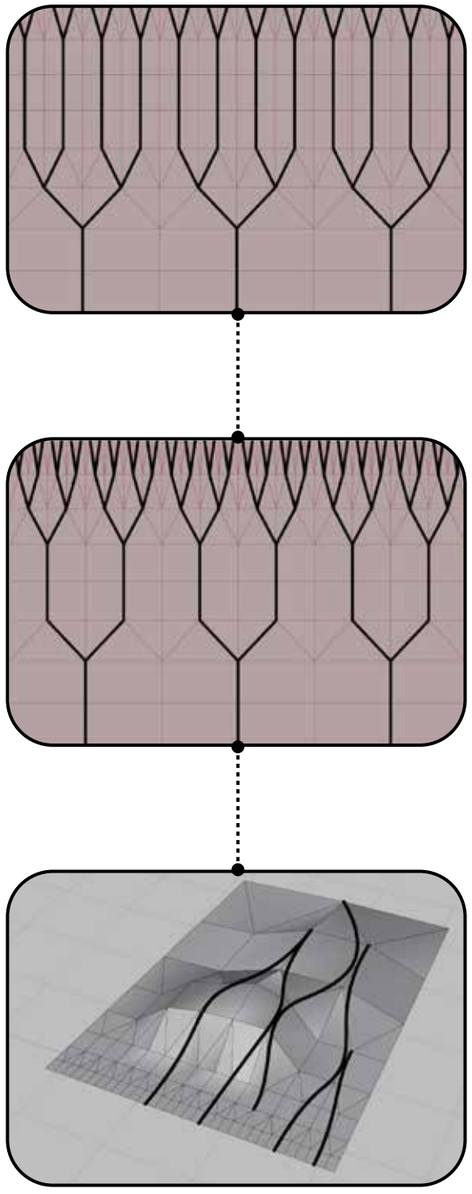

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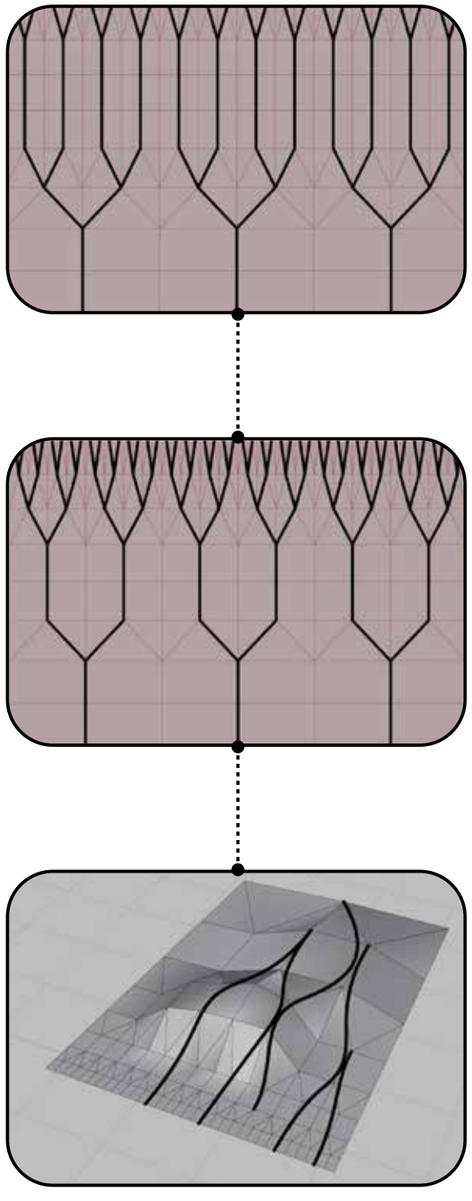
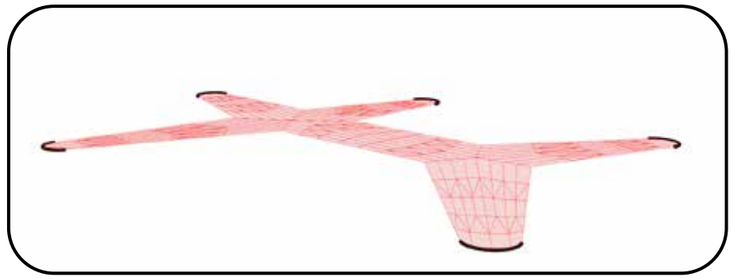


Base mesh generation



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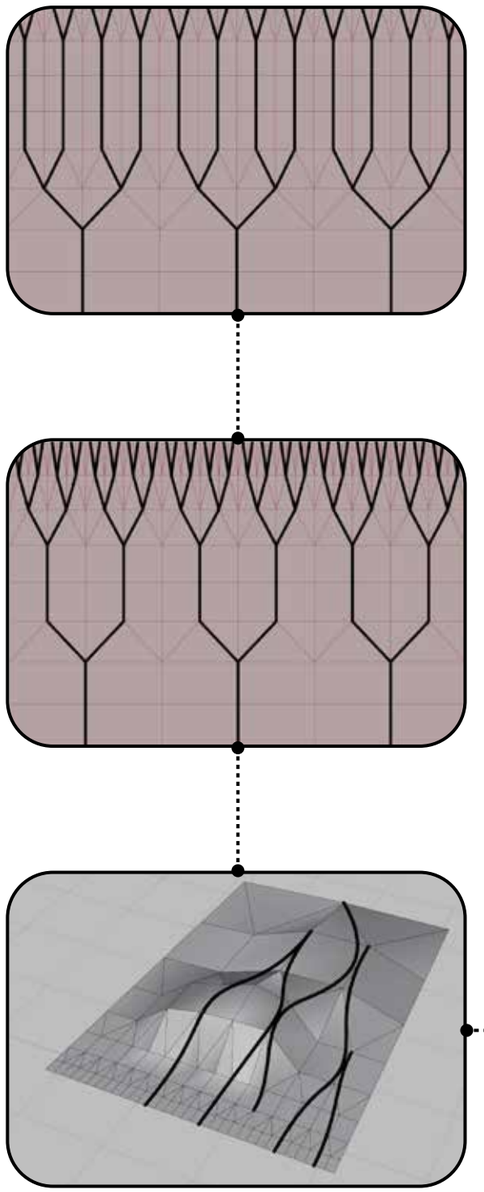
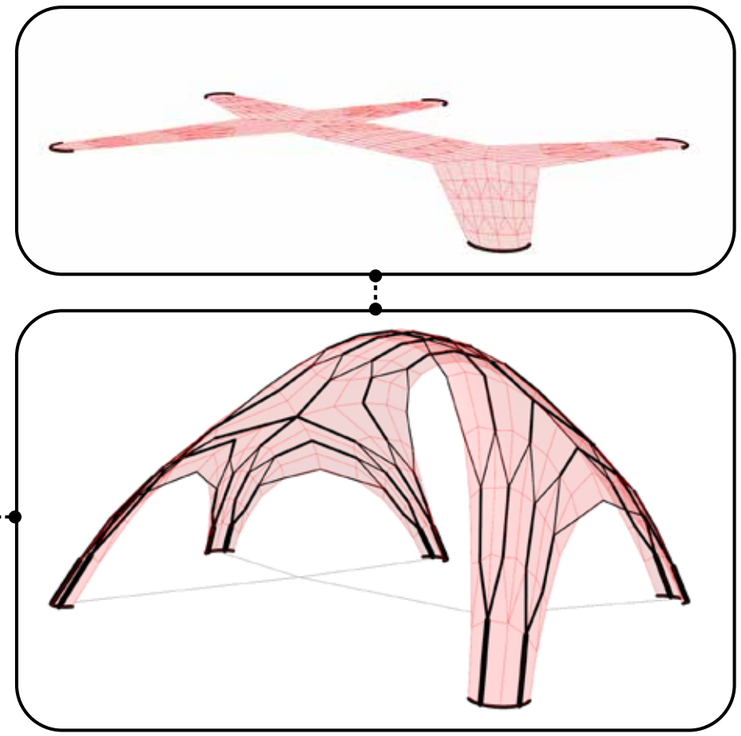


Base mesh generation



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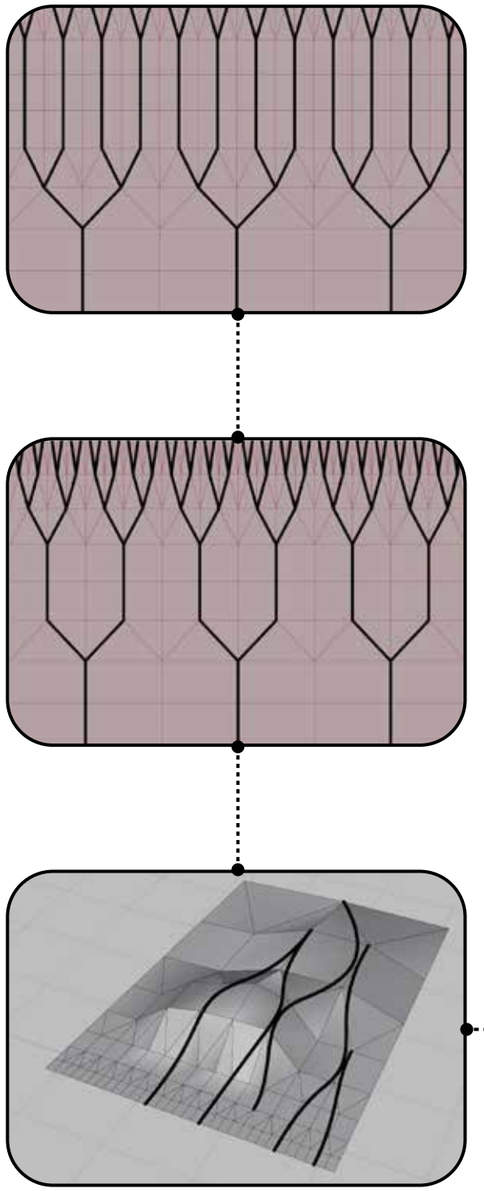

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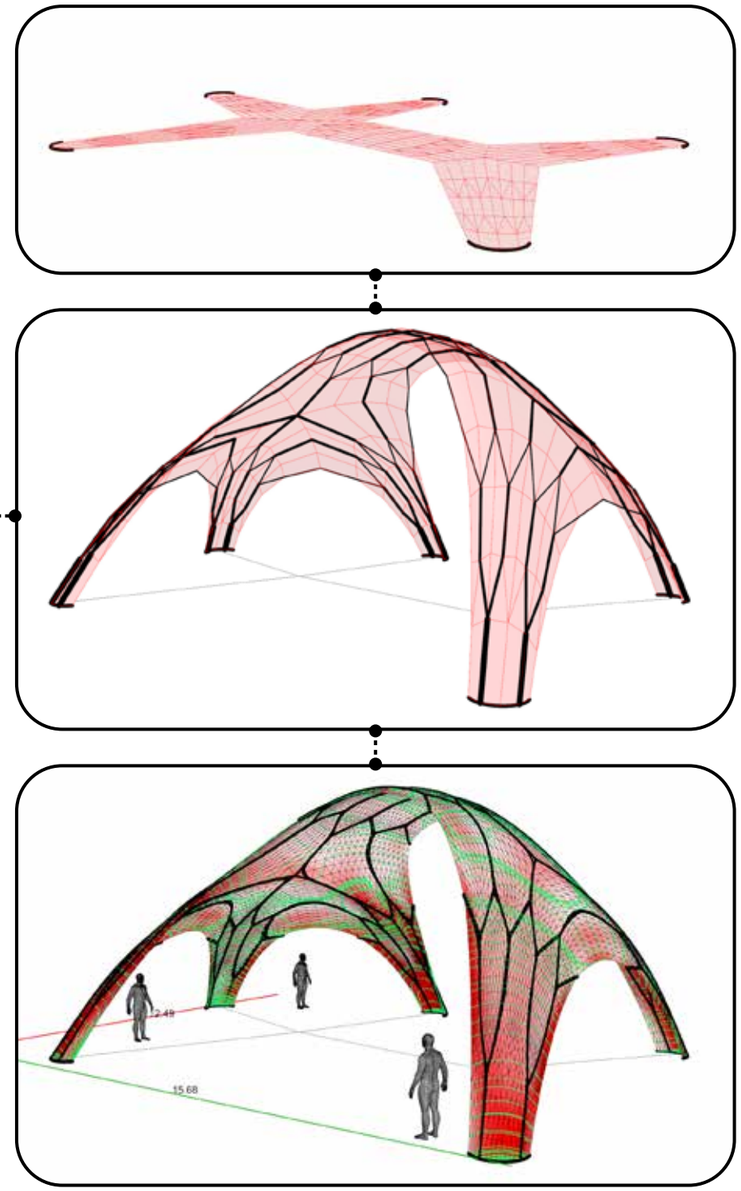

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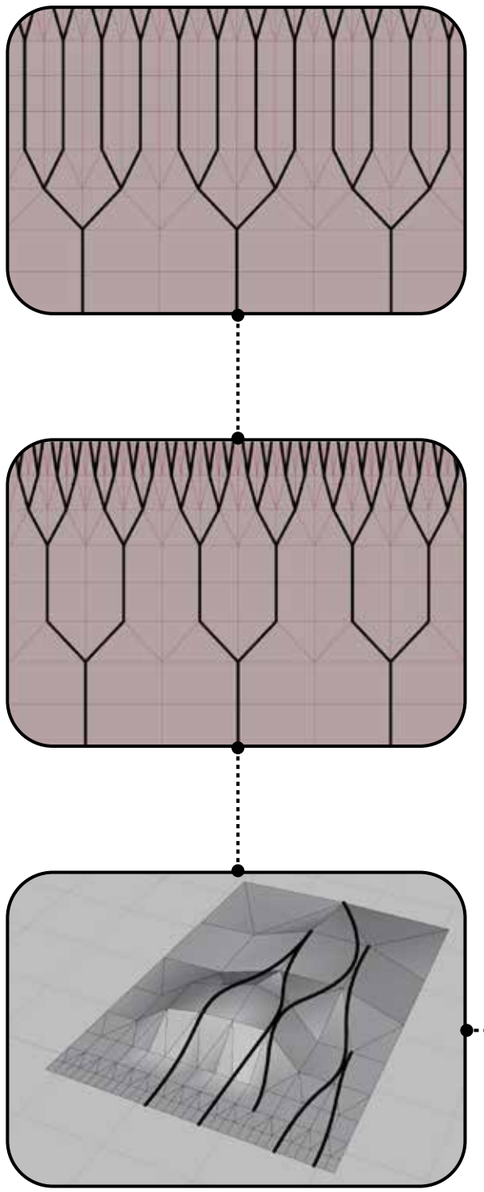

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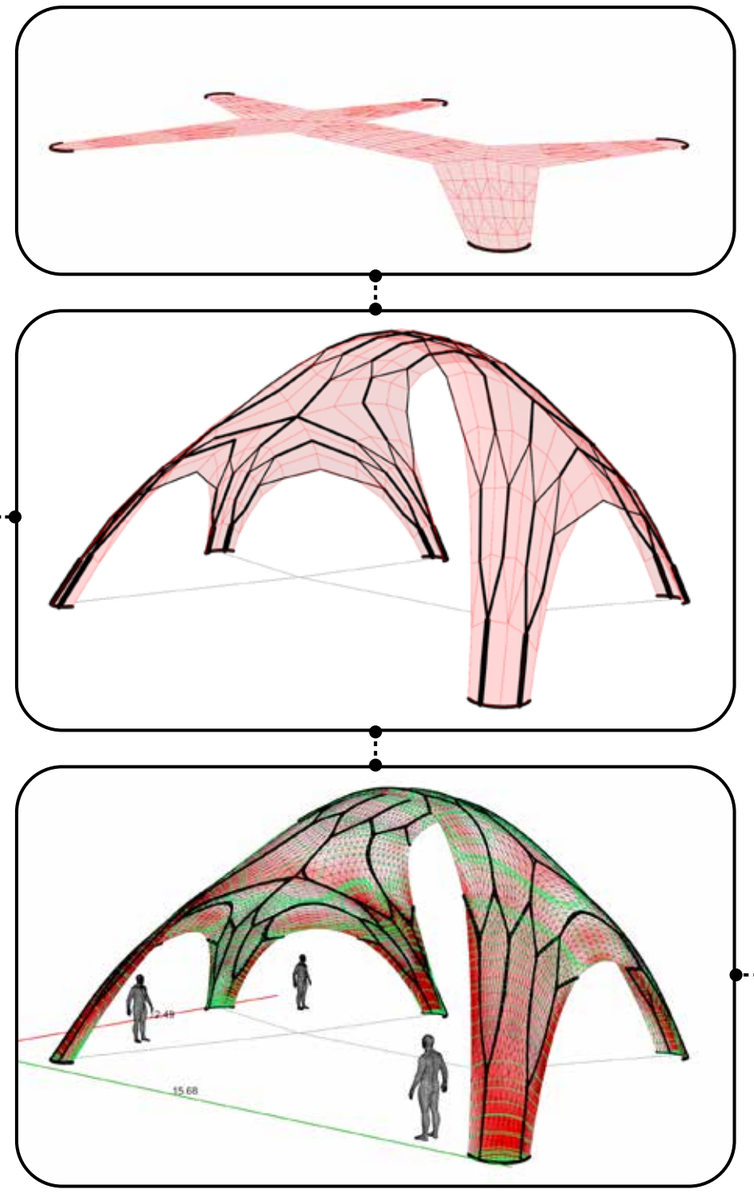
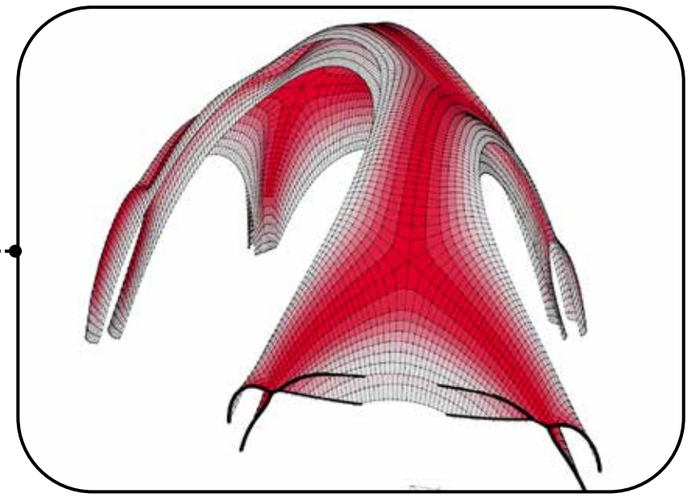


Mesh refinement and detailing



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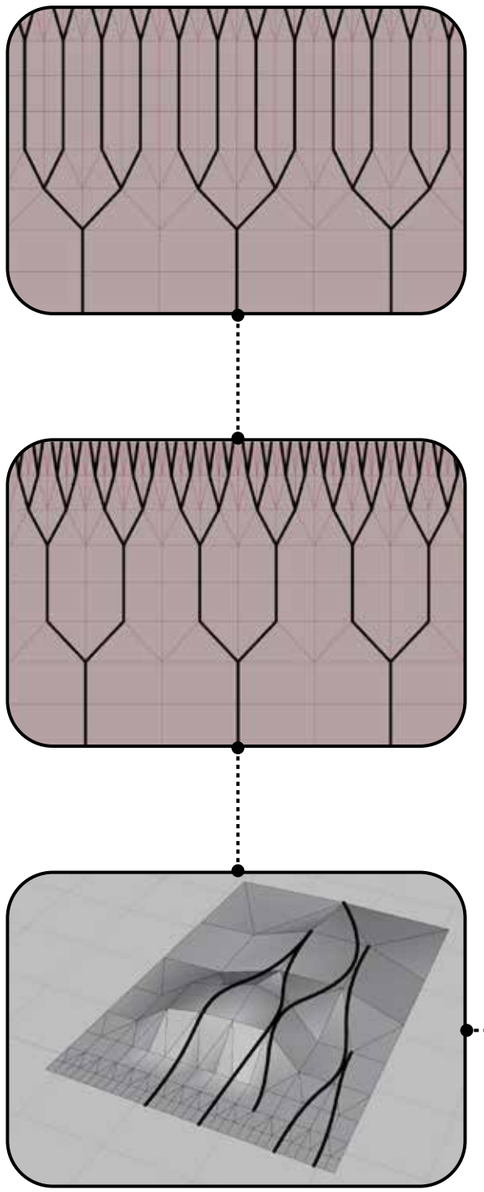

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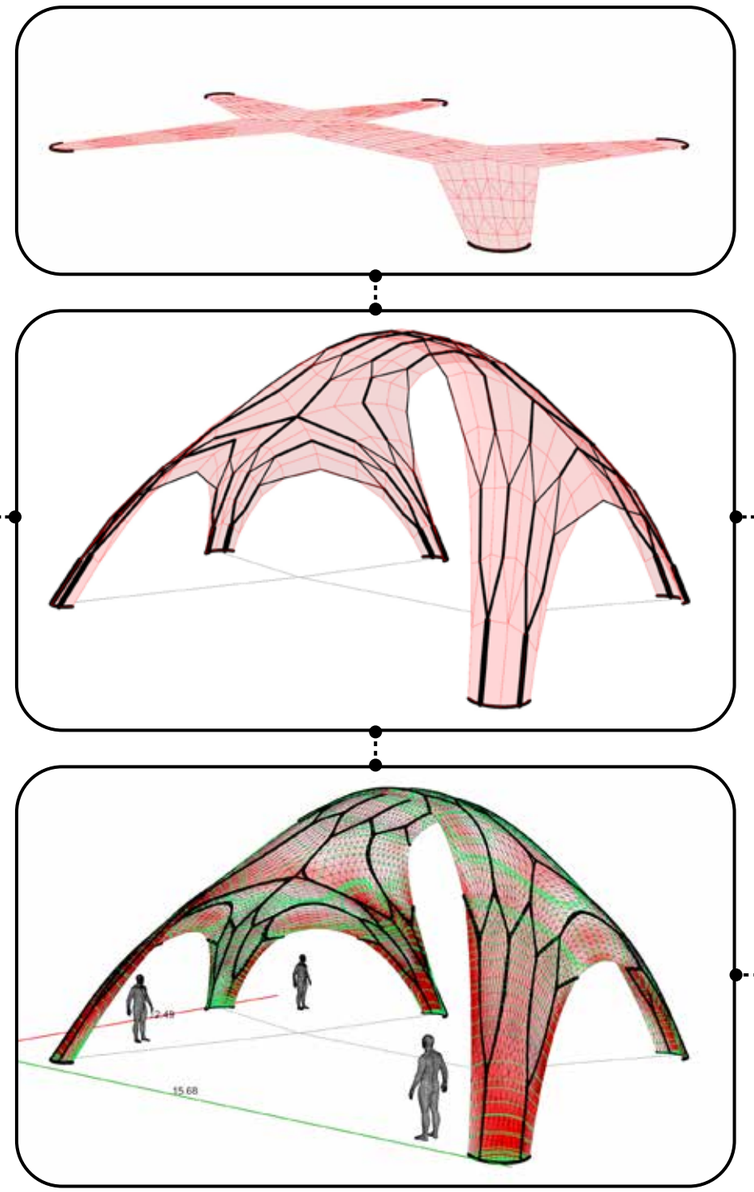
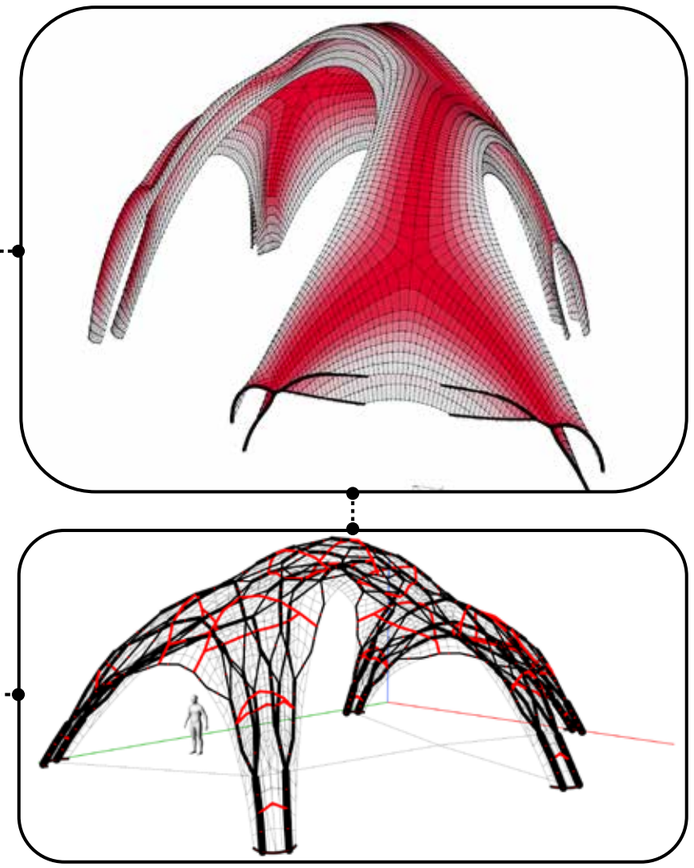


Mesh refinement and detailing



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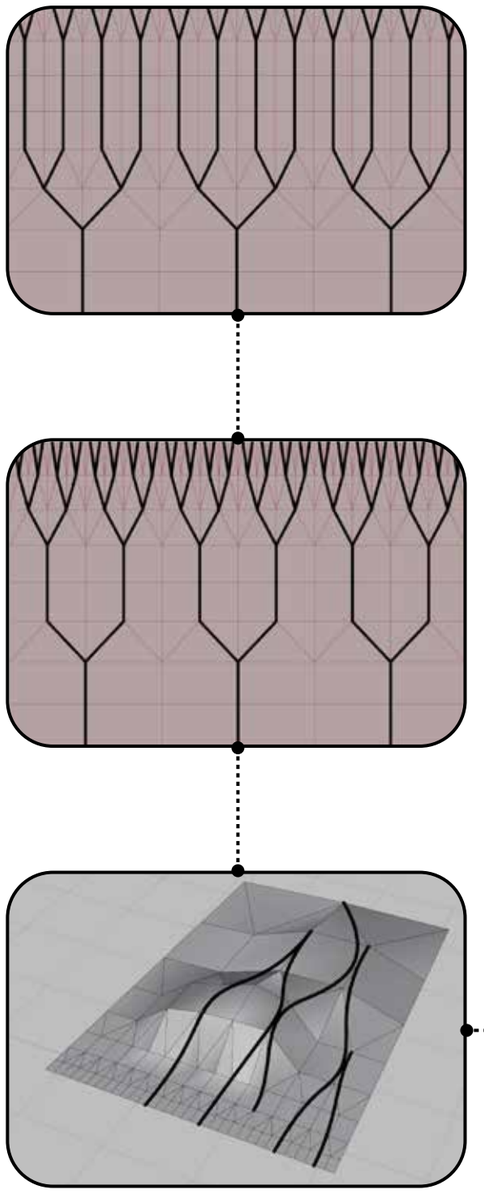
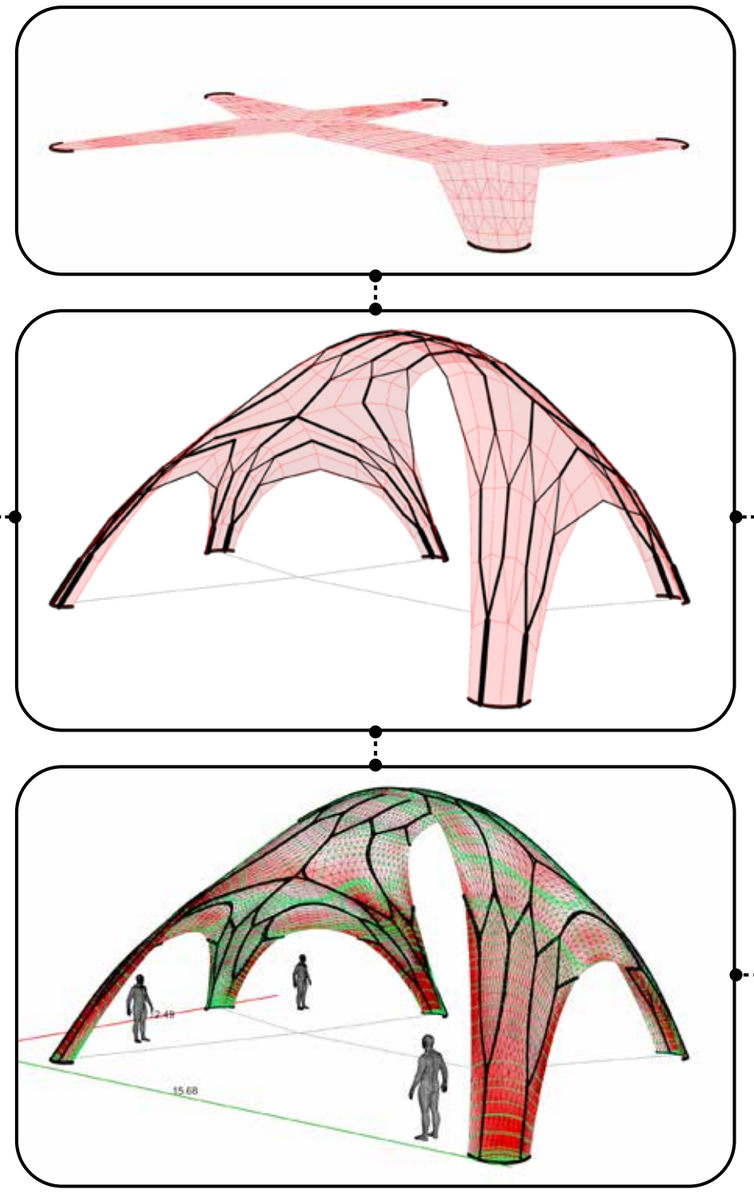


Base mesh generation



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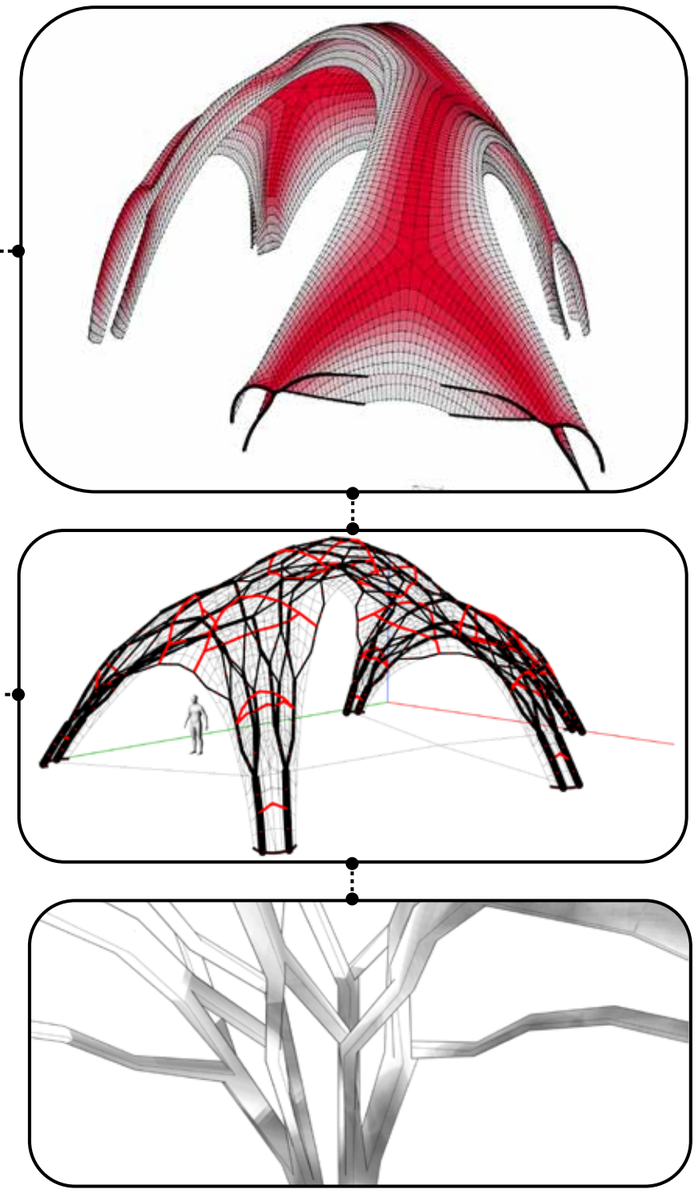

Multi-Scalar Modelling for Free-form Timber Structures

A5 - The Tallinn Architecture Biennale Installation Competition (2017)

Key question:
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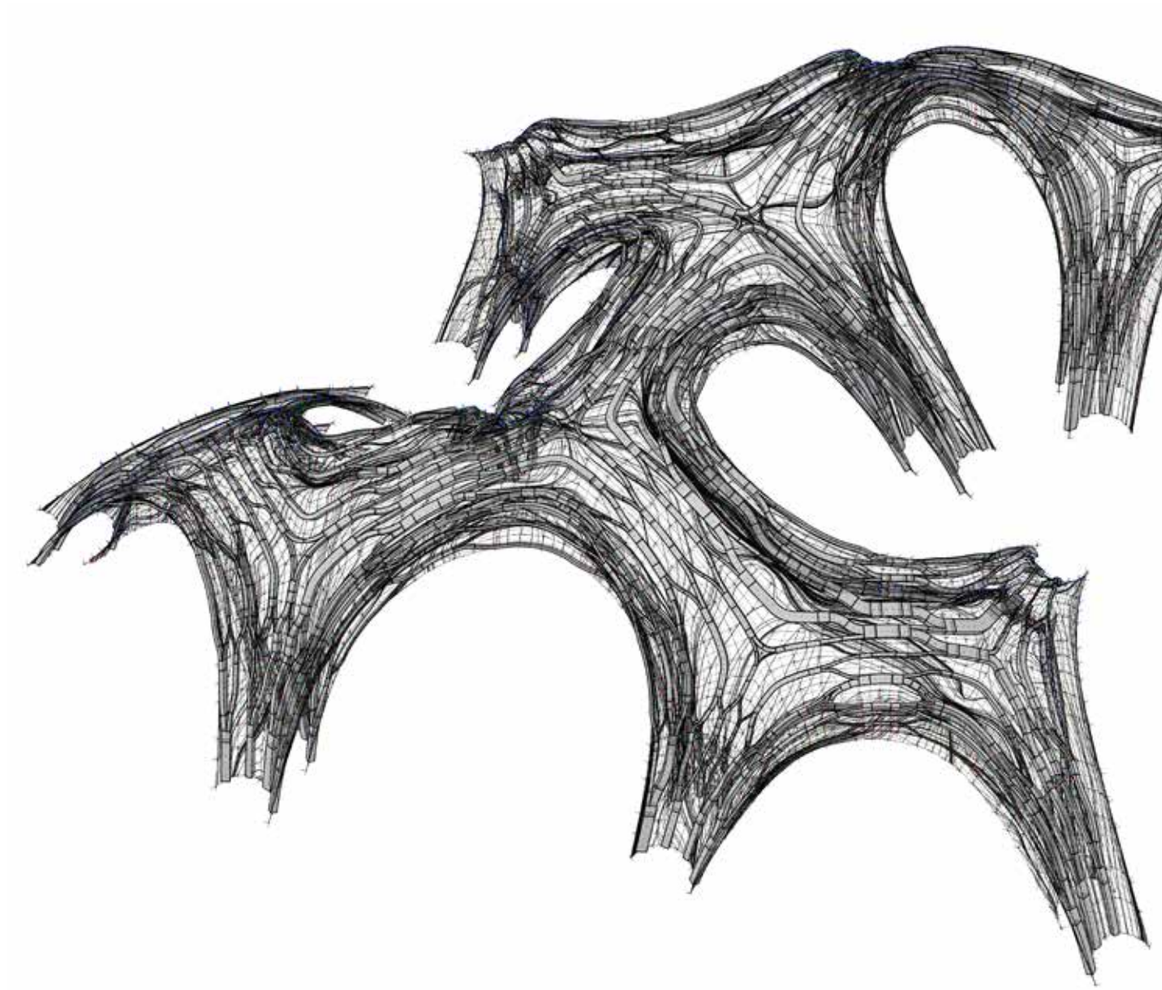
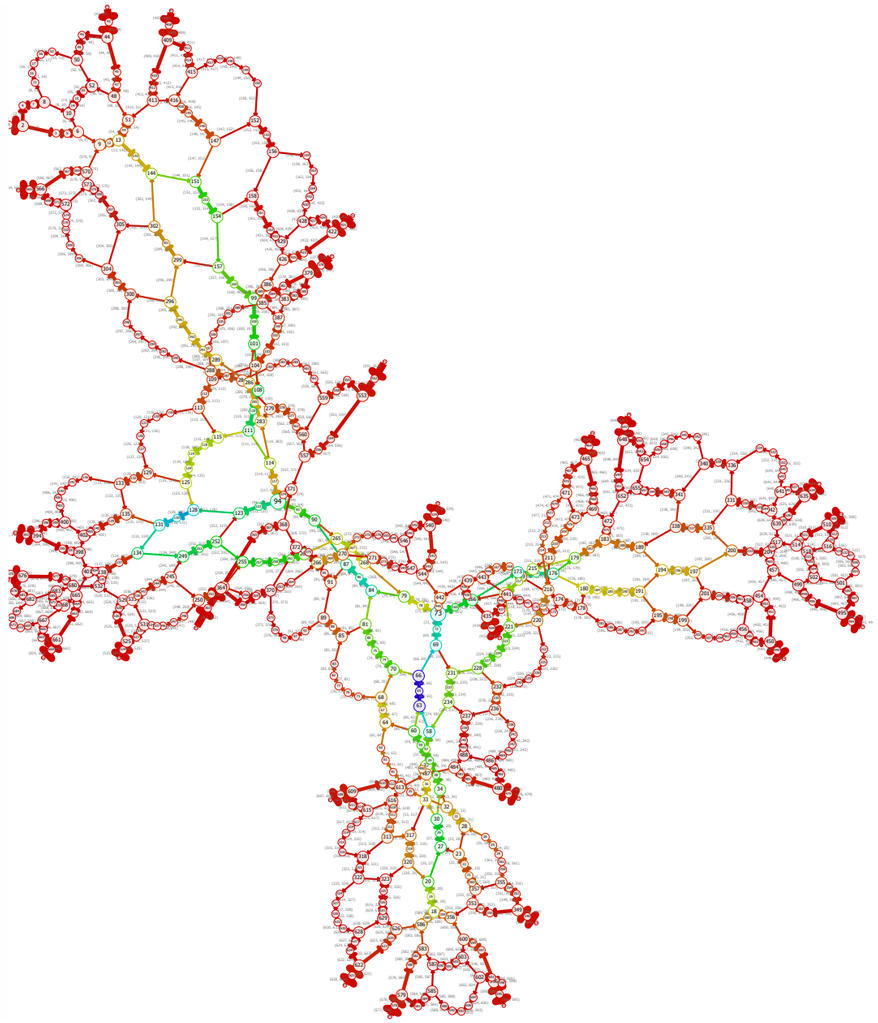
3D Model

Corresponding Graph





Multi-Scalar Modelling for Free-form Timber Structures

A5 - The Tallinn Architecture Biennale Installation Competition (2017) - 2nd Place

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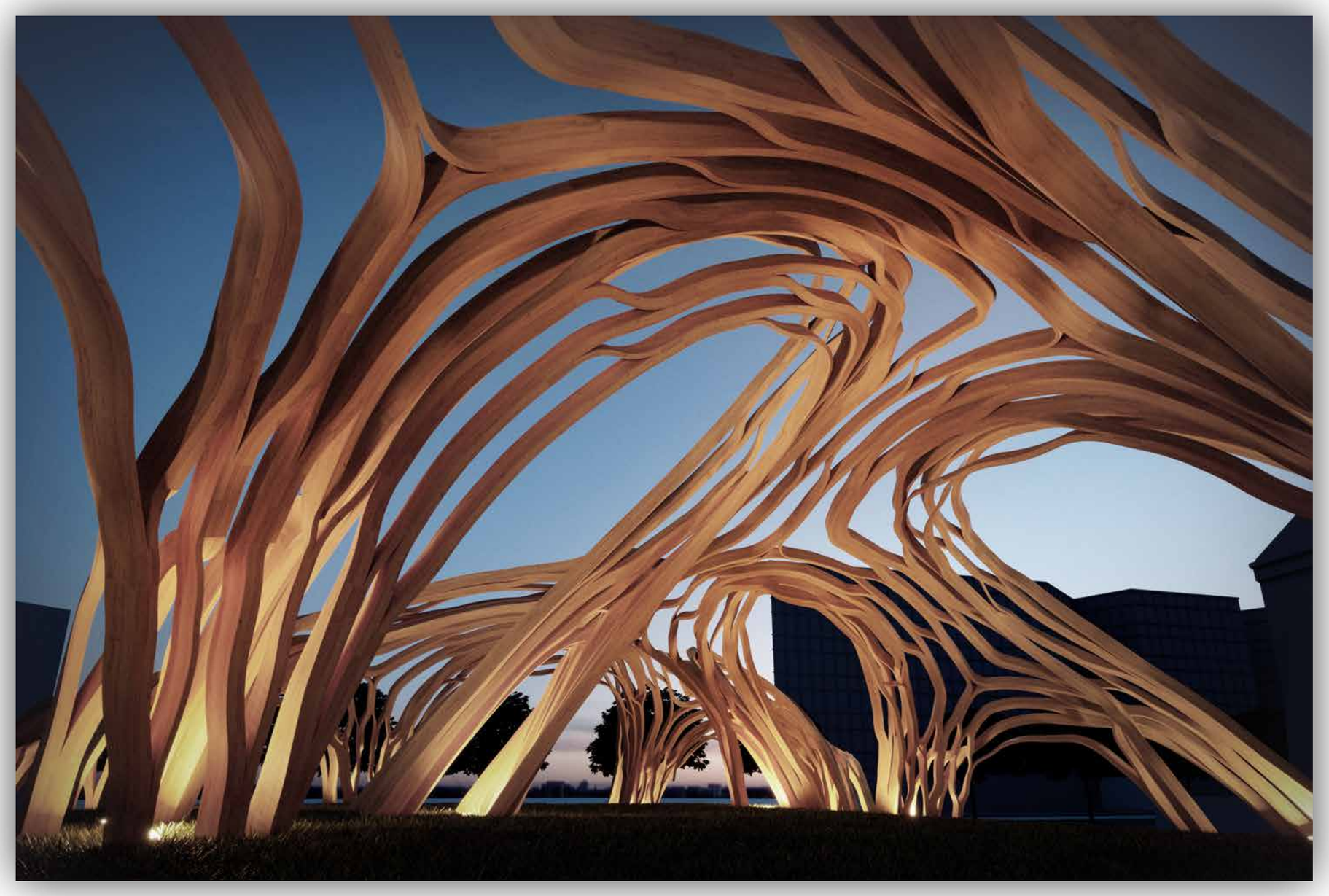

Multi-Scalar Modelling for Free-form Timber Structures

A5 - The Tallinn Architecture Biennale Installation Competition (2017)

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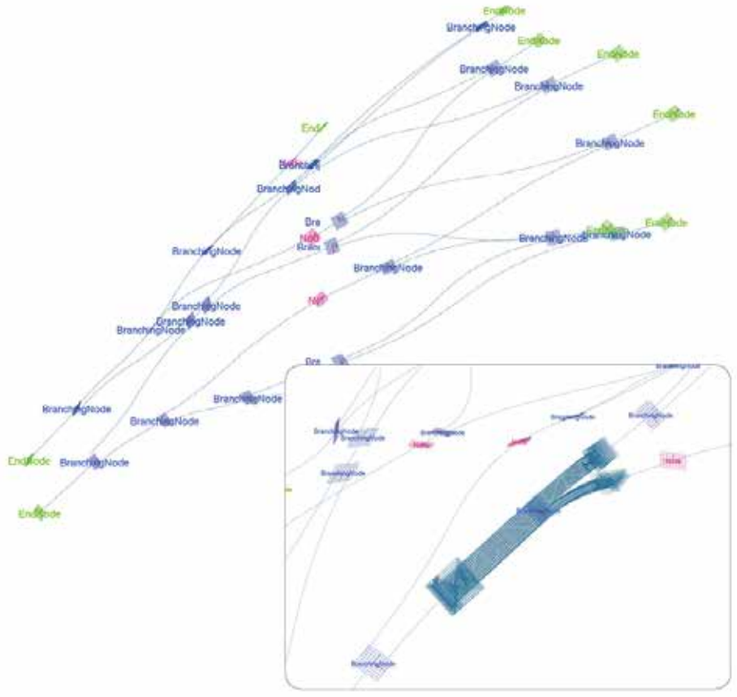

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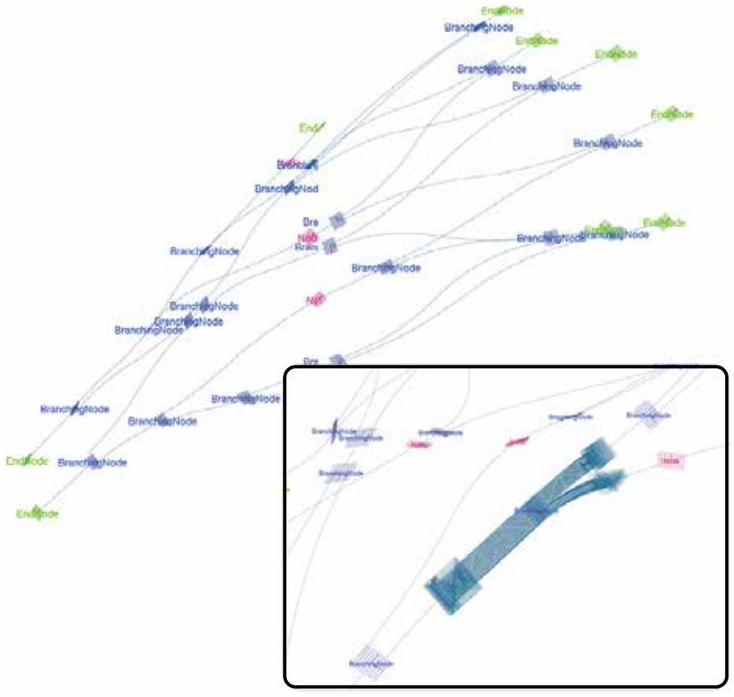

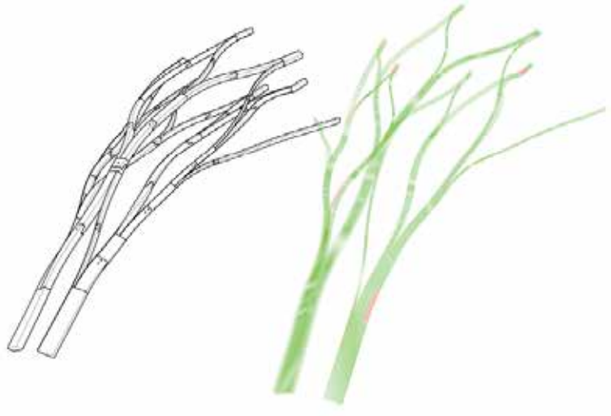

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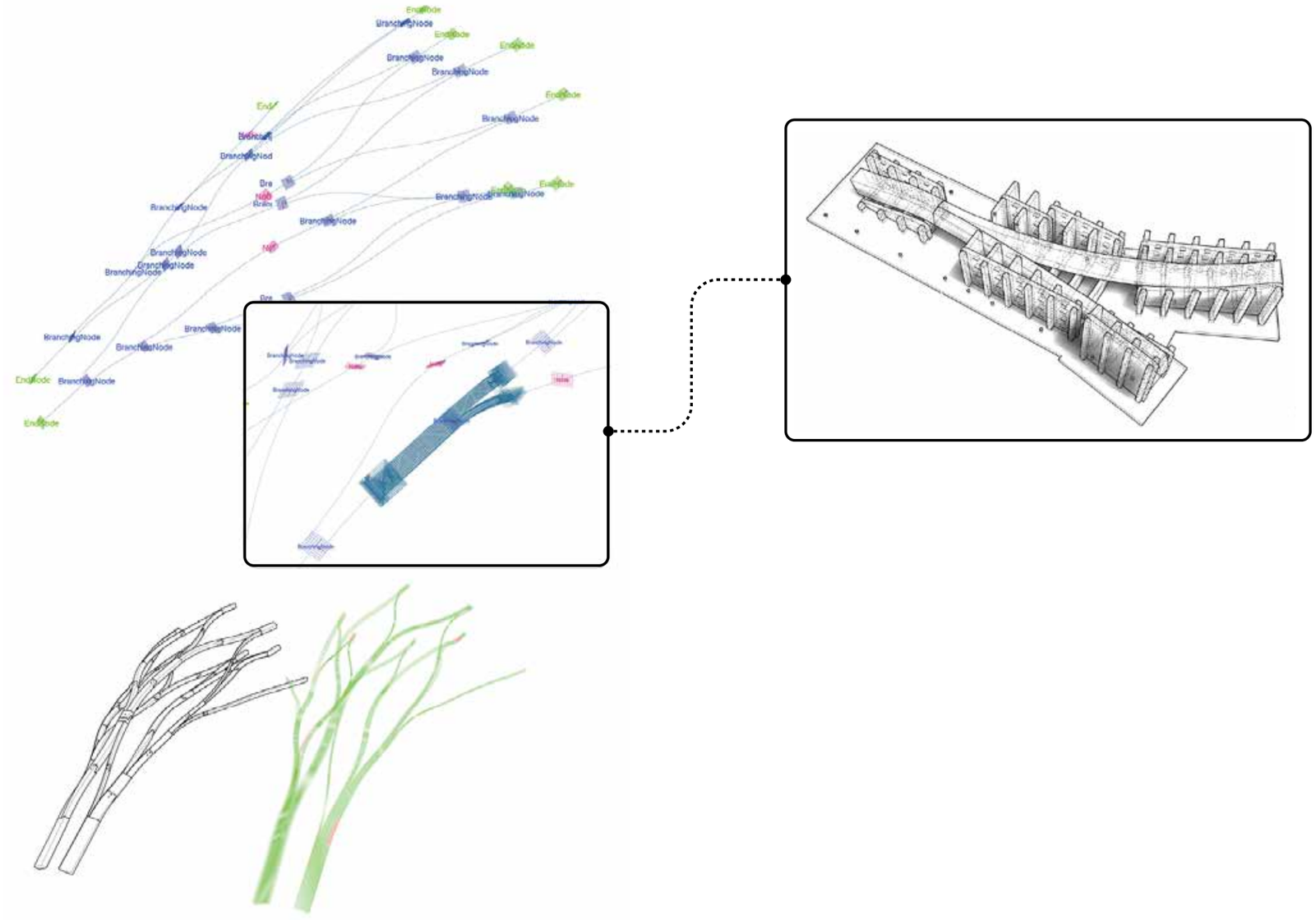

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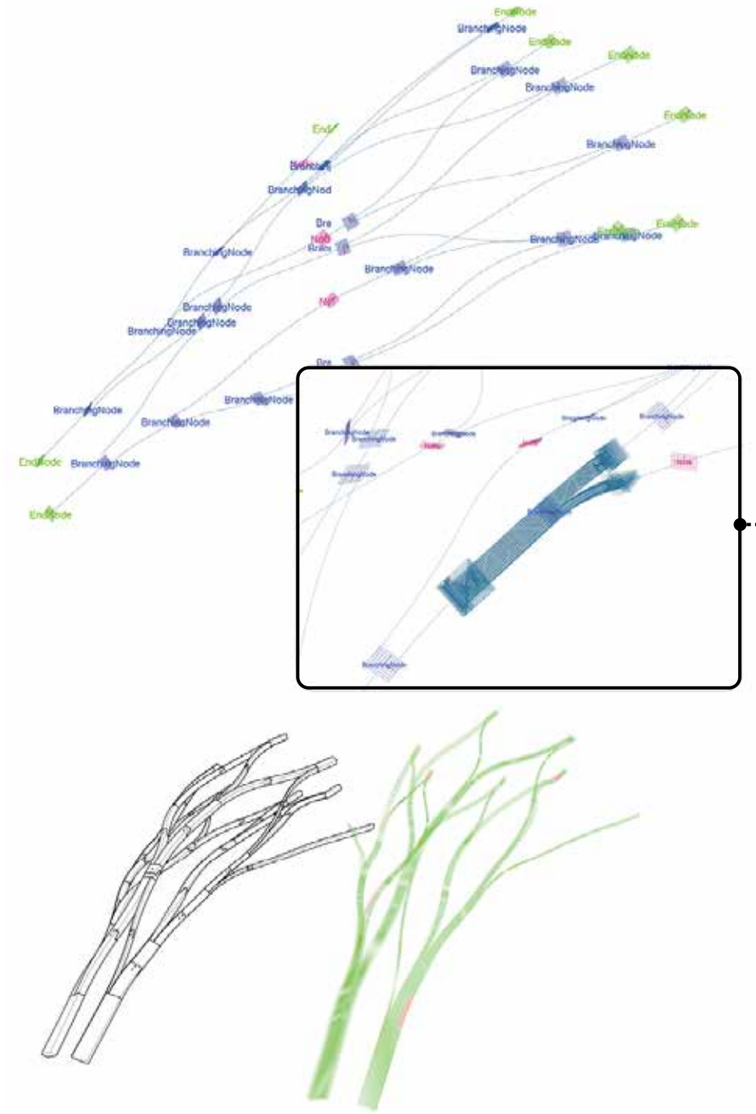

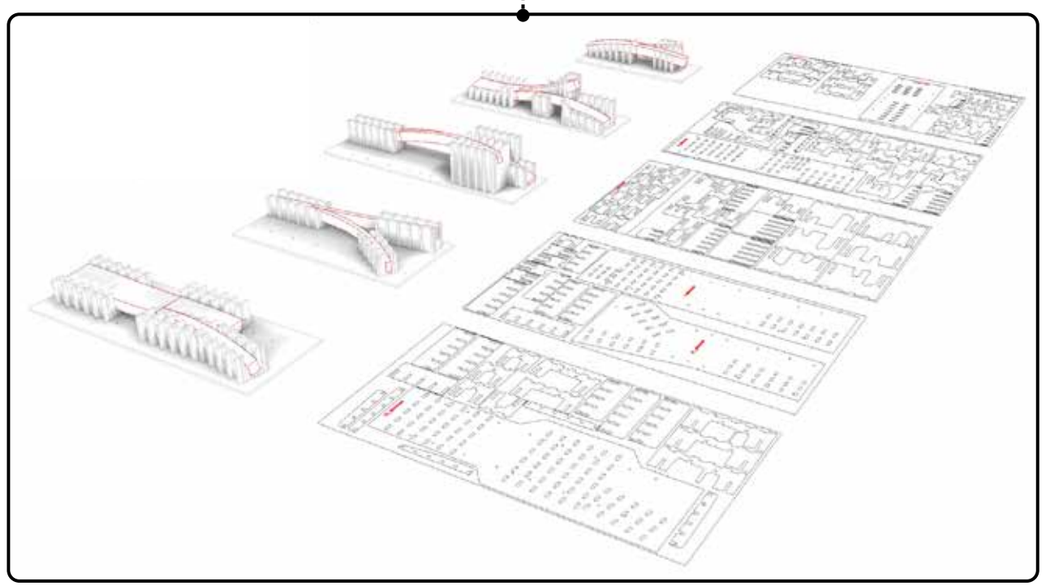

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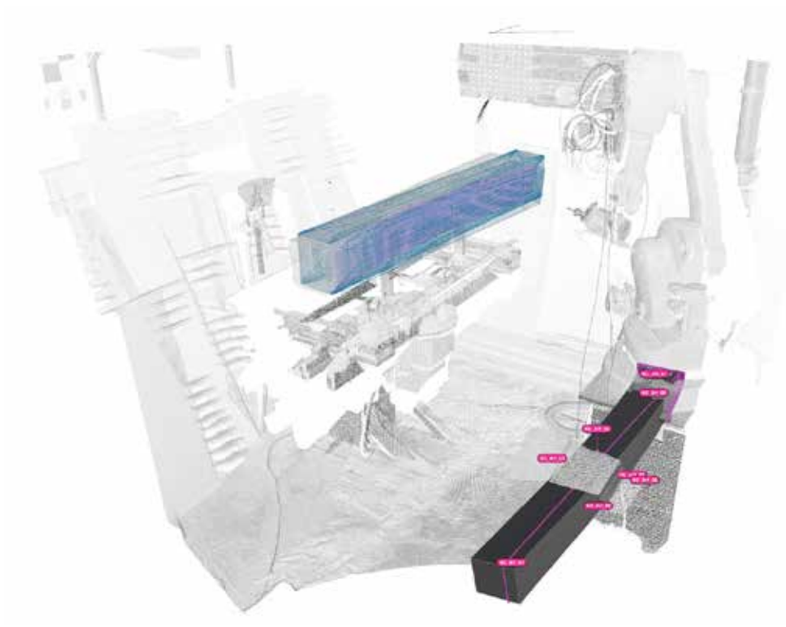
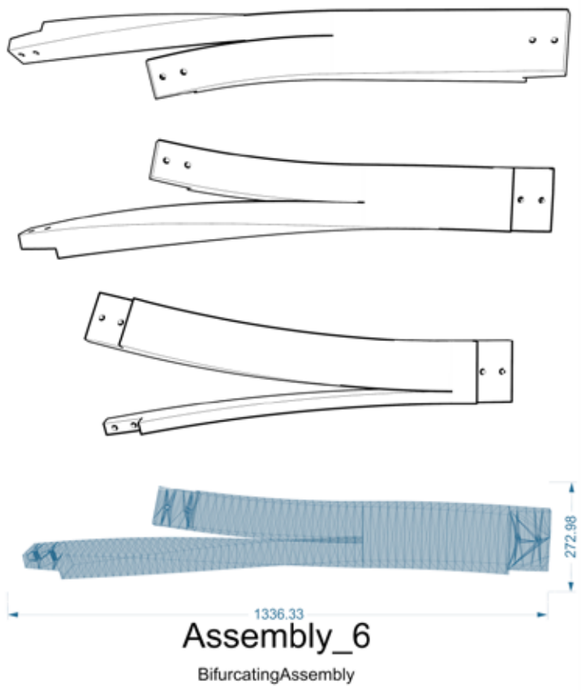
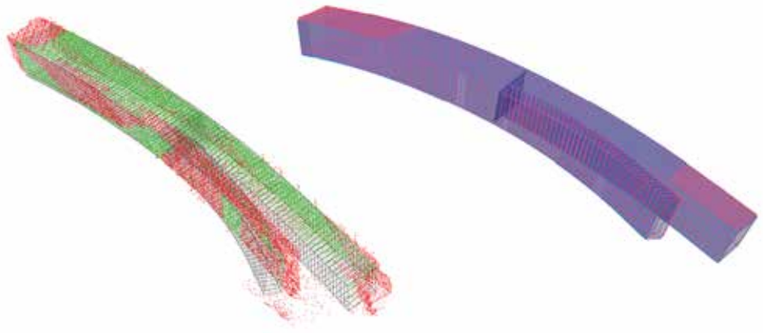
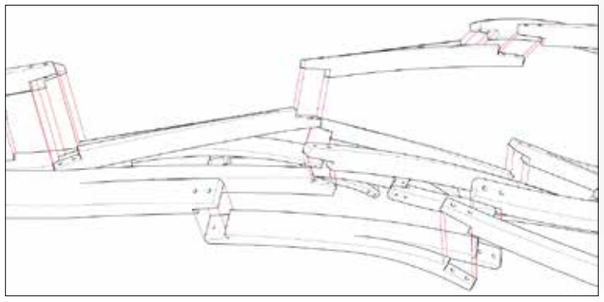




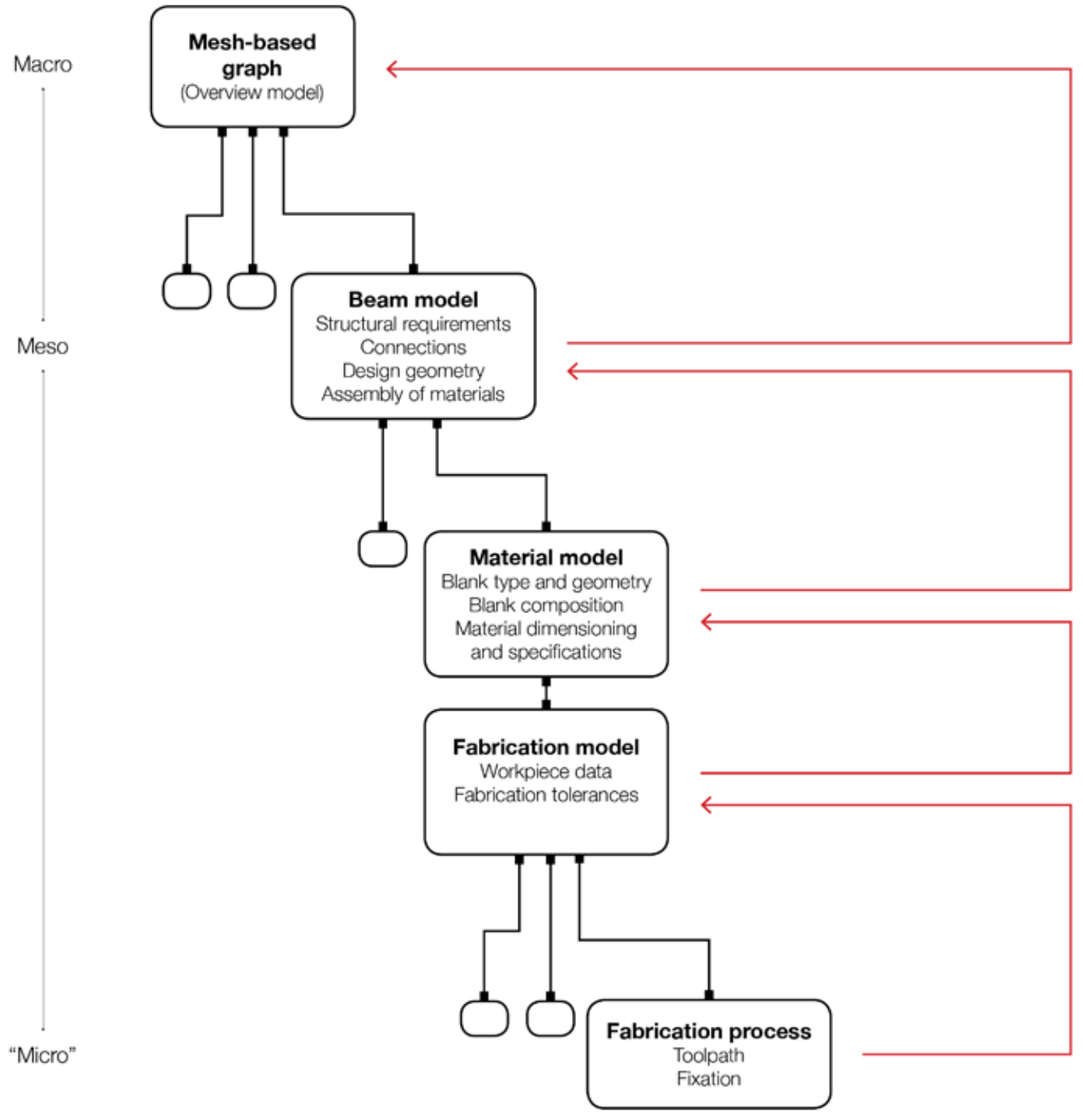




Multi-Scalar Modelling for Free-form Timber Structures

A5 - The Tallinn Architecture Biennale Installation Competition (2017)

Key question:
"How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?"



Learning from the experiment

A5 - The Tallinn Architecture Biennale Installation Competition (2017)

Key question:
"How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?"

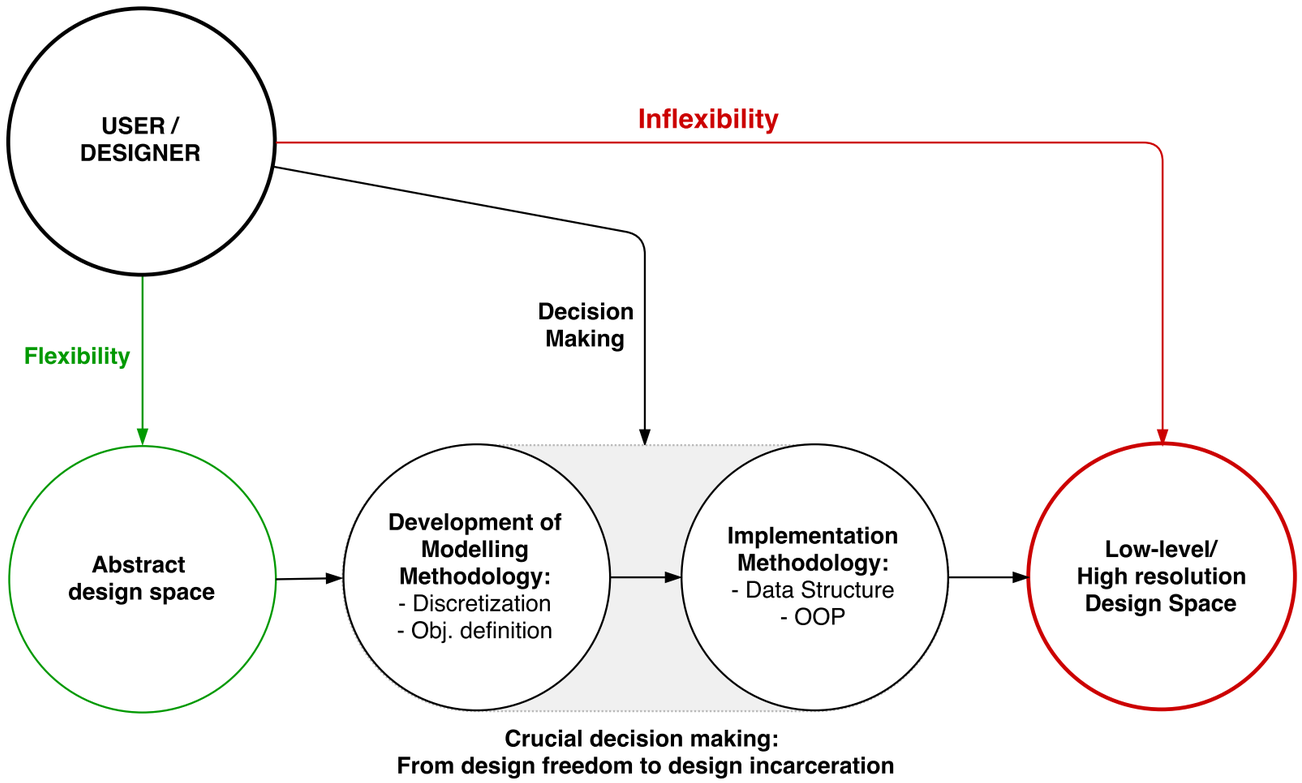
1. **Seamless design strategies & "integrated feedback loops" only exist partially.**

2. **Communication can be difficult.**

3. **A certain amount of residual models was created for this demonstrator-scale research project**

Academia

Academia has **the luxury to have a total control over the design intent across all scales and predict perfectly the outcome at early design stages**. Integrative design workflows can be deployed until all parameters are fullfilled.



Industry

In industry, the **design intent is a fallacy**. **Design happens throughout the project with the participation of all trades until completion of the building**.

"Premature optimization is the root of all evil."
- Knuth, 1972

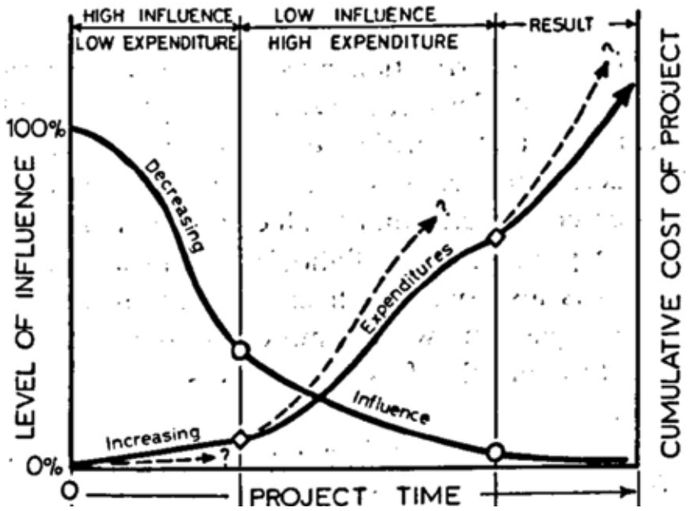
Early design strategies

Facing the classical "cost-of-change problem"...

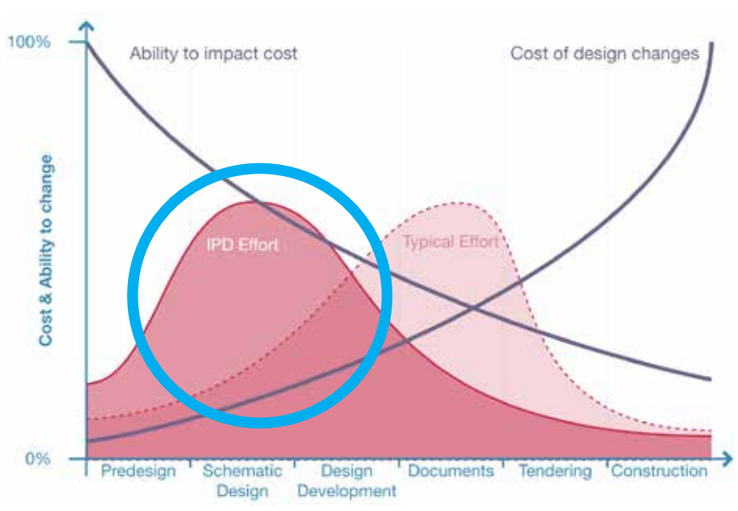
*...the usual "**early design**" answer...*

...and methods.

PROBLEM OBSERVATION	***PROPOSED SOLUTION***	***PROPOSED METHODS***
The cost of design changes increases during the timeline of a project	***The design effort should be placed at early design stage in the project***	***Early design research activies***



Paulson's curve (1976)

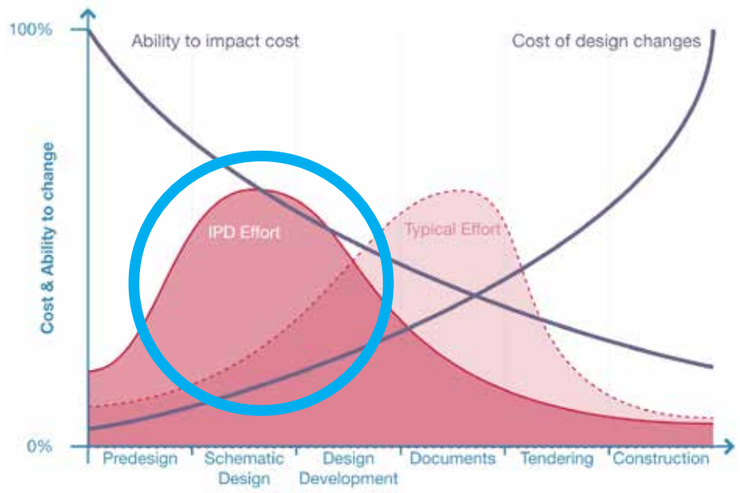


Paulson and MacLeamy's curve (Davis, 2013)

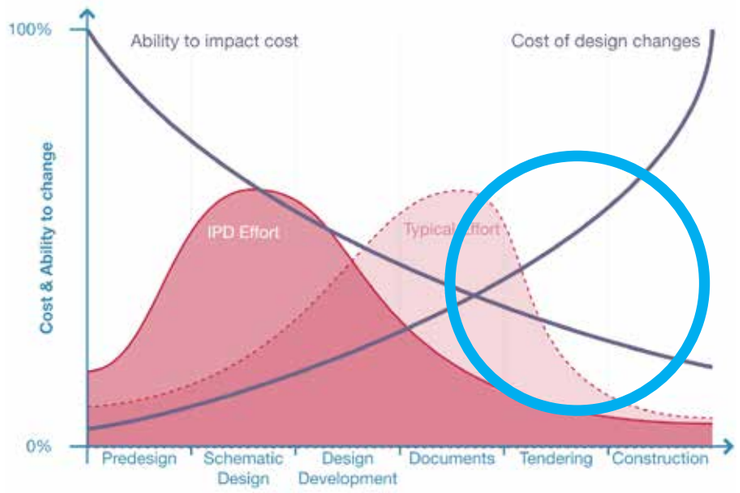
- ***early design*** analysis
- ***early design*** decision
- ***early design*** data management
- ***early design*** simulation
- ***early design*** optimization
- ***early design*** machine learning
- ***early design...*** ?

The problem also needs to be tackled from the other end of the spectrum.

Late changes can be prevented...



...but they will most probably have to be challenged...



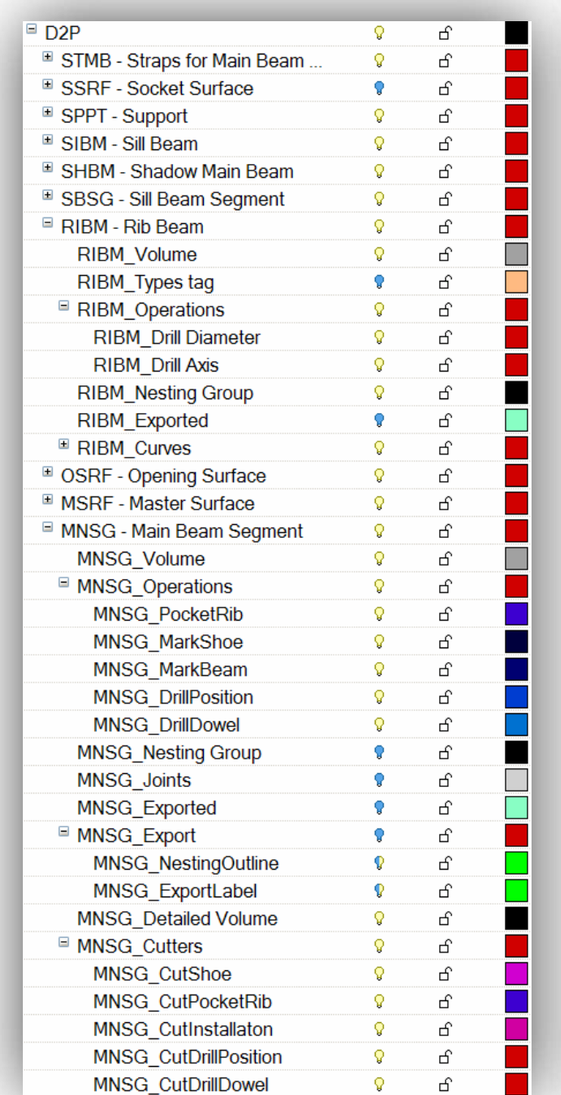
Paulson and MacLeamy's curve (Davis, 2013)

The **late stages** of **large scale and complex architectures** remain challenging because it contains a **huge amount of intricate data** that needs to be **communicated and accessed between different trades and across scales**.

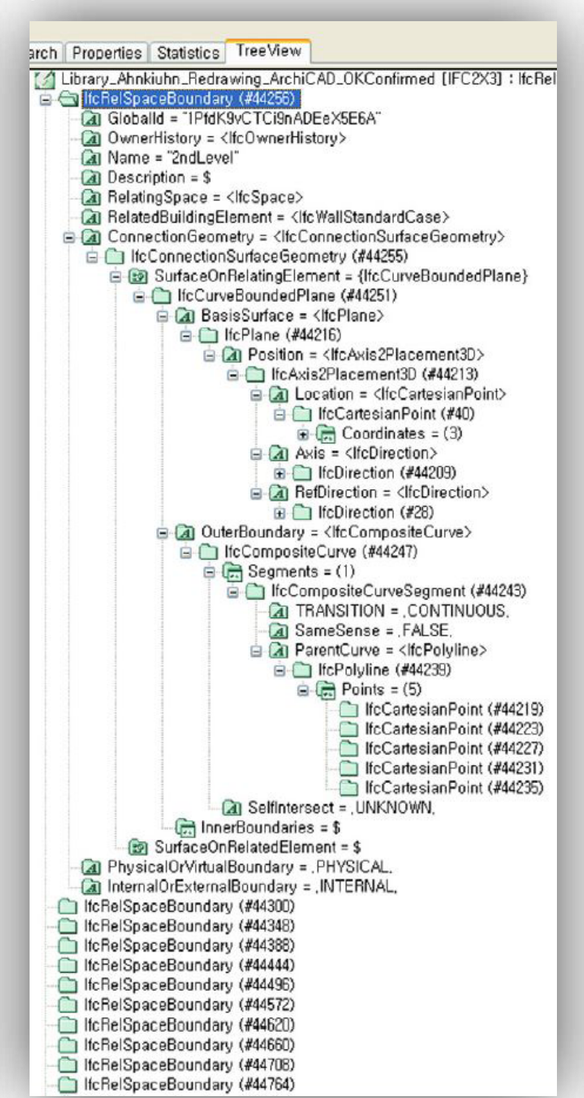
5. Schema-based and Cross-practice Collaboration Experiments

State of the art in organizing data

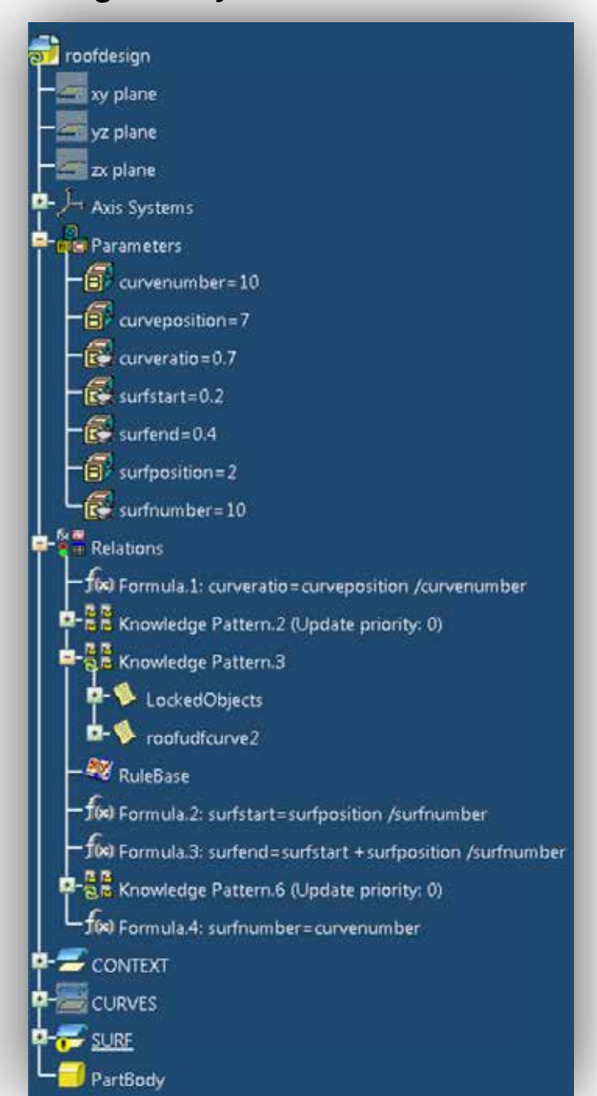
The LayerTable in Rhino3D



The IFC Tree Structure for BIM



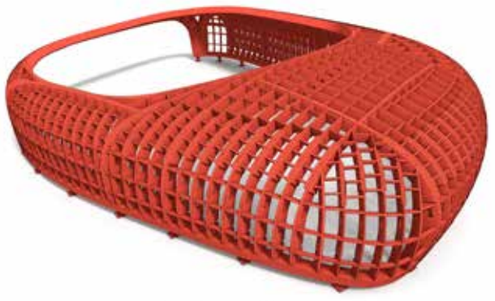
The Tree Directory in Digital Project



Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

Key question:
"How can we keep track, add and modify data within a common directory structure until completion of the building?"

3D Model



Terminal Pavilions Oslo
(Oslo, Norway, 2016)
Image Courtesy of Design-To-Production

Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

Key question:
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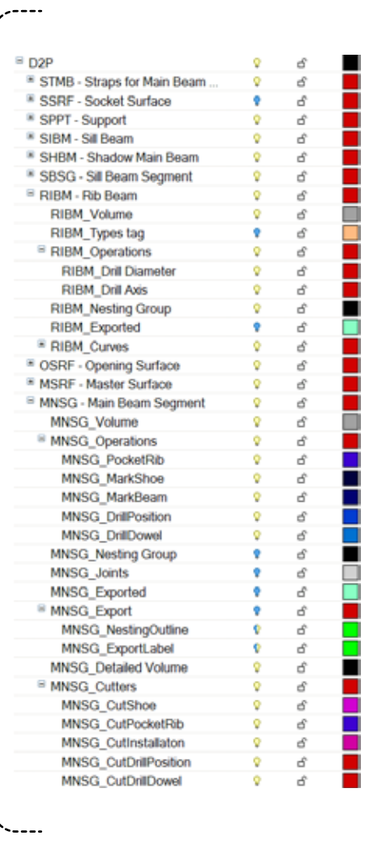
3D Model | ***Corresponding LayerTable***

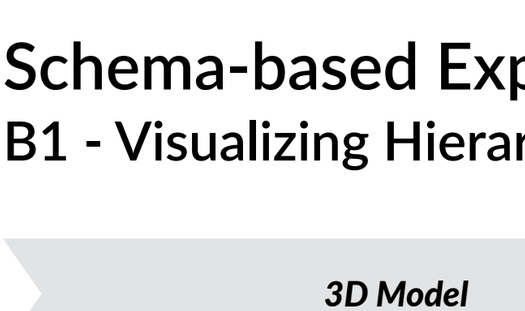
Terminal Pavilions Oslo
(Oslo, Norway, 2016)
Image Courtesy of Design-To-Production



Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

Key question:
"How can we keep track, add and modify data within a common directory structure until completion of the building?"

3D Model | ***Corresponding LayerTable*** | ***Corresponding Directed Acyclic Graph (DAG)***



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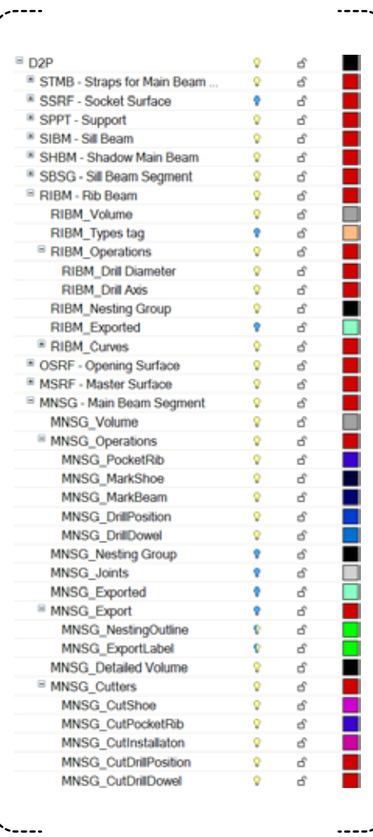
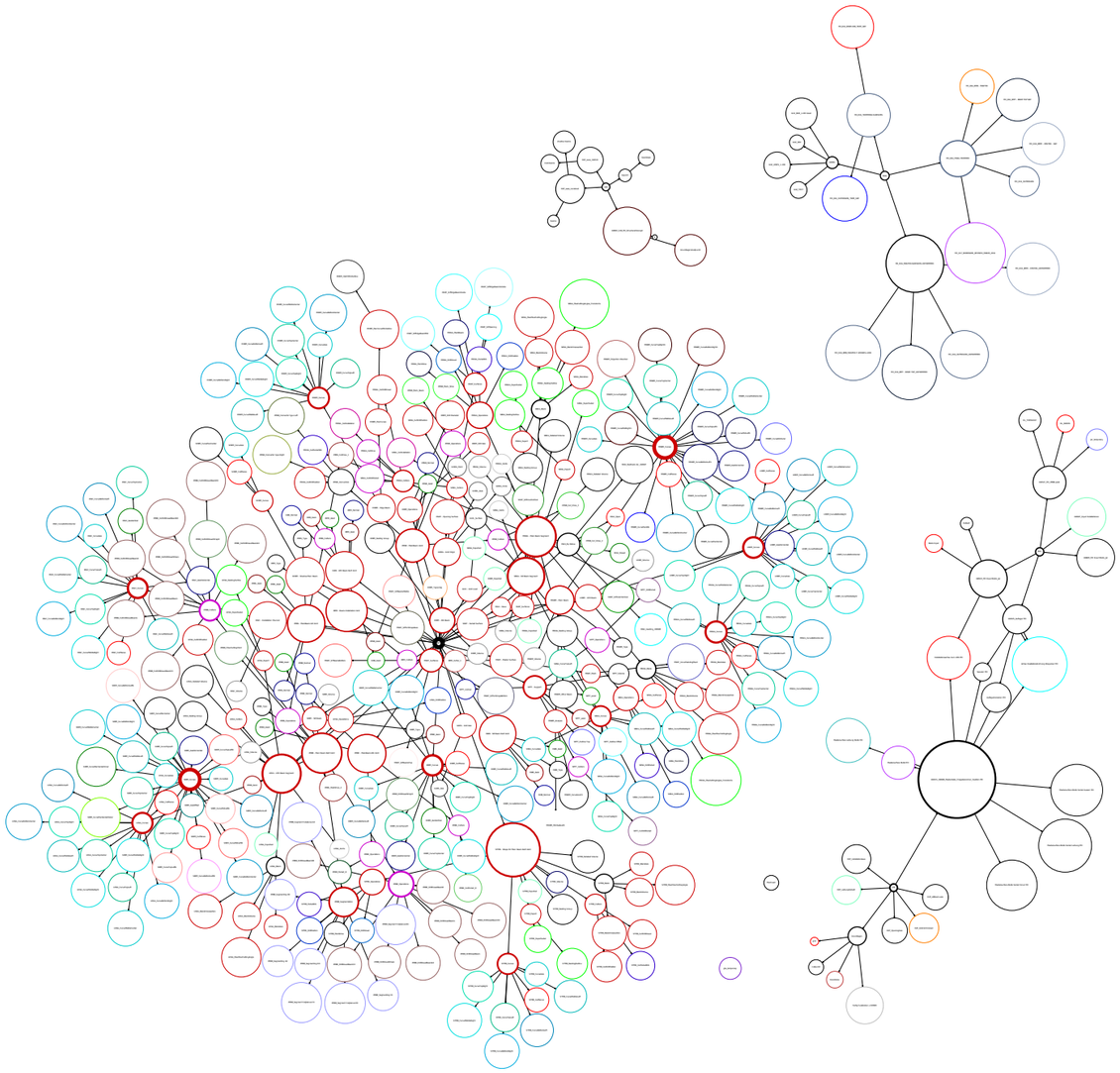
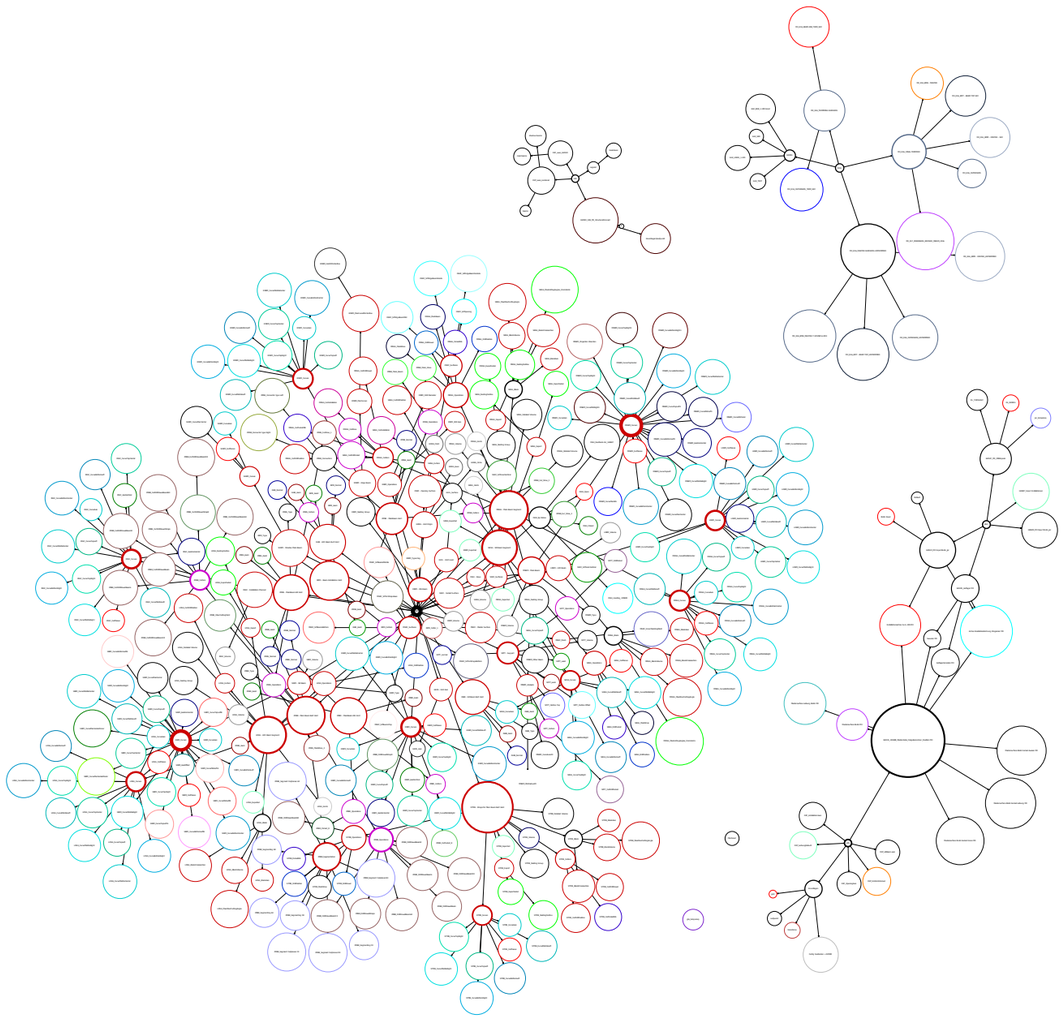




Schema-based Experiments

B1 - Visualizing Hierarchies: LayerFootprint

From the Directed Acyclic Graph (DAG)...



Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

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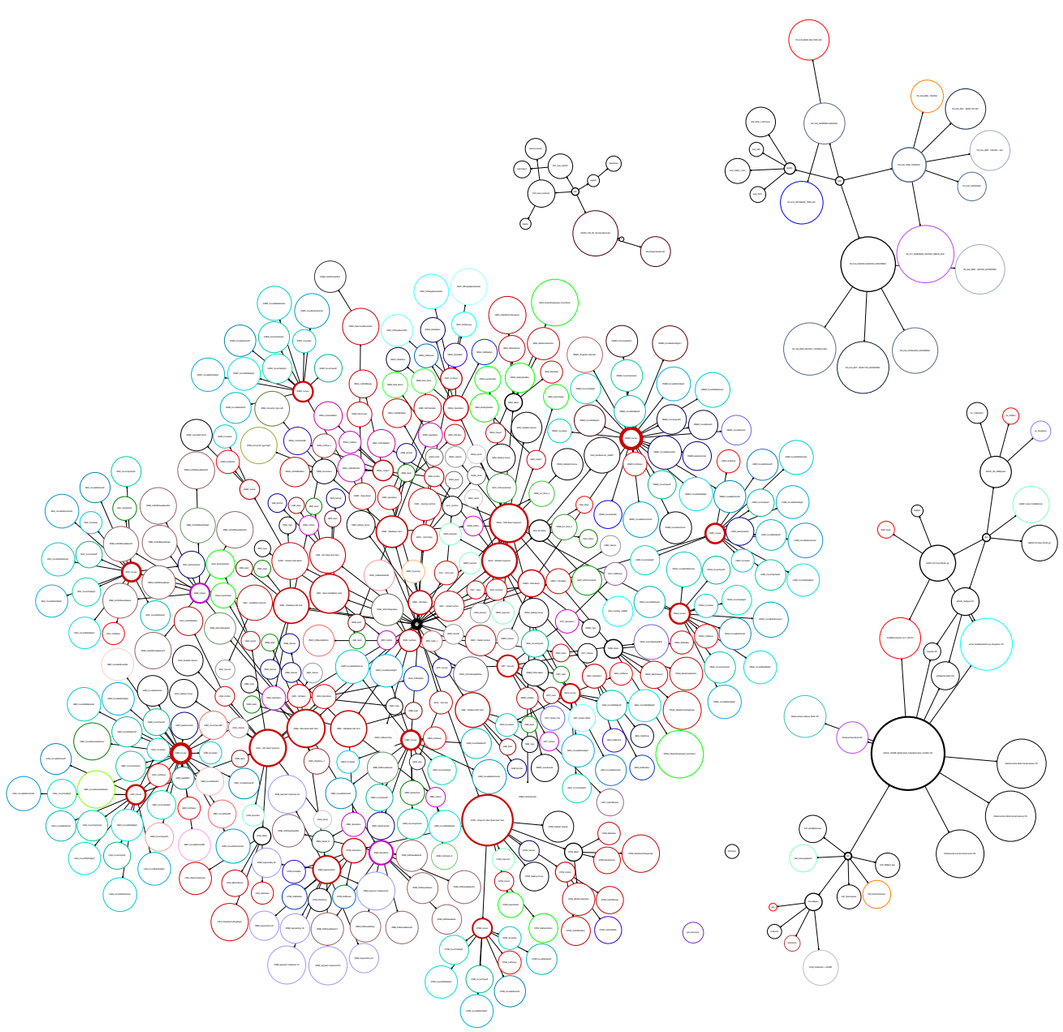
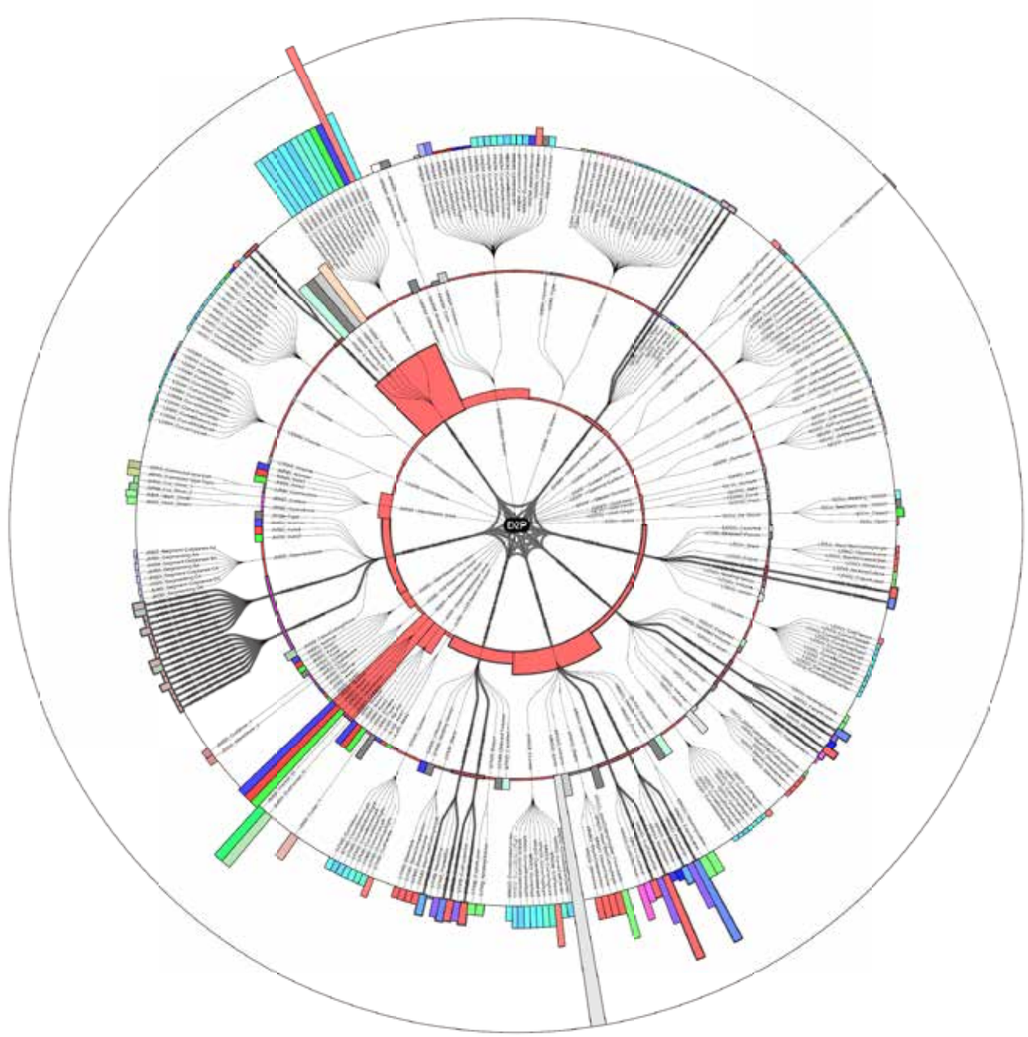
From the Directed Acyclic Graph (DAG)...



...to the Sunburst Diagram



Schema-based Experiments

B1 - Visualizing Hierarchies: LayerFootprint

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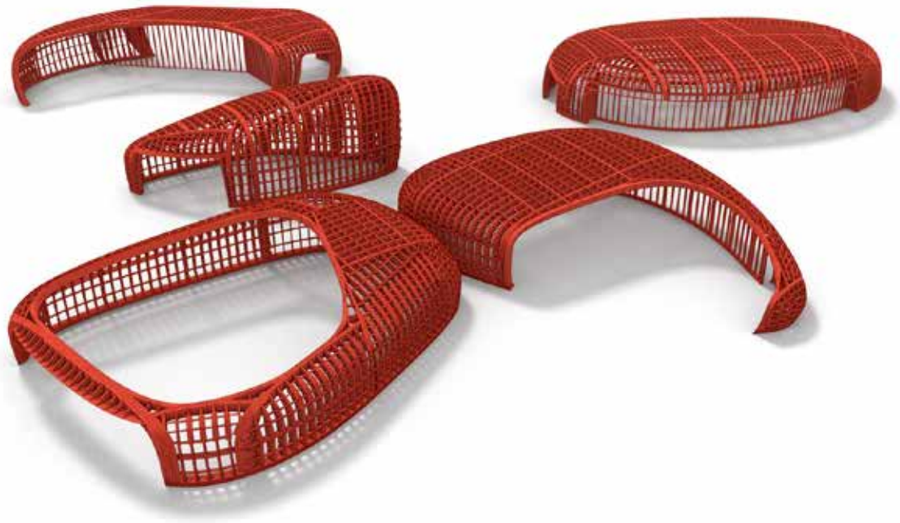
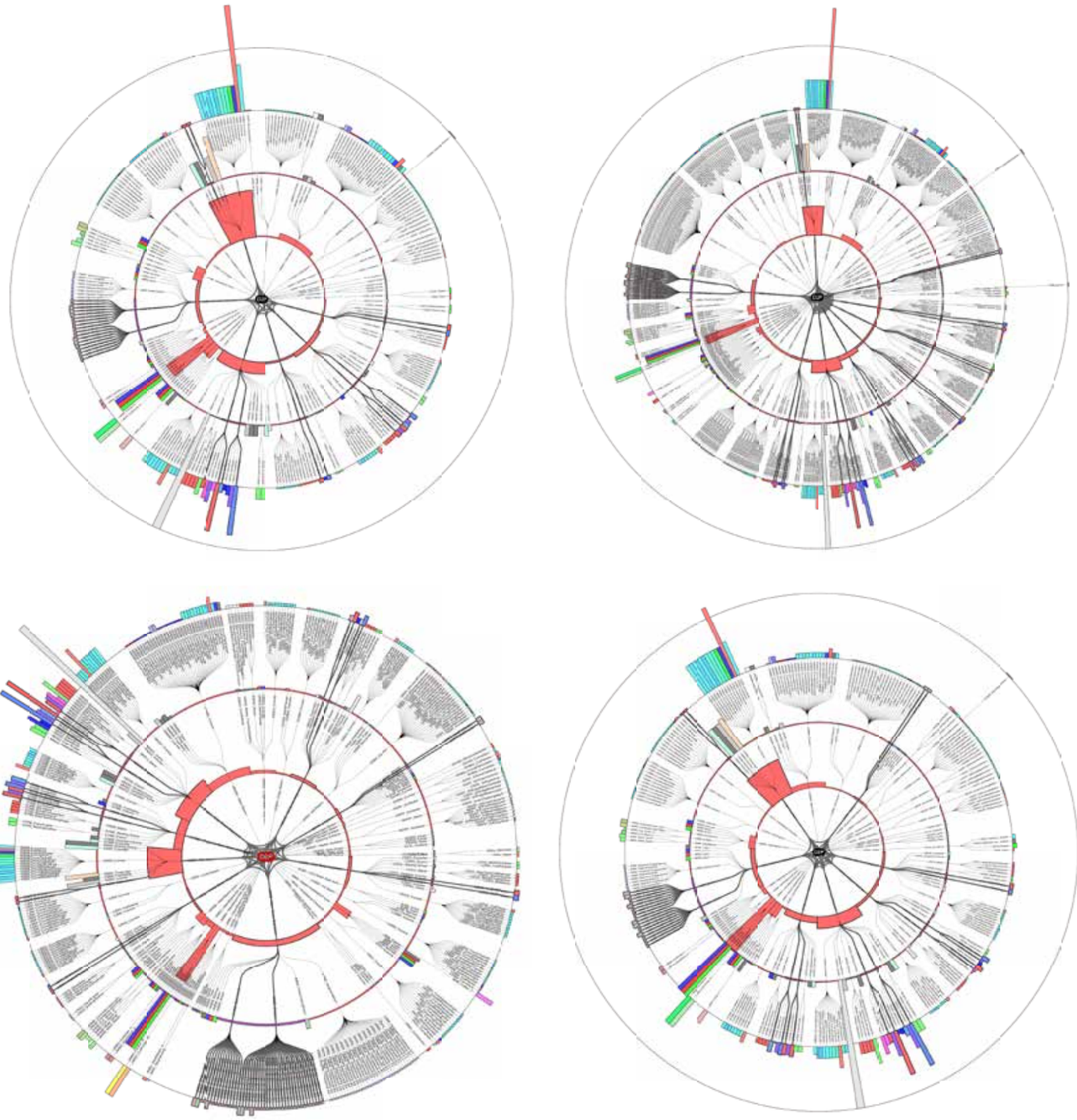


Terminal Pavilions Oslo (Oslo, Norway, 2016)
Image Courtesy of Design-To-Production

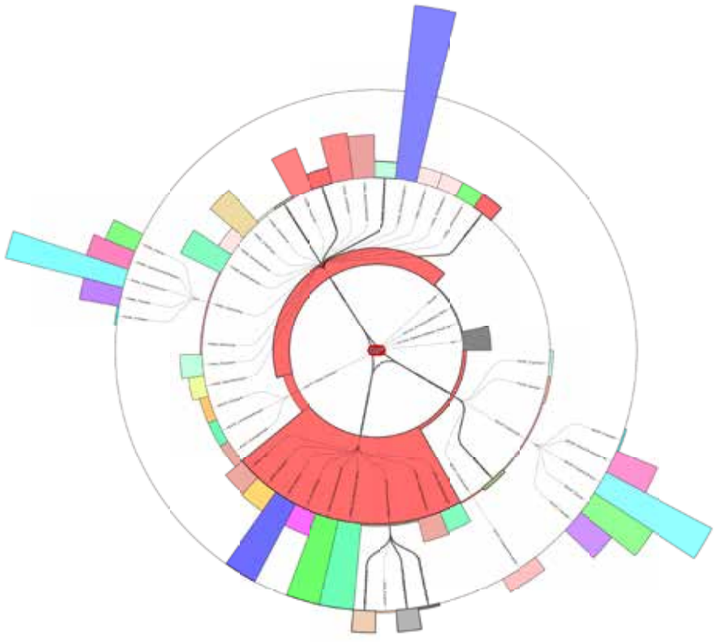


Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

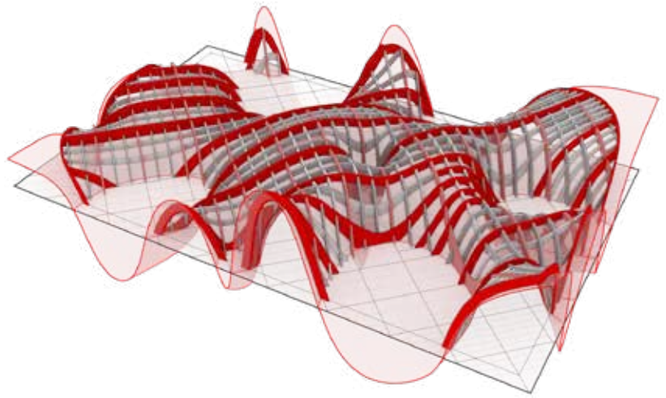
Key question:
"How can we keep track, add and modify data within a common directory structure until completion of the building?"

Scale: 19 meter high
Elements: More than 600 CNC-cut timber panels

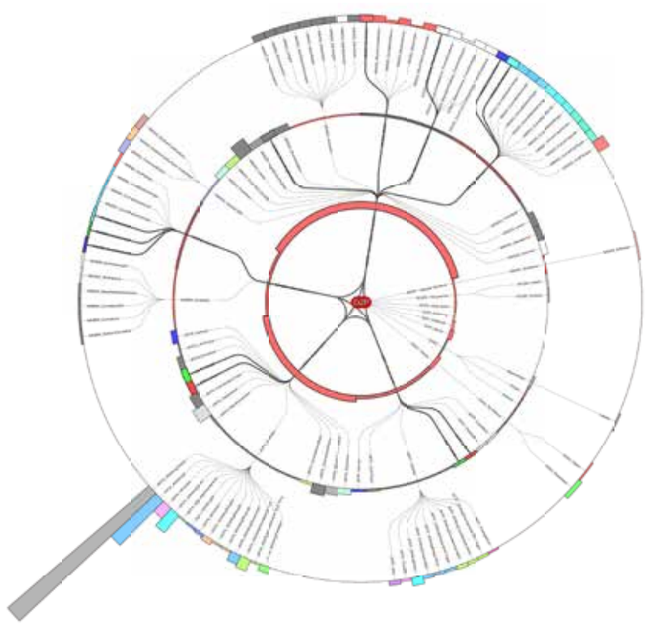
Ski World-Championship (St. Moritz, Switzerland, 2017)
Image Courtesy of Design-To-Production



Scale: 12 meter high
Elements: 730 curved structural segments

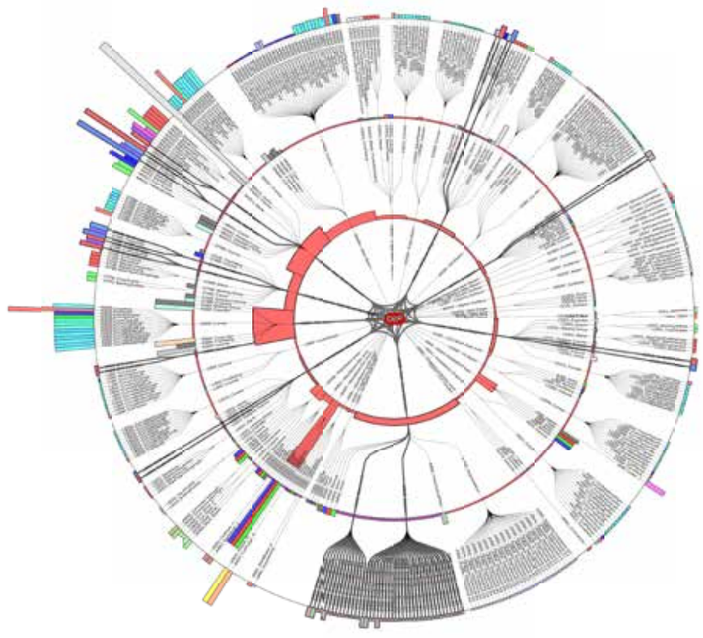


French Expo-Pavilion (Milan, Italy, 2015)
Image Courtesy of Design-To-Production



Scale: 7-8 meter high
Elements: 1300 unique timber parts

Terminal Pavilions Oslo (Oslo, Norway, 2016)
Image Courtesy of Design-To-Production



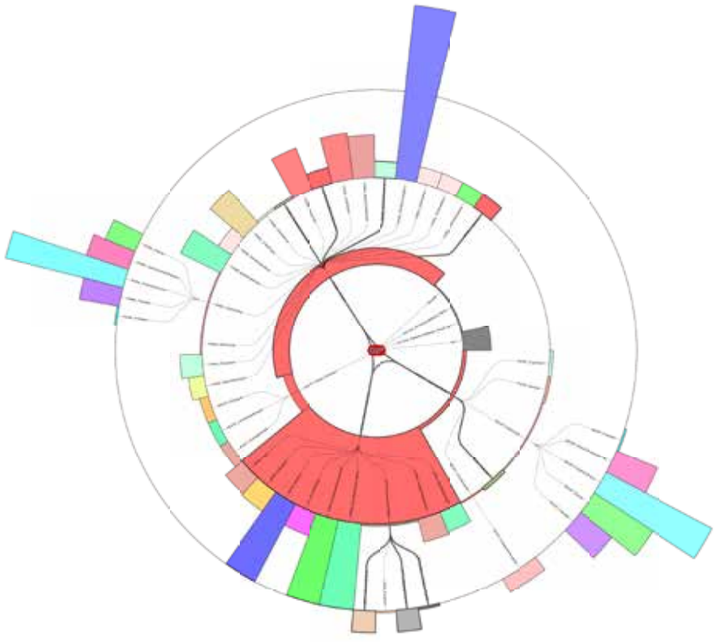
Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

Key question:
"How can we keep track, add and modify data within a common directory structure until completion of the building?"

Embedded Rationality / Pre-rationalization

Scale: 19 meter high
Elements: More than 600 CNC-cut timber panels

Ski World-Championship (St. Moritz, Switzerland, 2017)
Image Courtesy of Design-To-Production



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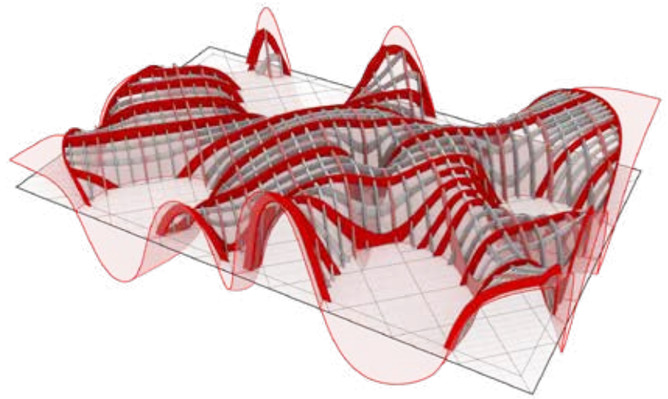

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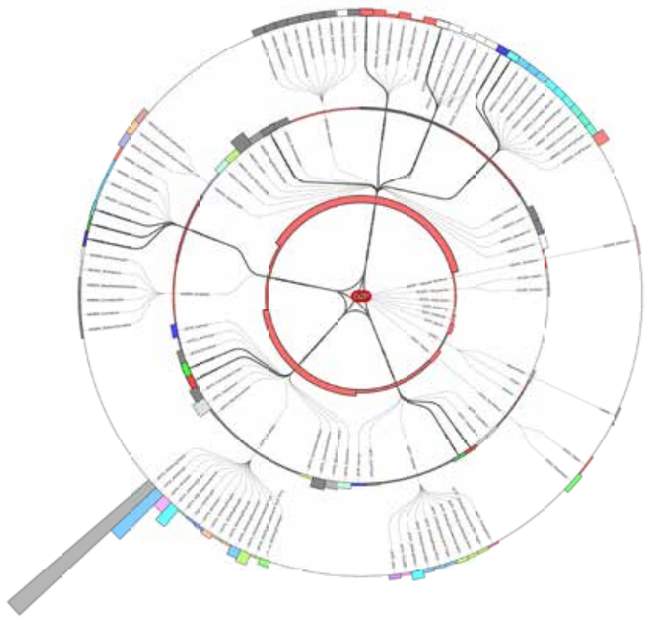
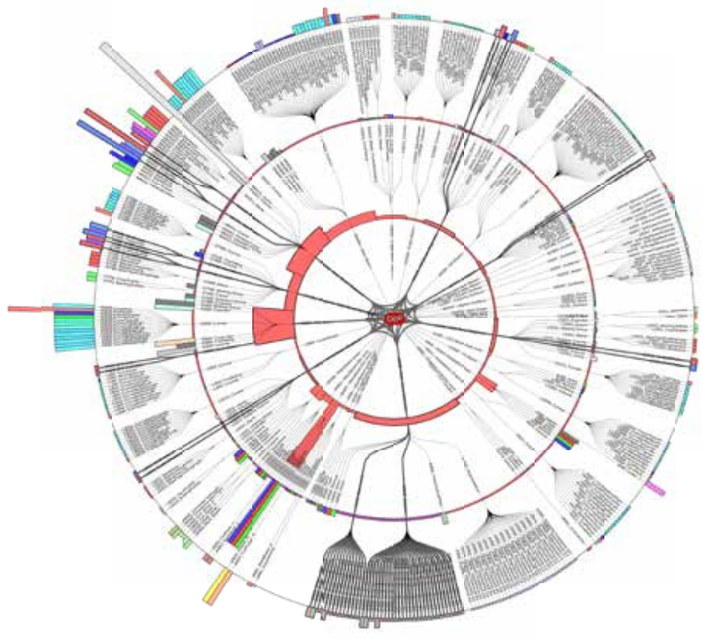


Post-rationalization

Scale: 7-8 meter high
Elements: 1300 unique timber parts

Terminal Pavilions Oslo (Oslo, Norway, 2016)
Image Courtesy of Design-To-Production

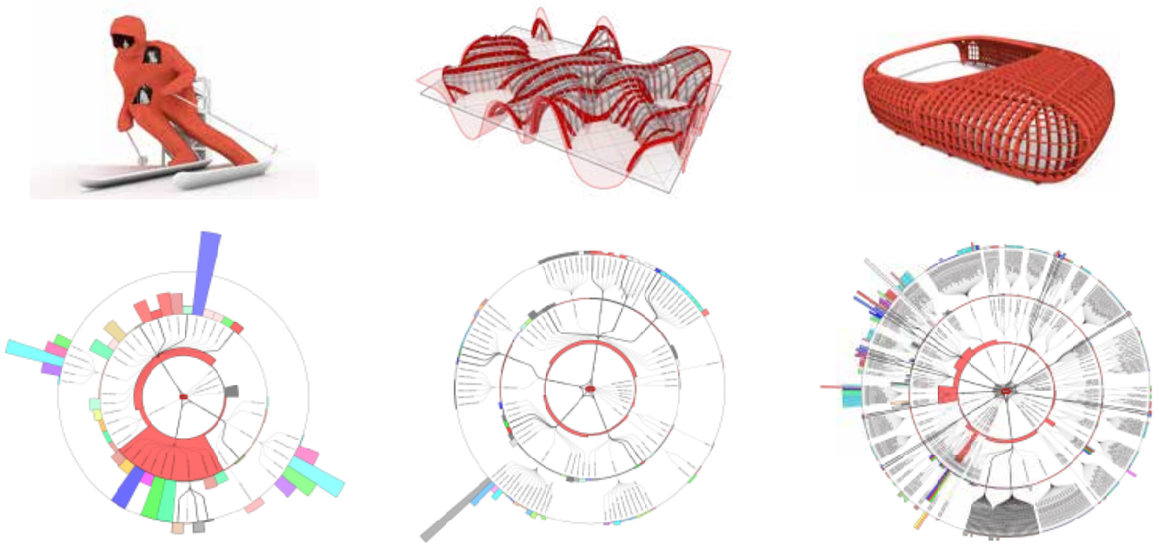


Schema-based Experiments
B1 - Visualizing Hierarchies: LayerFootprint

Key question:
"How can we keep track, add and modify data within a common directory structure until completion of the building?"

Result

Through multiple stress-tests against different source models, *LayerFootprint* could **leverage data and highlight the model's intricacy**.



Limitations / link to the next experiment

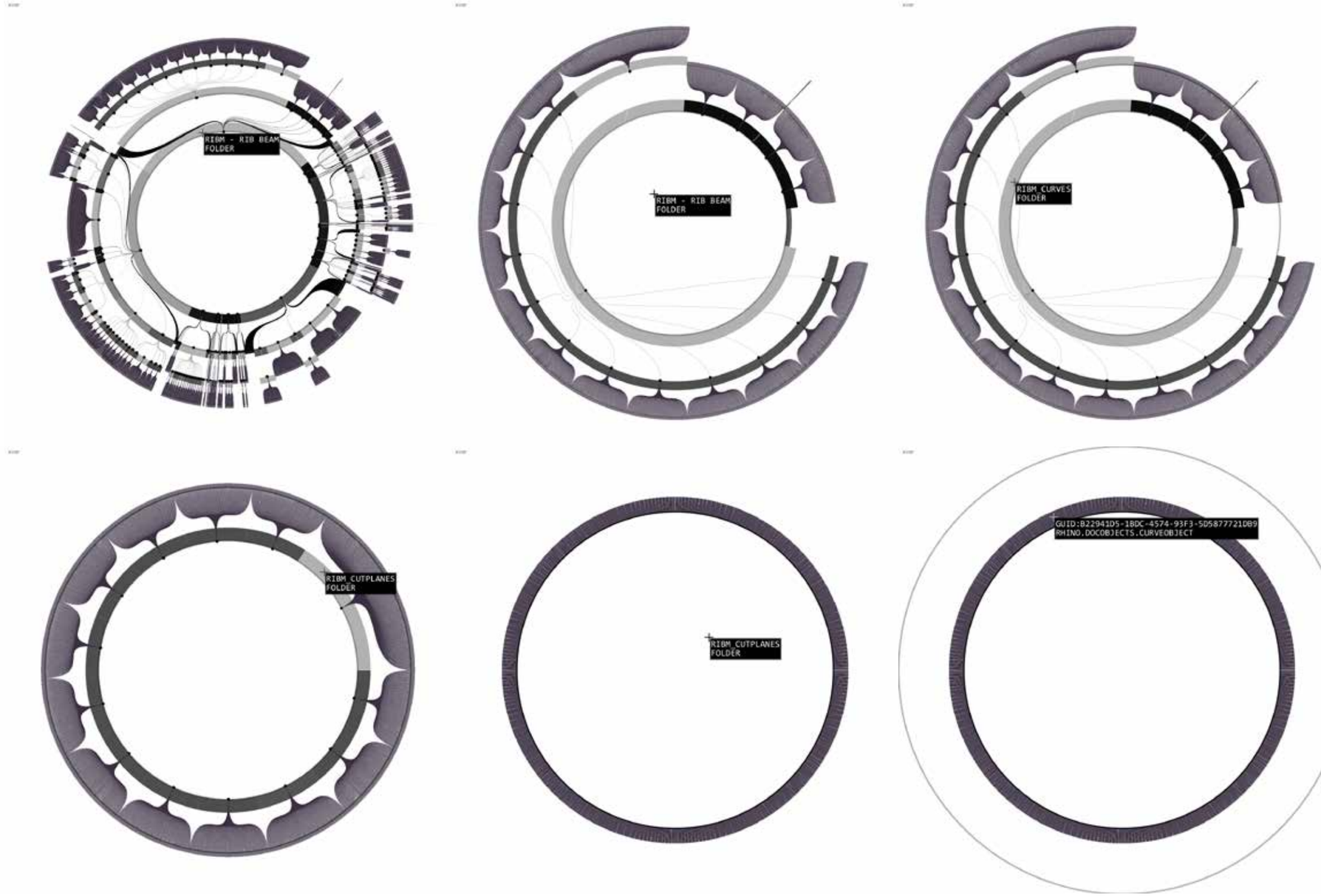
Through the different stress-tests carried against different source models, it has been observed that **the amount of information displayed by LayerFootprint might be too intricate and complex to be grasped at once as a whole**. Therefore, the next schema-based experiment attempts to **extend the capabilities of LayerFootprint by integrating zoomable features**, allowing the user to focus on a particular level of the hierarchical data structure.

Schema-based Experiments

B2 - Navigating across Hierarchies: LayerExplorer

Key question:
"How could the multi-scalar model be interacted and which User Interface (UI) and User Experience (UX) concepts would be needed?"

GIF
PLACEHOLDER



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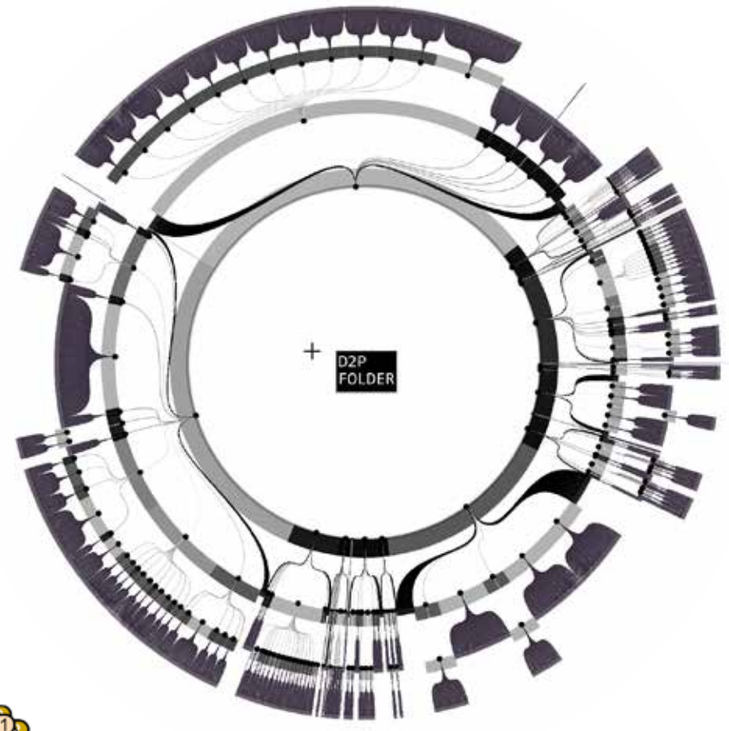

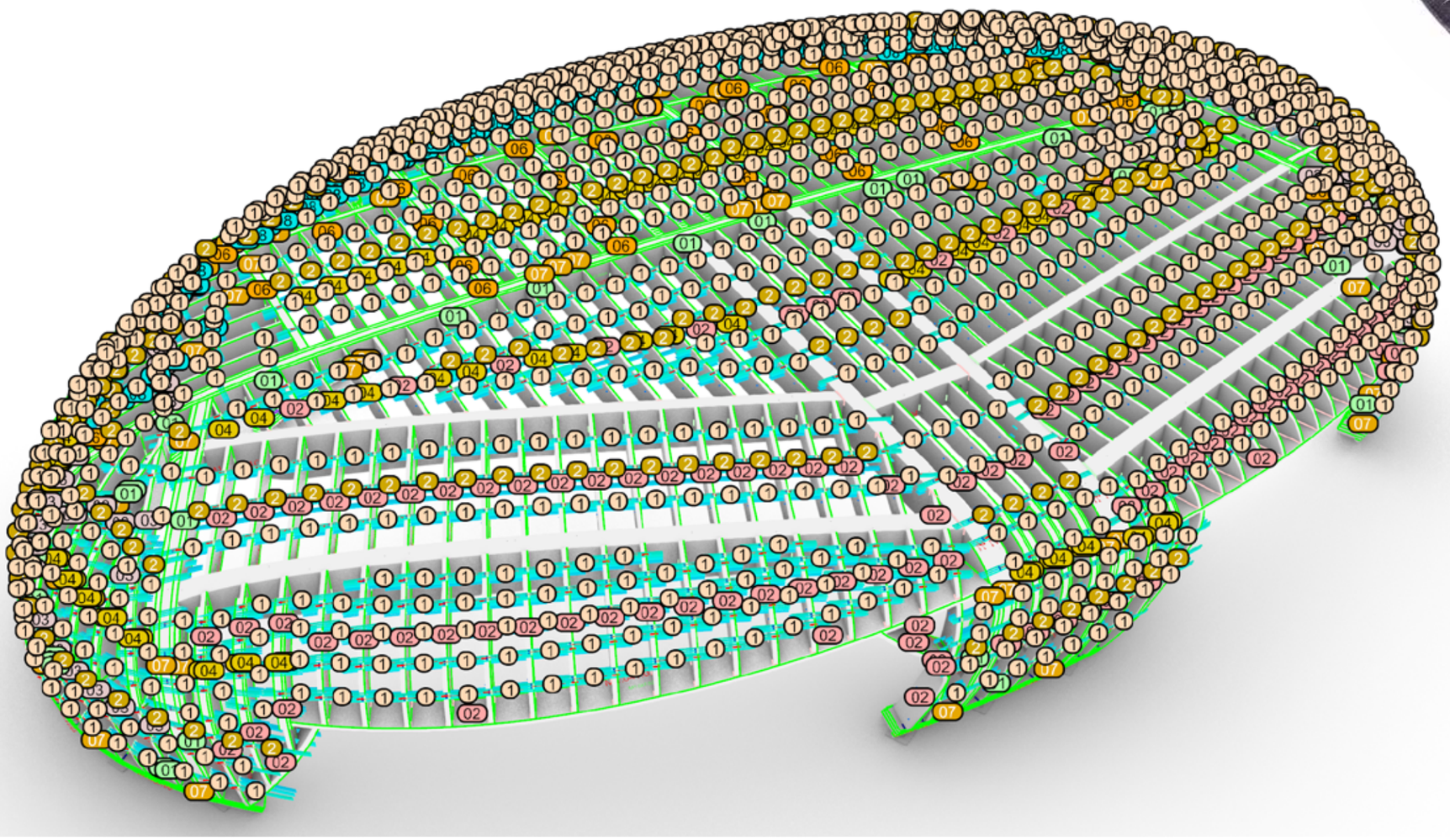

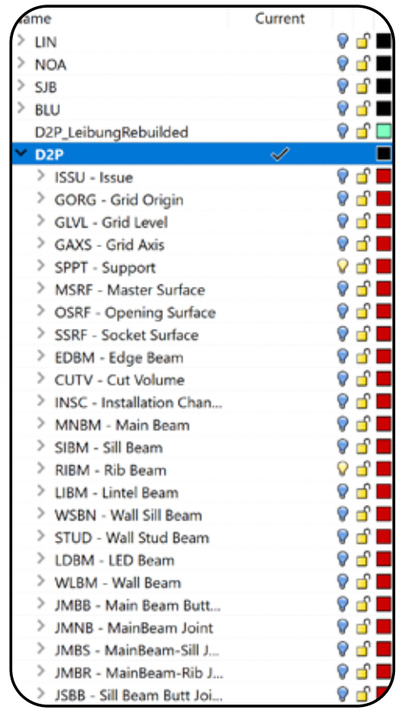

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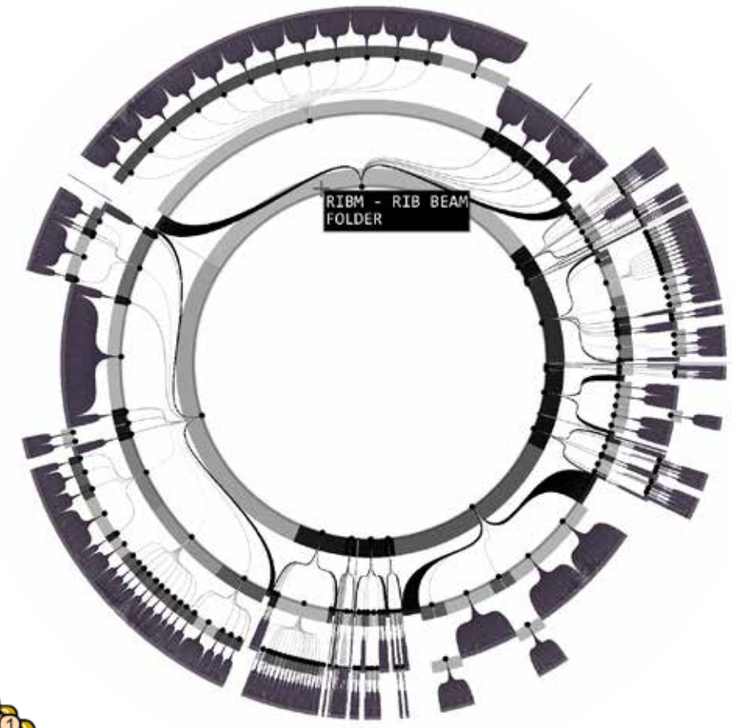

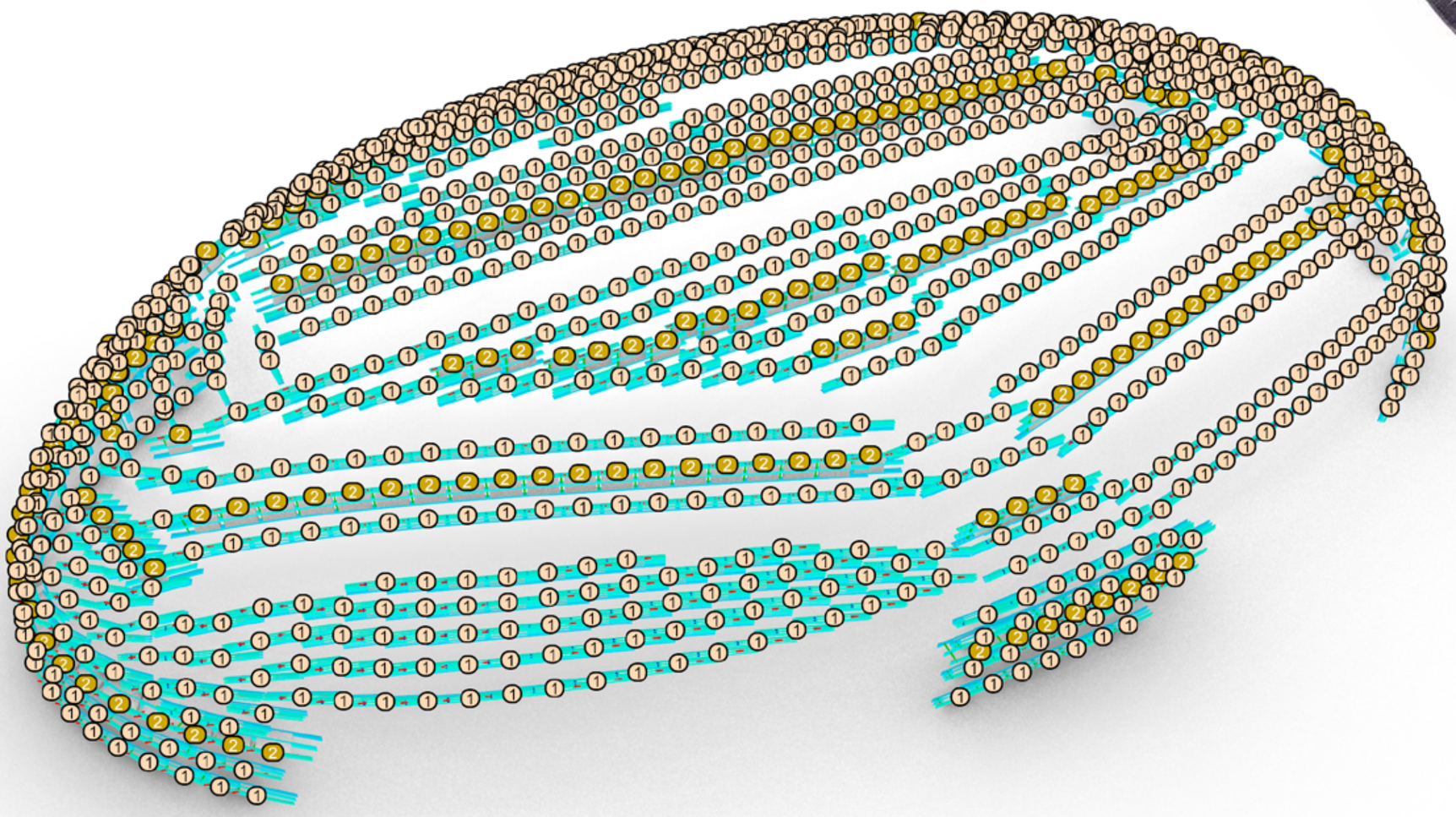

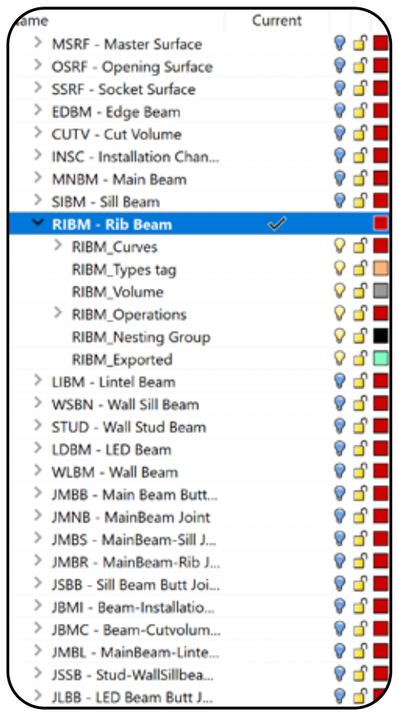

Schema-based Experiments

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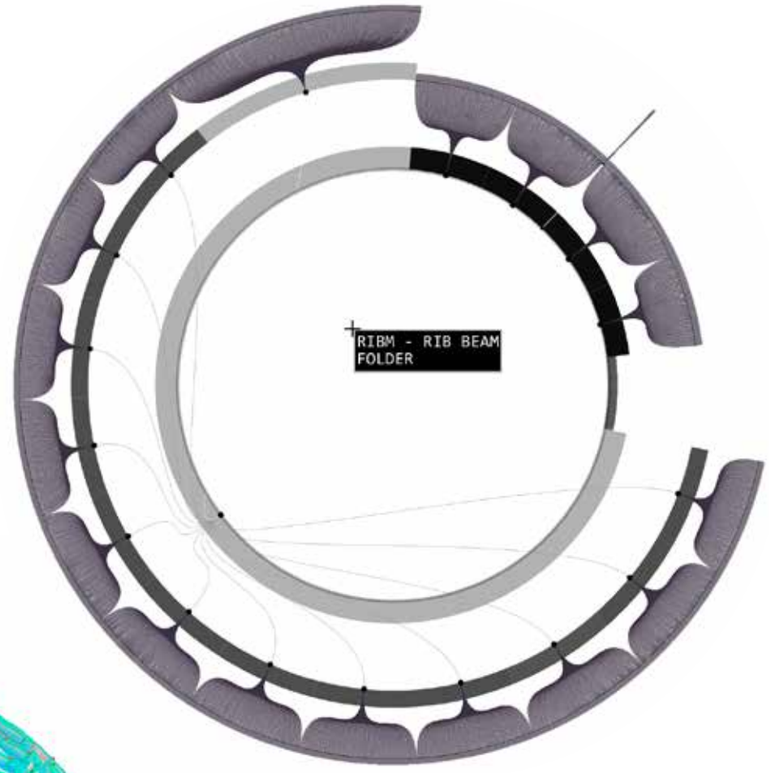

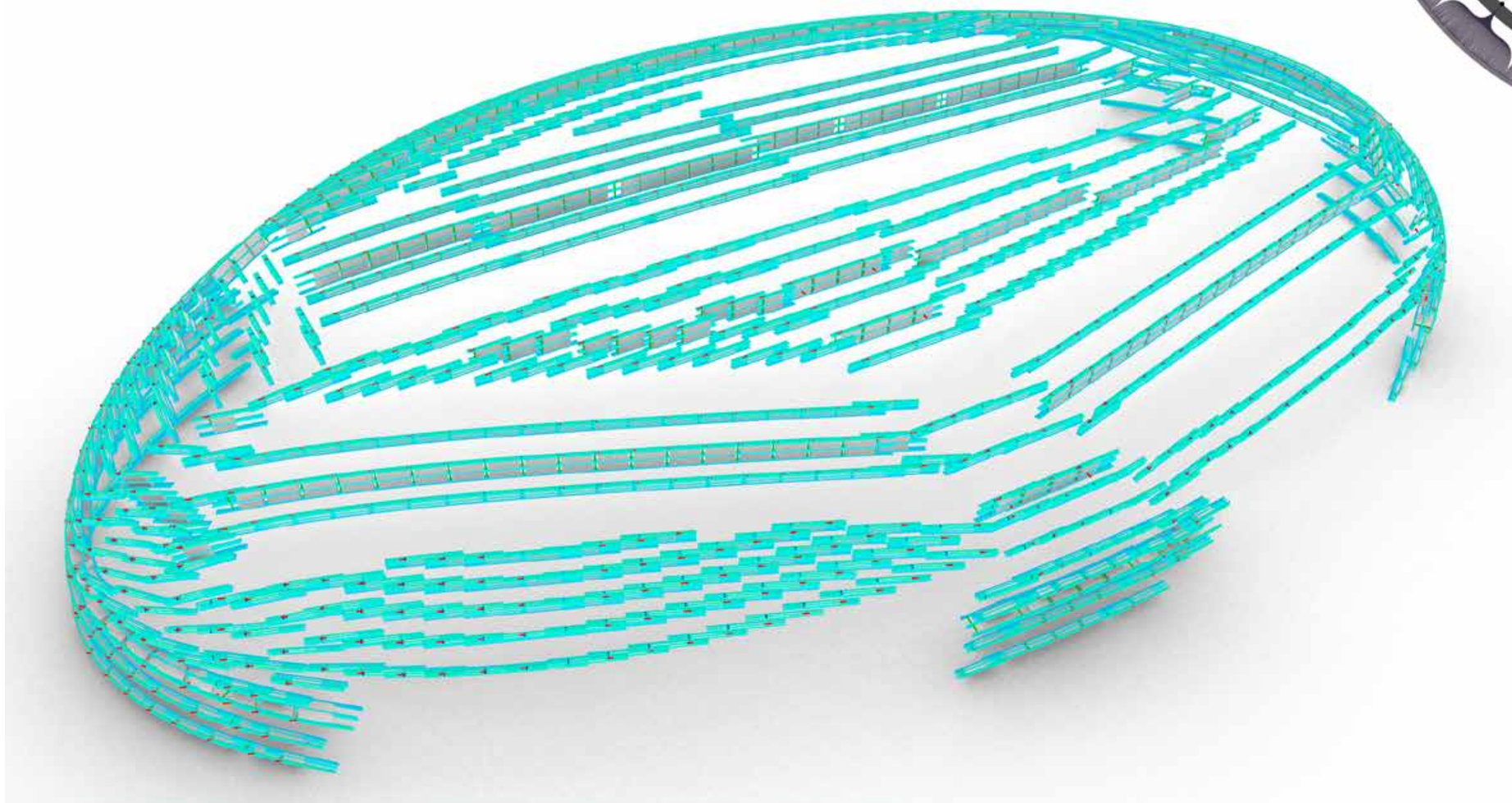

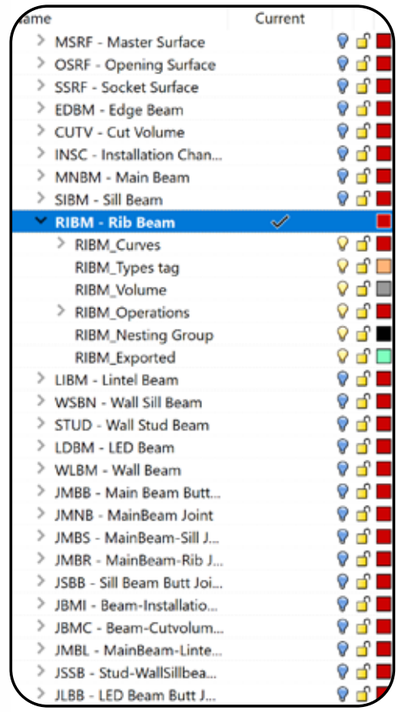

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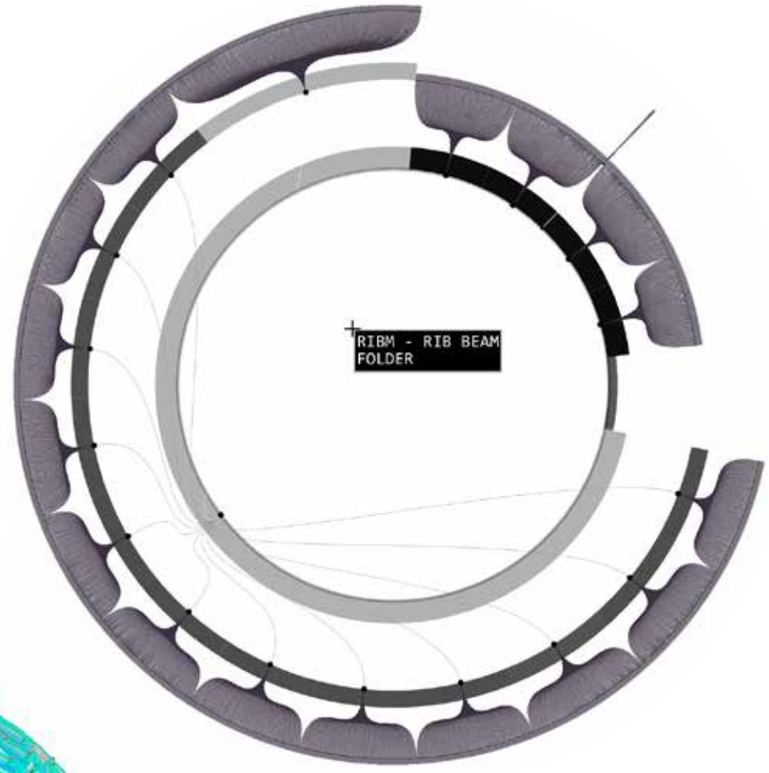

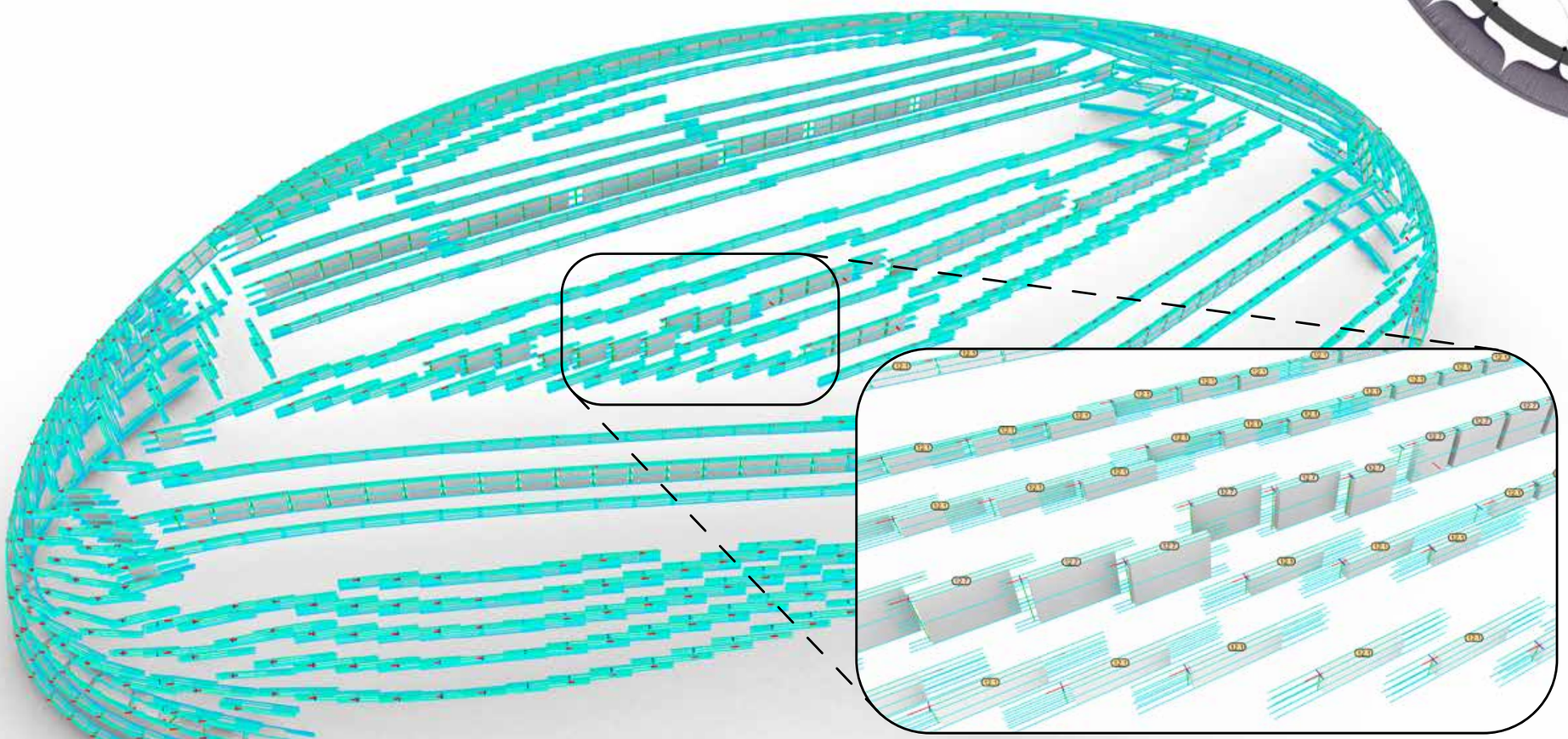

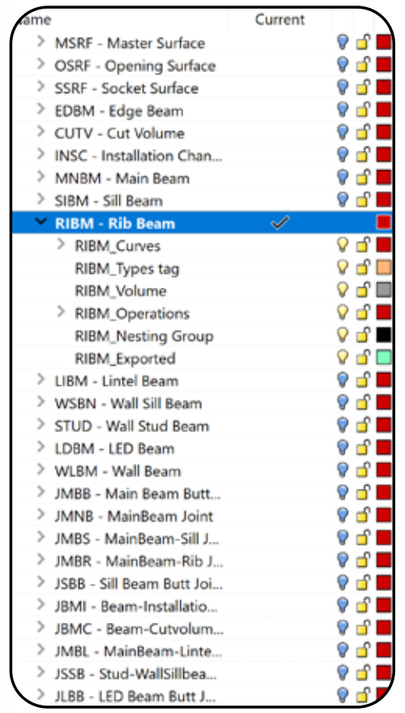

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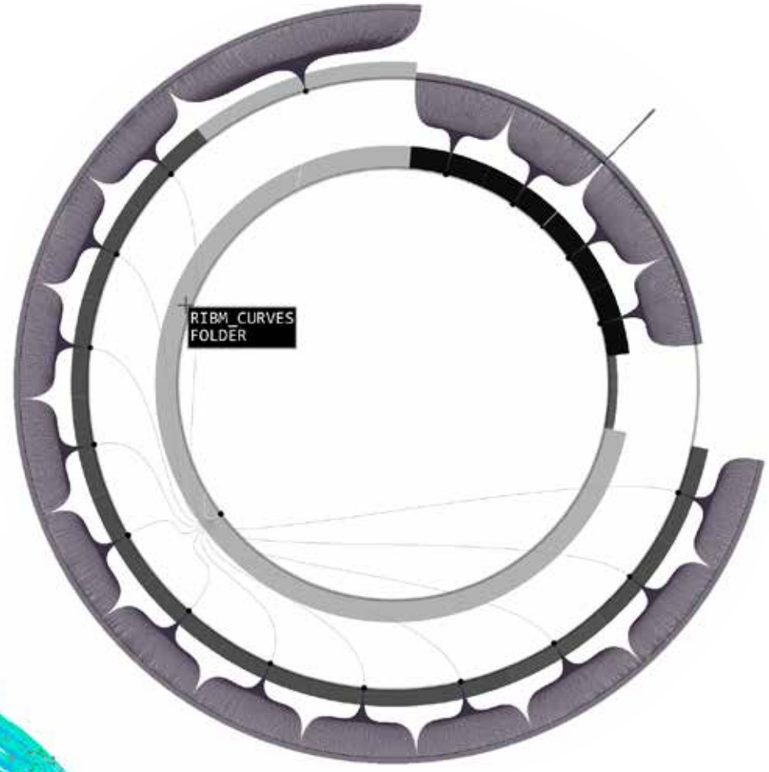

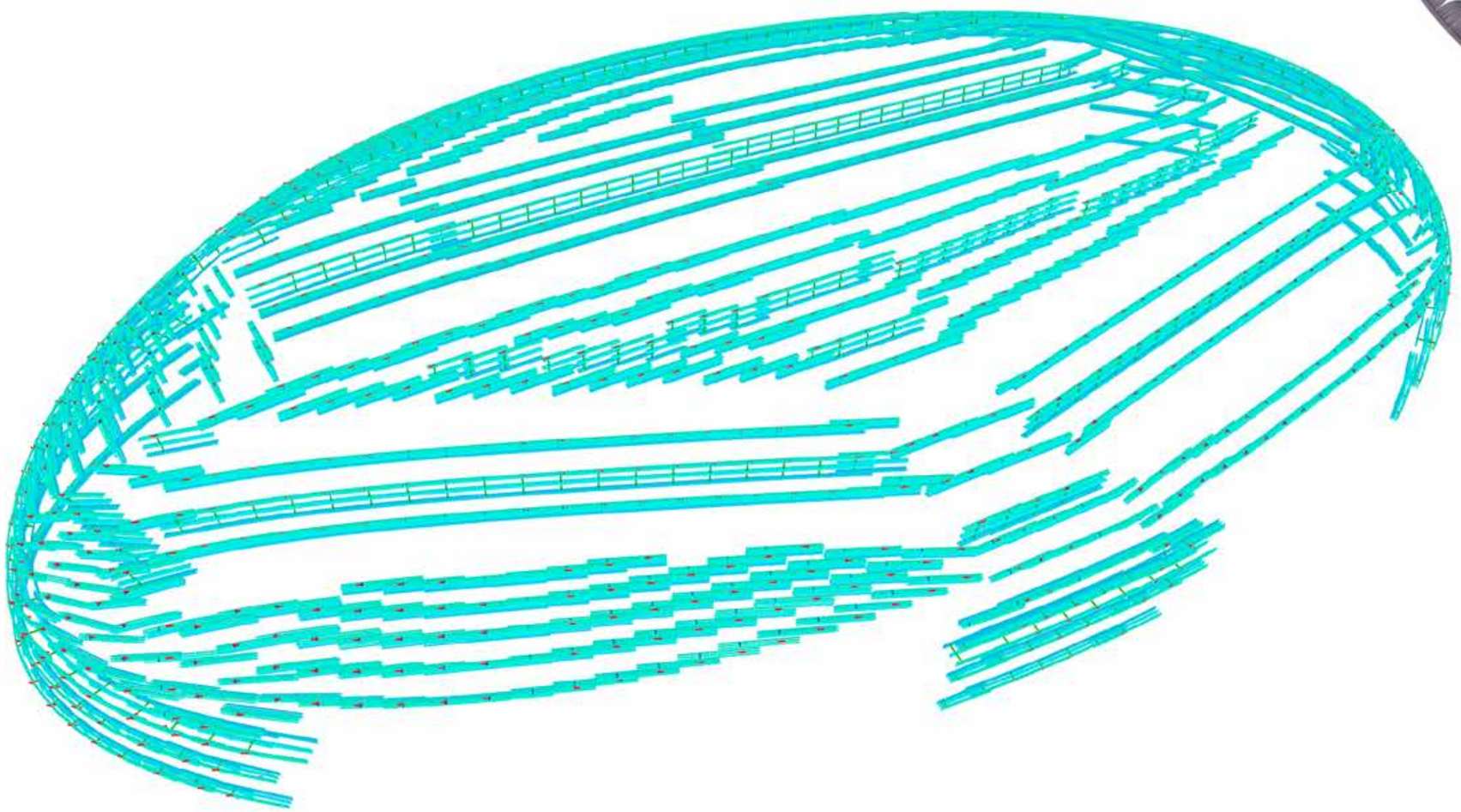

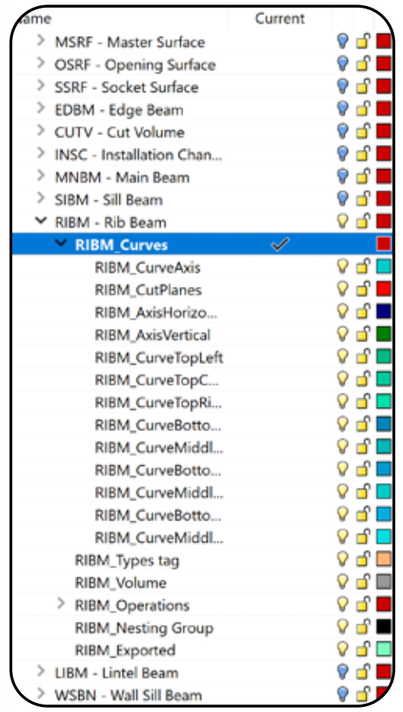

Schema-based Experiments

B2 - Navigating across Hierarchies: LayerExplorer

Key question:
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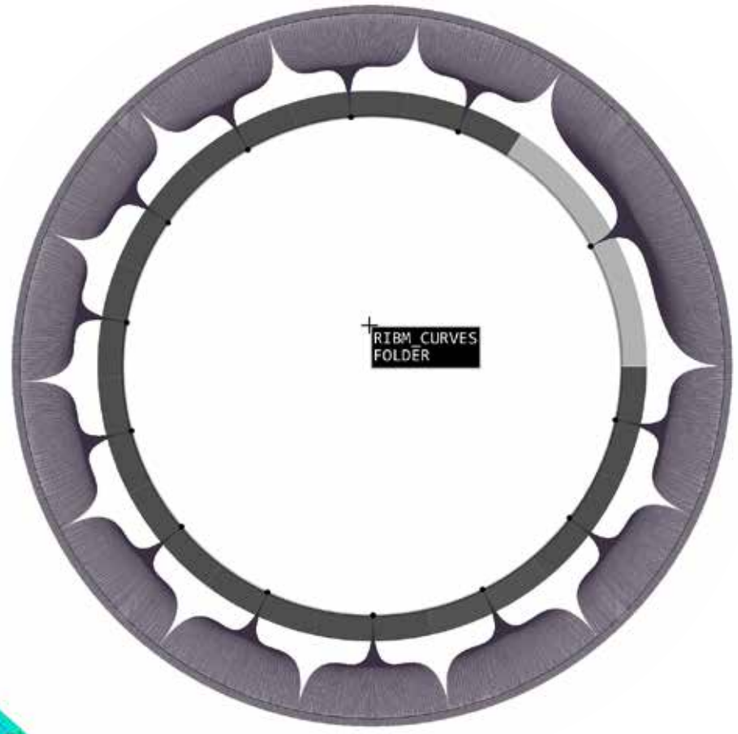

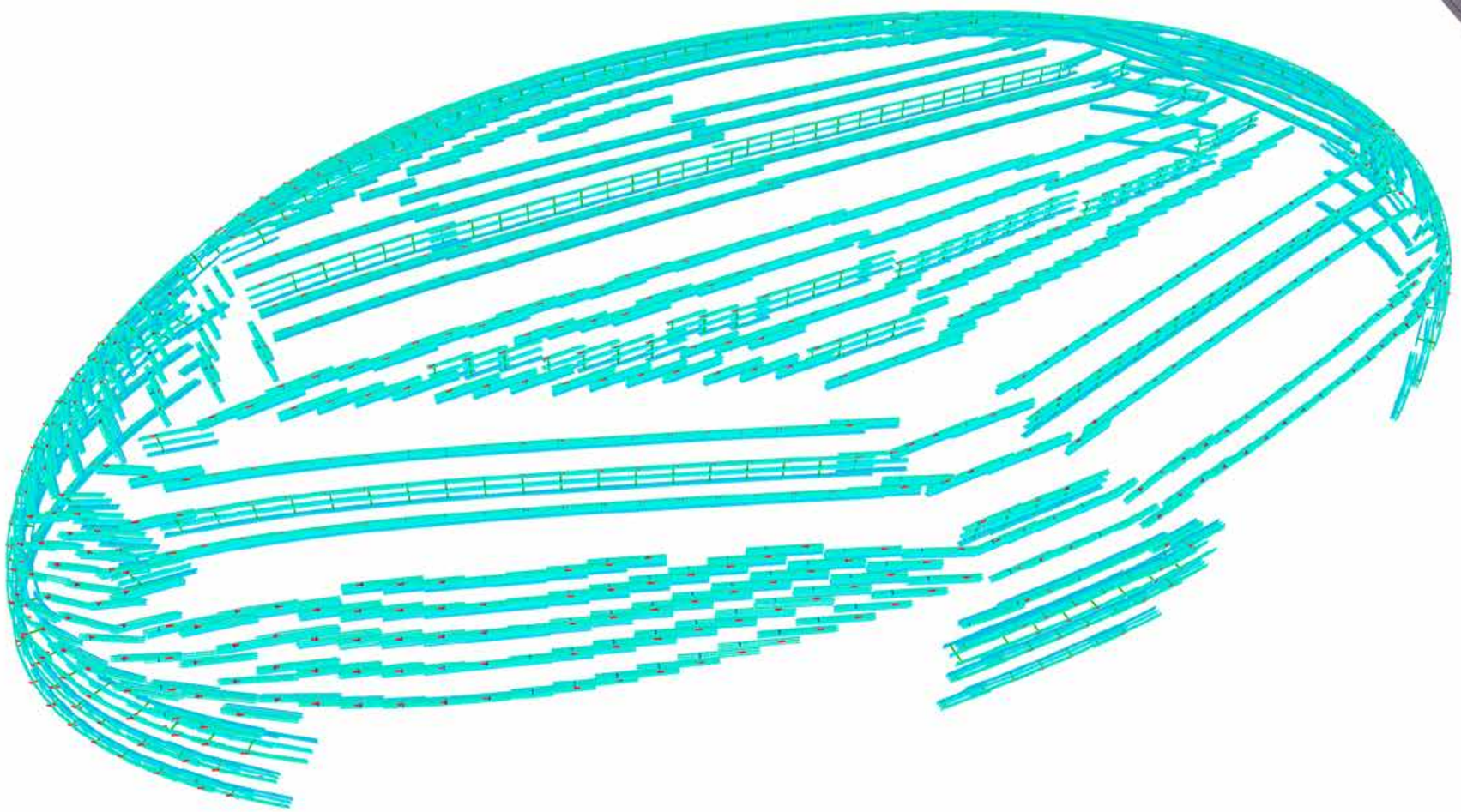

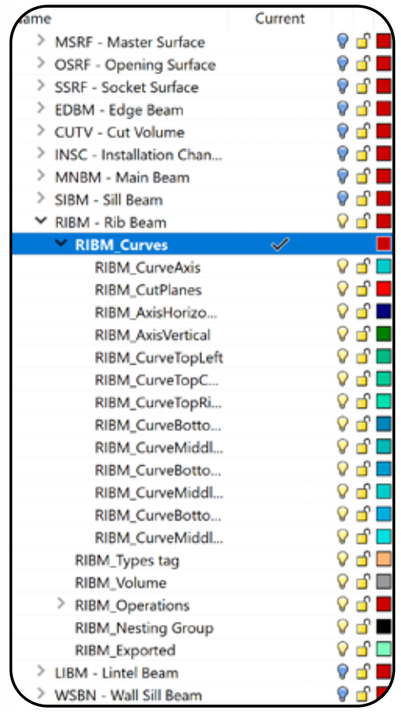

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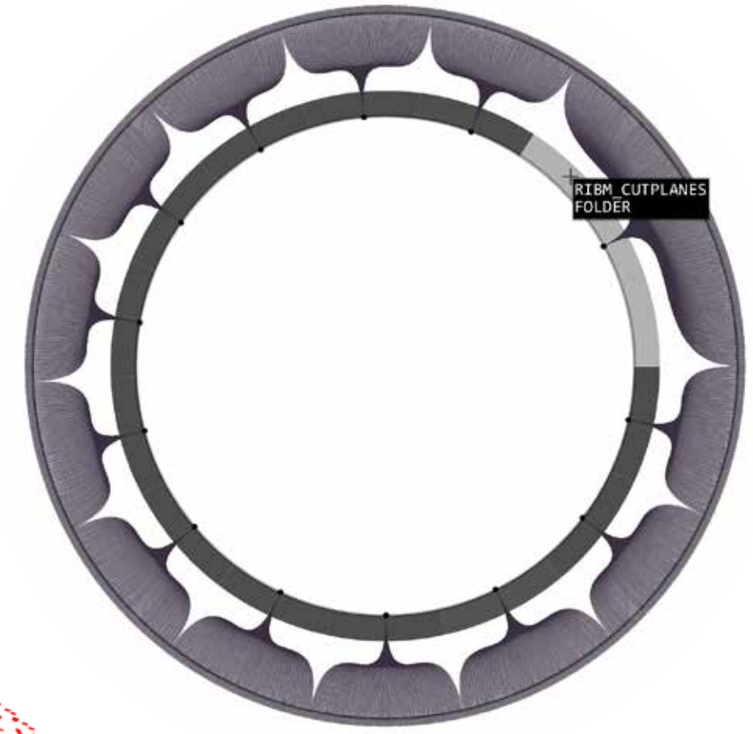

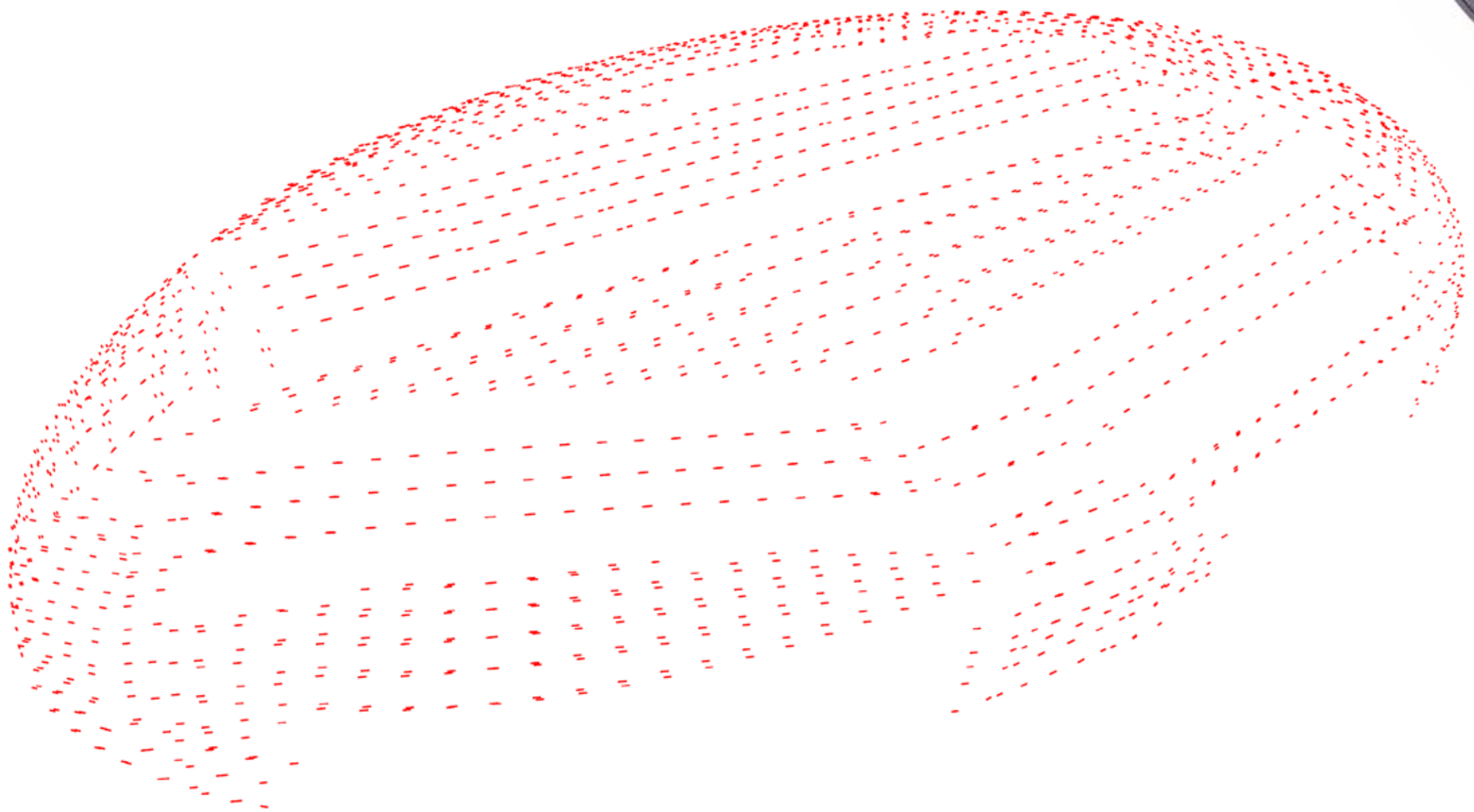

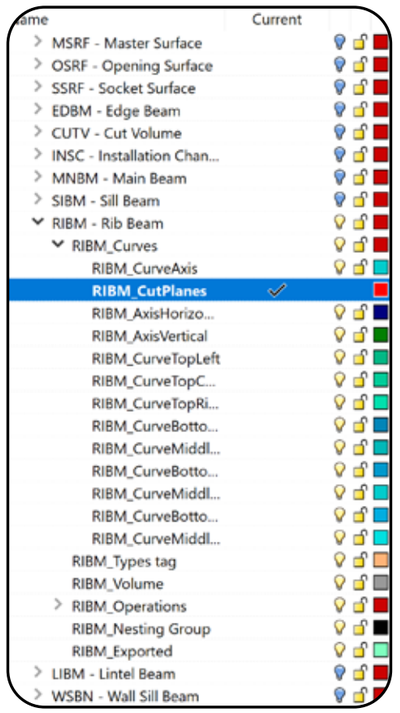

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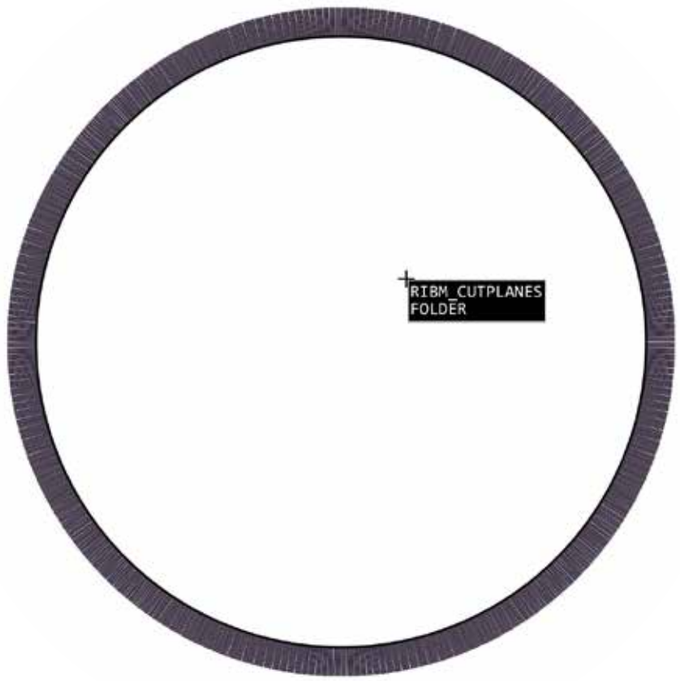

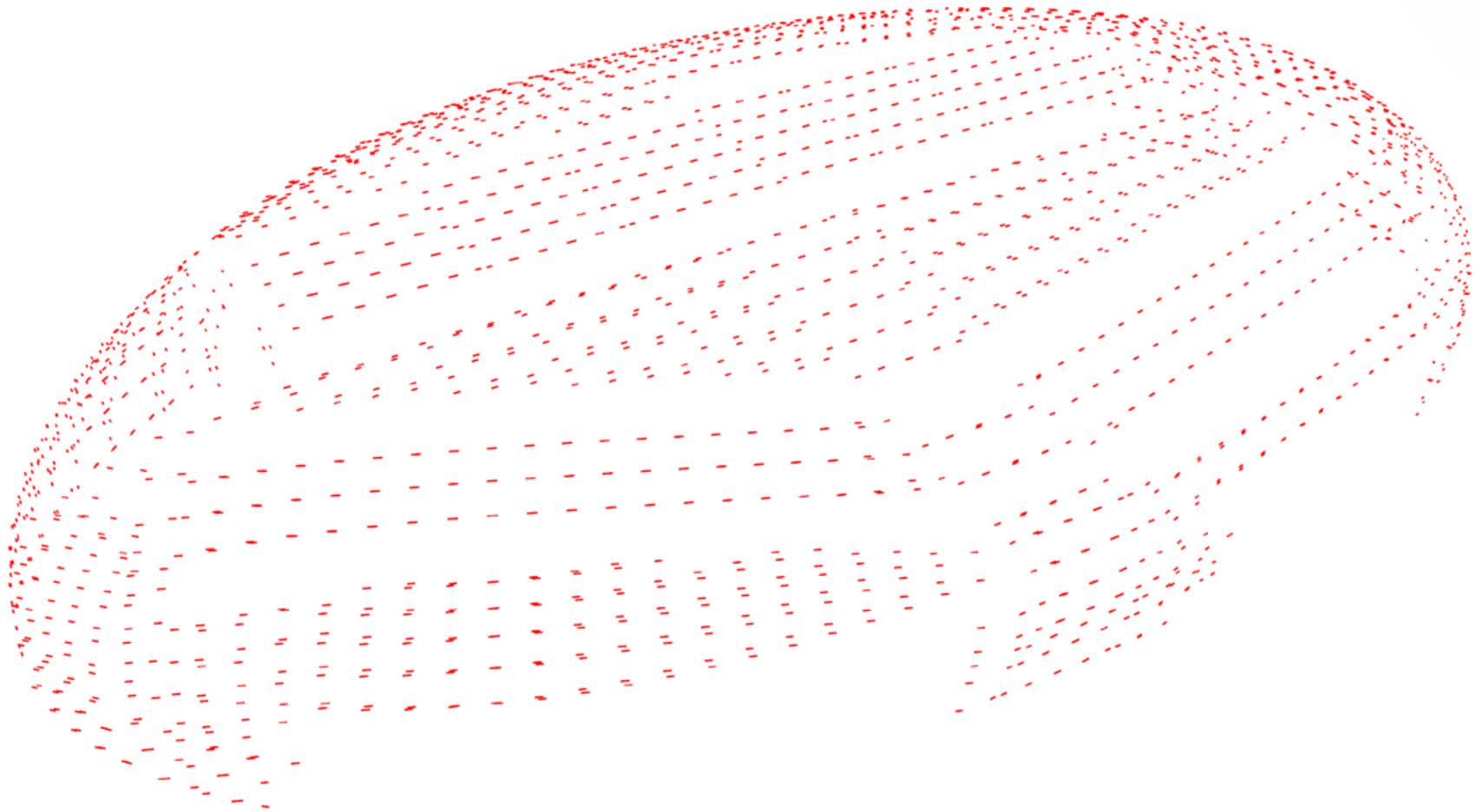

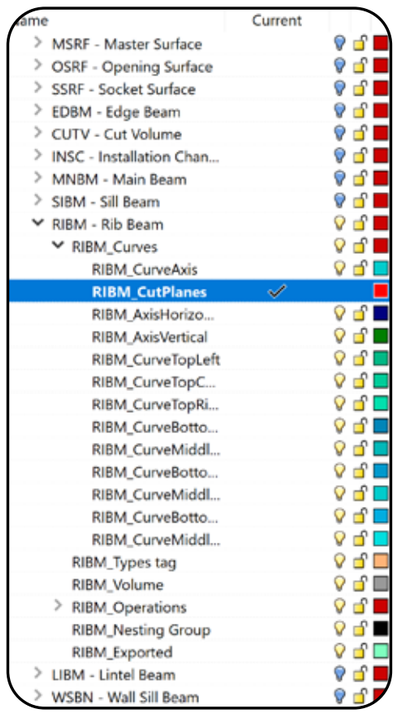

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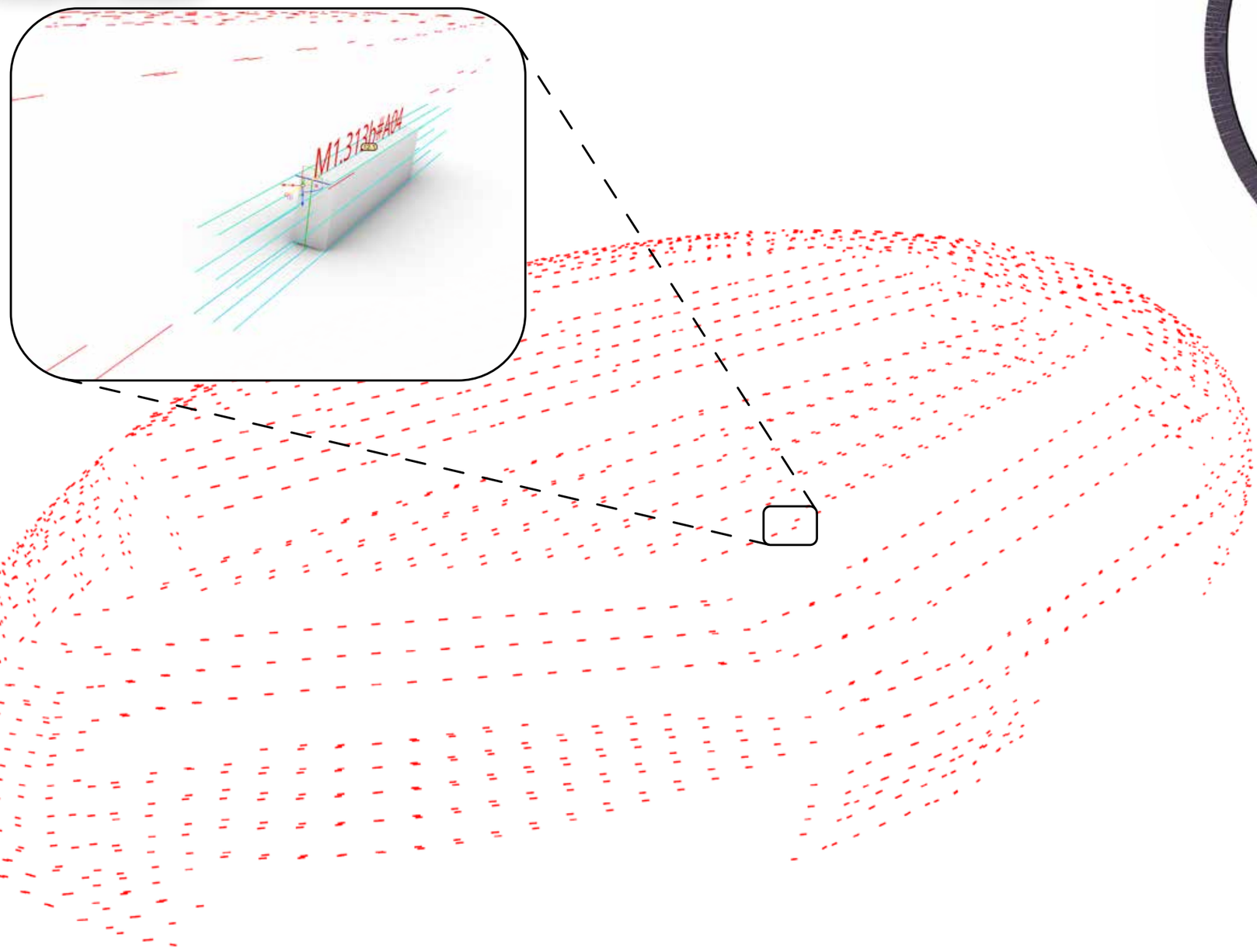

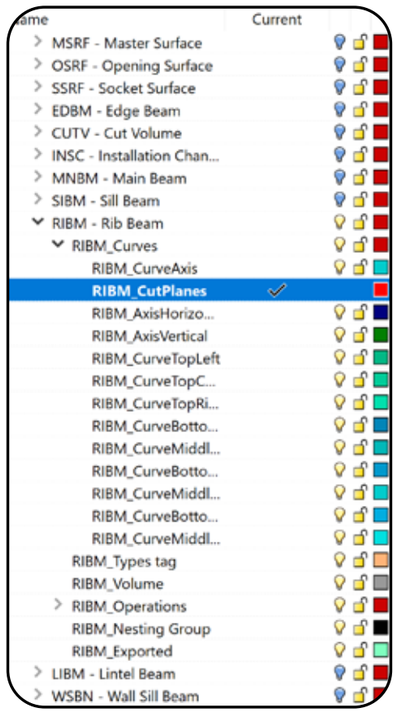

Schema-based Experiments

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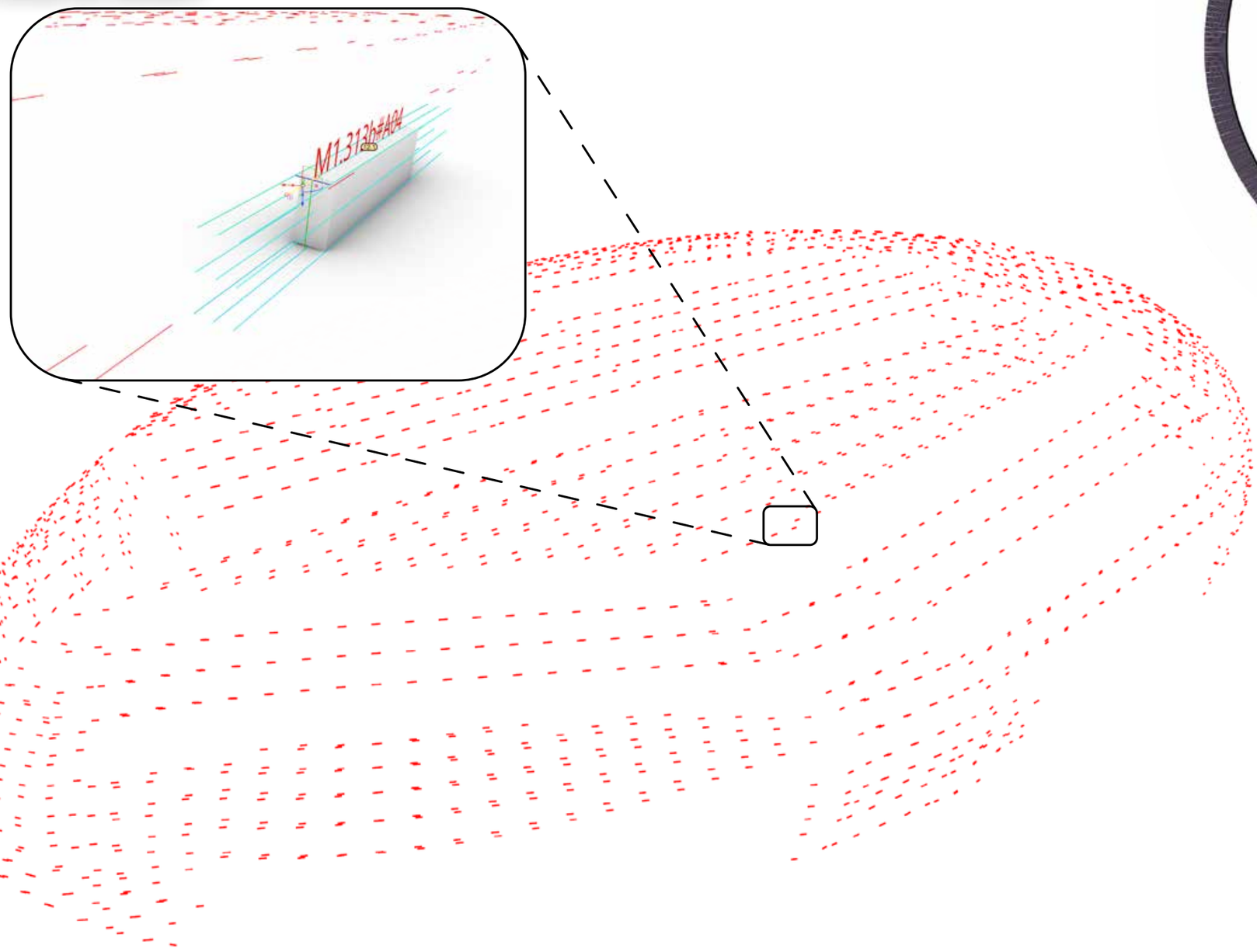
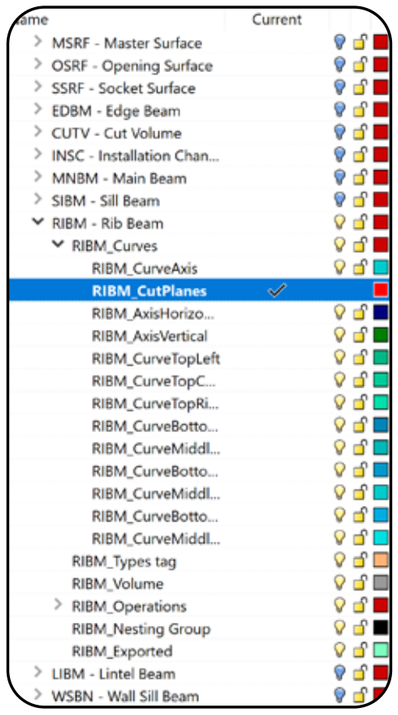




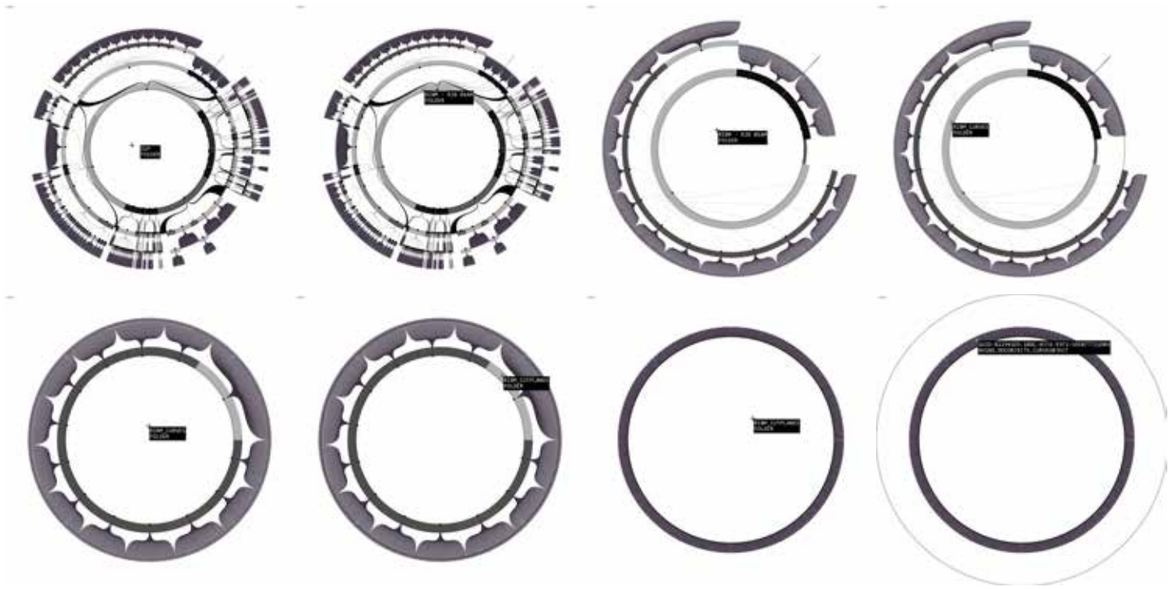
Schema-based Experiments

B2 - Navigating across Hierarchies: LayerExplorer

Key question:
"How could the multi-scalar model be interacted and which User Interface (UI) and User Experience (UX) concepts would be needed?"

Result

LayerExplorer enables the possibility to zoom on particular, local levels of the hiearchical data structure. Thus, instead of continuously trying to comprehend the whole database at once through the complete overview of the sunburst diagram, **the user is finally able to focus on local levels and navigate between them**.



Limitations / link to the next experiment

However, the present experiment **operates outside of the 3D modelling environment, as the data structure has been simply externalized to be further manipulated**. Therefore, the next experiment will investigate how **custom Graphical User Interface features can directly interface within the 3D model itself**.

Schema-based Experiments

B5 - Exploring Hierarchies: LayerStalker

Key question:
"How would an ideal Multi-Scalar Modelling AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which User Interface (UI) and User Experience (UX) concepts would be needed?"

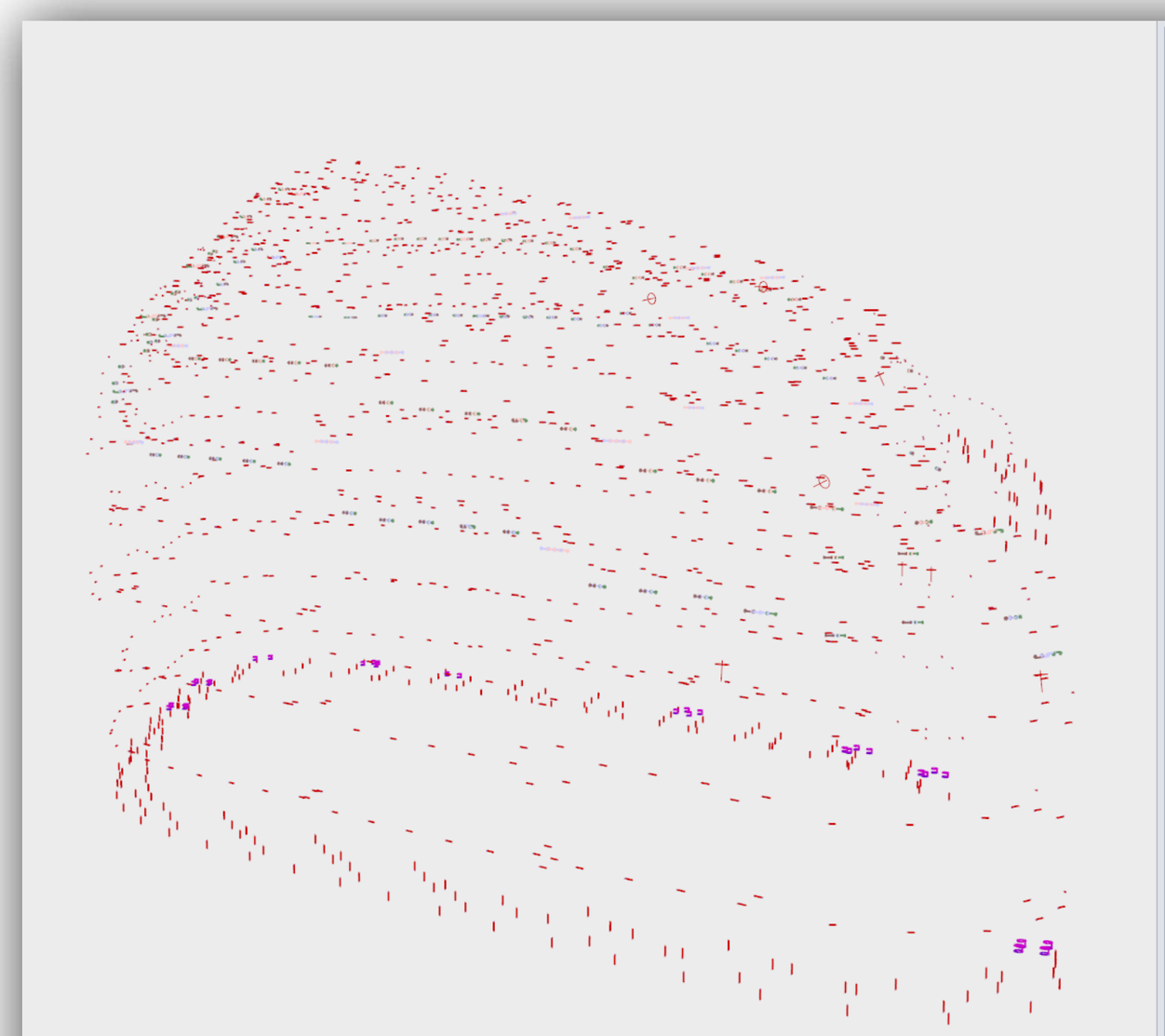
VIDEO PLACEHOLDER

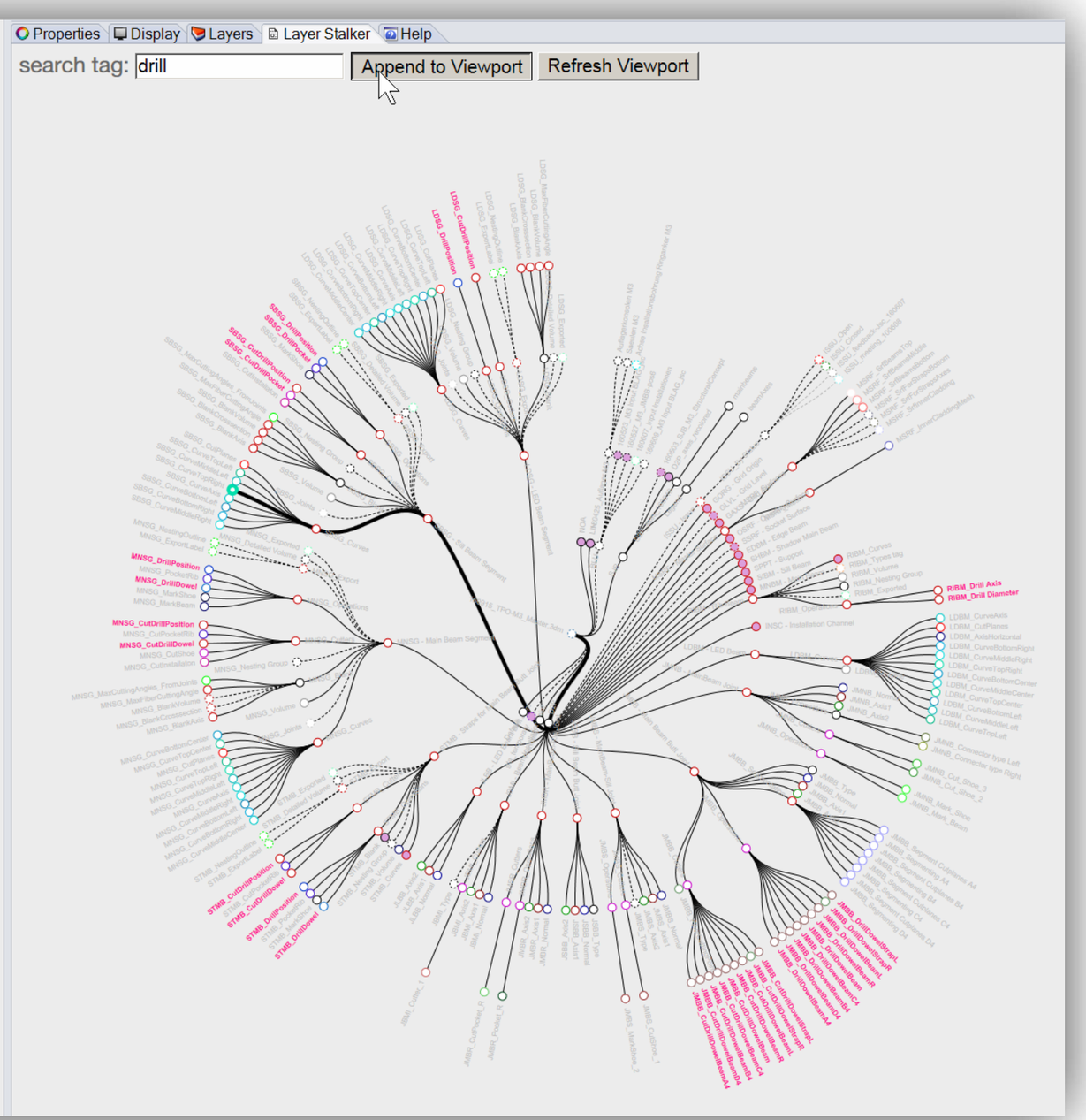
Schema-based Experiments

B5 - Exploring Hierarchies: LayerStalker - Unstructured Query

Key question:

"How would an ideal Multi-Scalar Modelling AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which User Interface (UI) and User Experience (UX) concepts would be needed?"





Schema-based Experiments

B5 - Exploring Hierarchies: LayerStalker - Structured Query

Key question:

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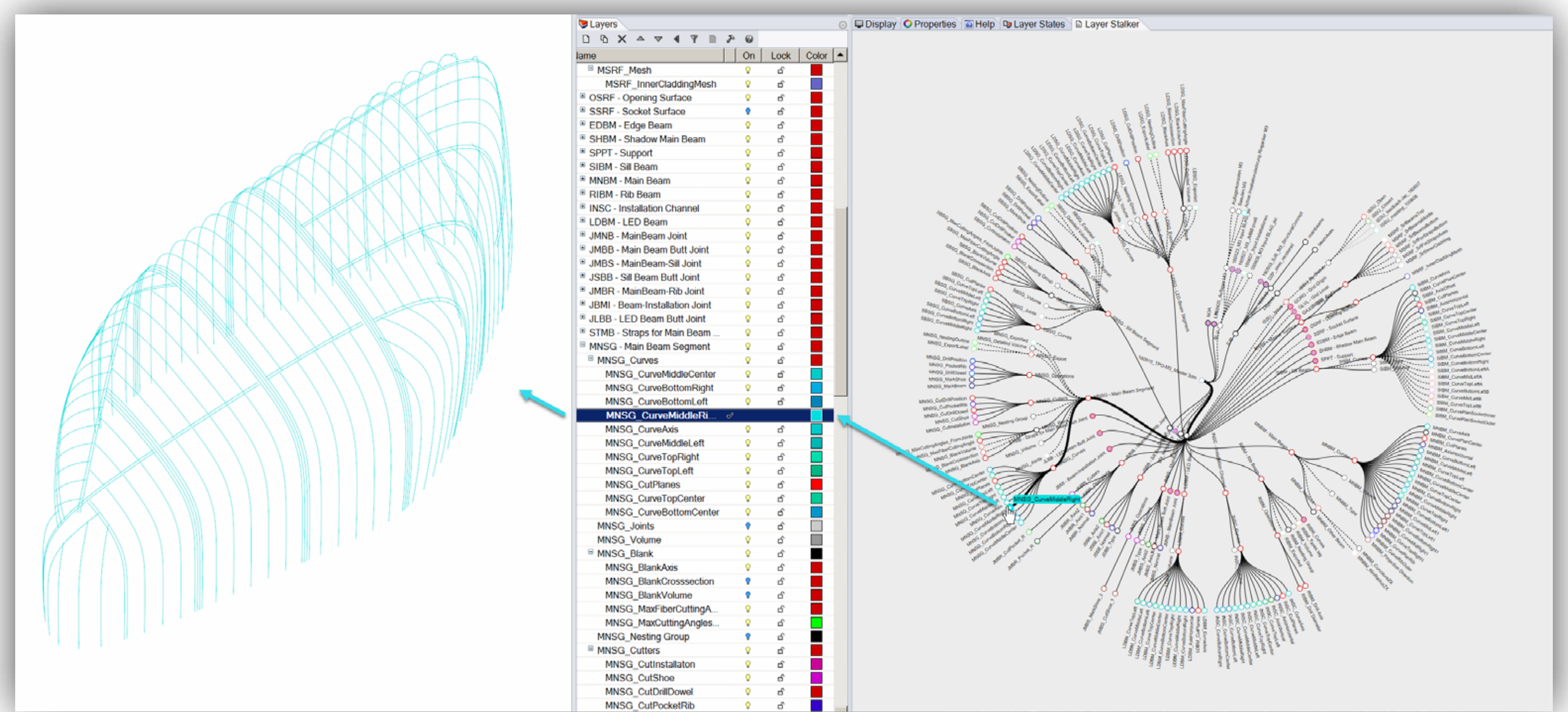


Schema-based Experiments

B5 - Exploring Hierarchies: LayerStalker

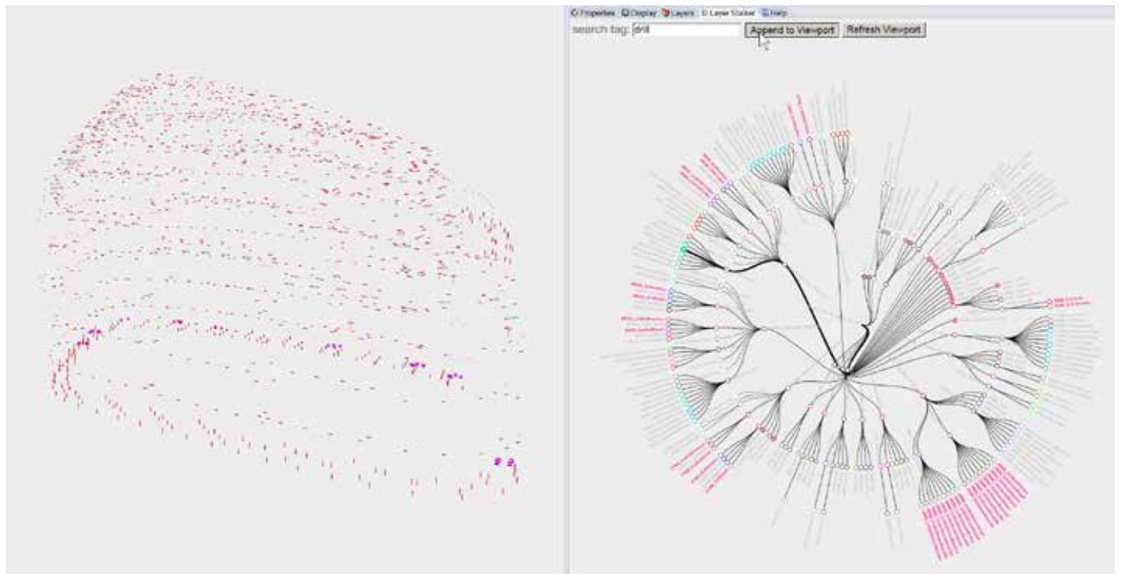
Key question:
"How would an ideal Multi-Scalar Modelling AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which User Interface (UI) and User Experience (UX) concepts would be needed?"

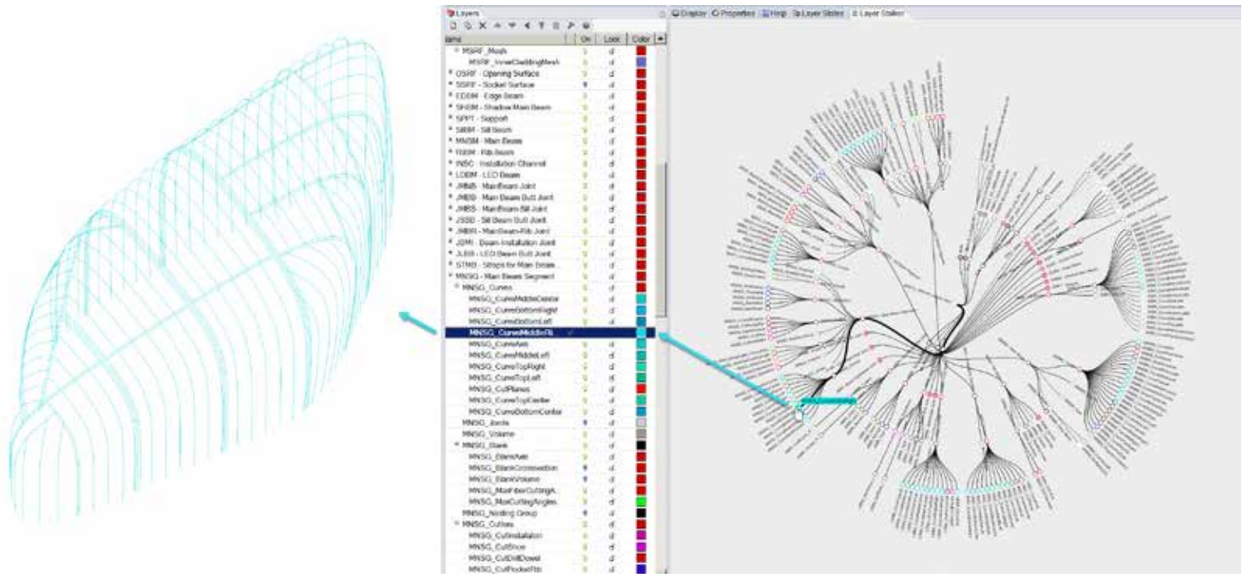
Result

The present experiment **demonstrated the possibility of performing both structured and unstructured queries from the 3D environment within the GUI interface of LayerStalker**. This prototypical application has been developed successfully and **it was possible to deploy and stress test it against multiple Rhino3D models**.

Limitations / link to the next experiment

However, as this interface **works exclusively with Rhino3D and on a model level**, the next experiments will investigate **alternative strategies to share data sets on an object level, across multiple models and software platforms**.

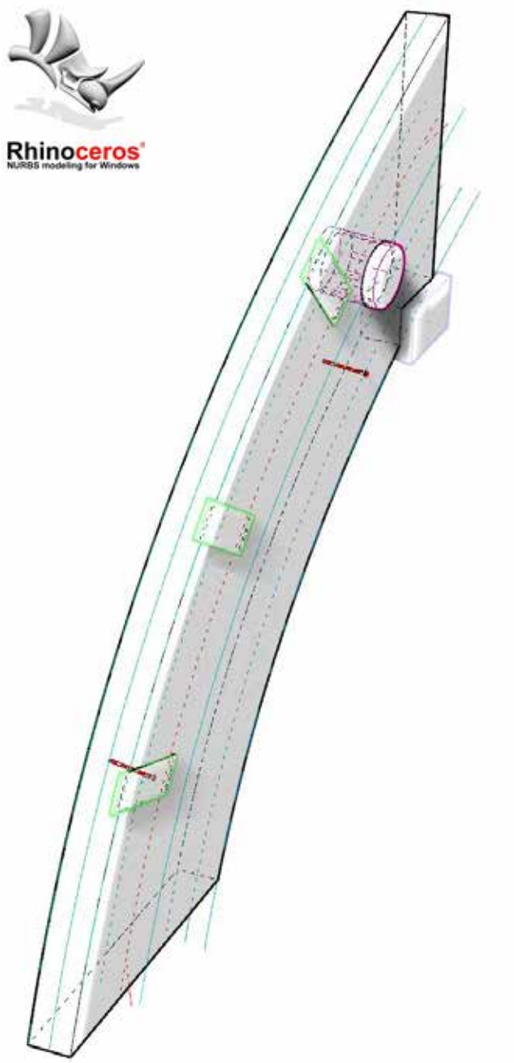




Schema-based Experiments

B7-B8 - Building & Transferring Hierarchies: SchemaBuilder

Key question:
"How can the end user share, access, track and modify at multiple scales data-rich objects sent and received from different trades within a common directory structure until completion of the building?"



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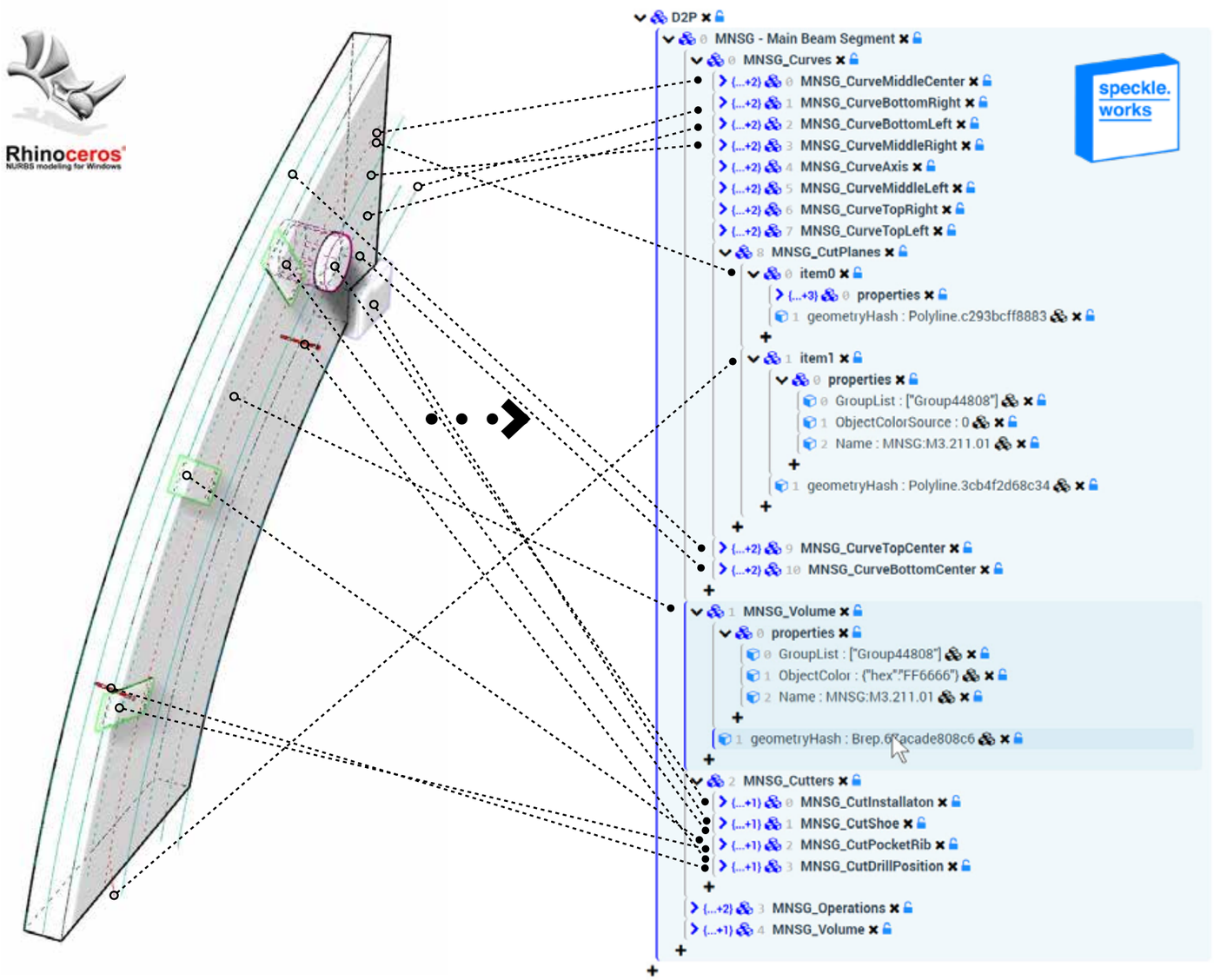

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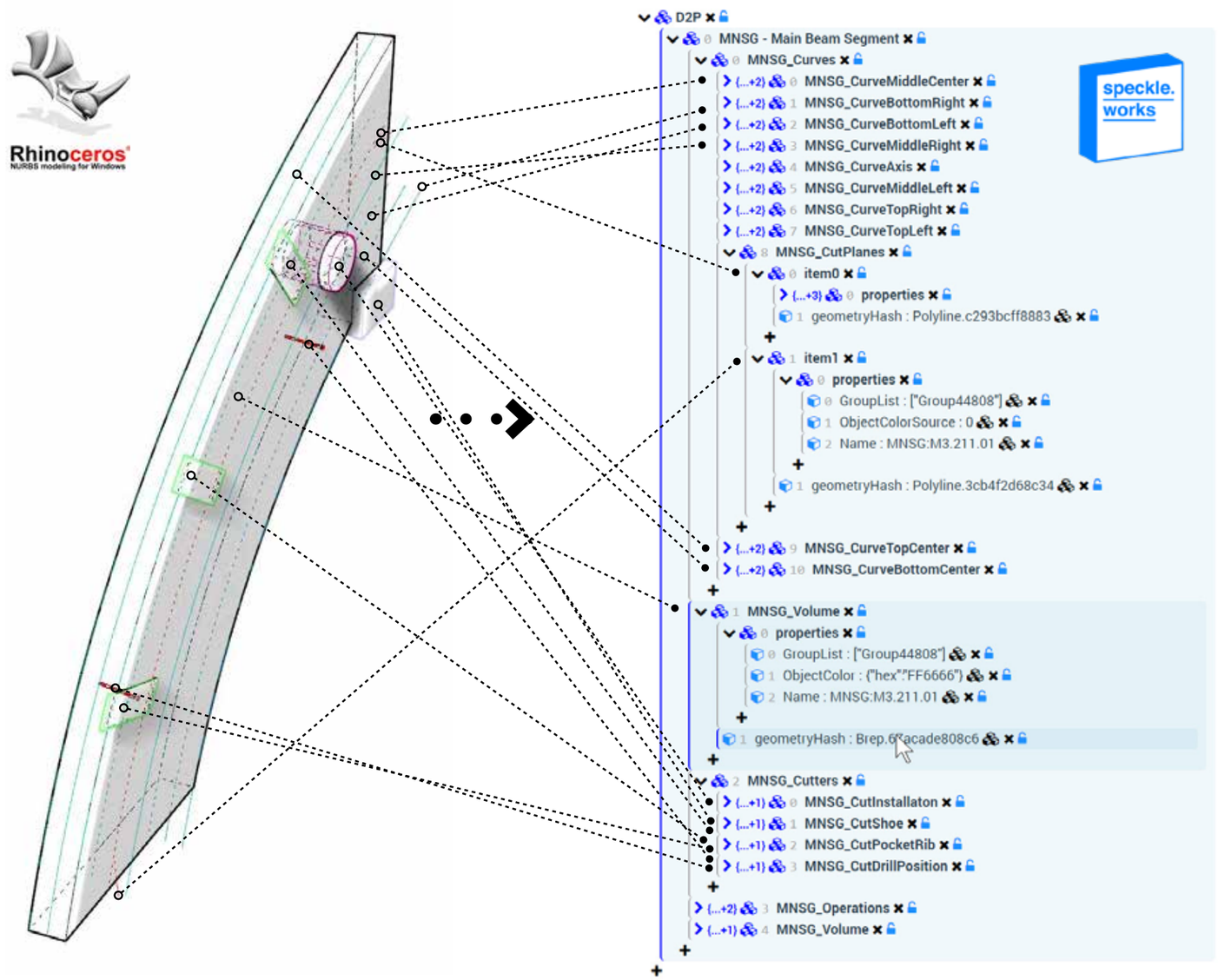

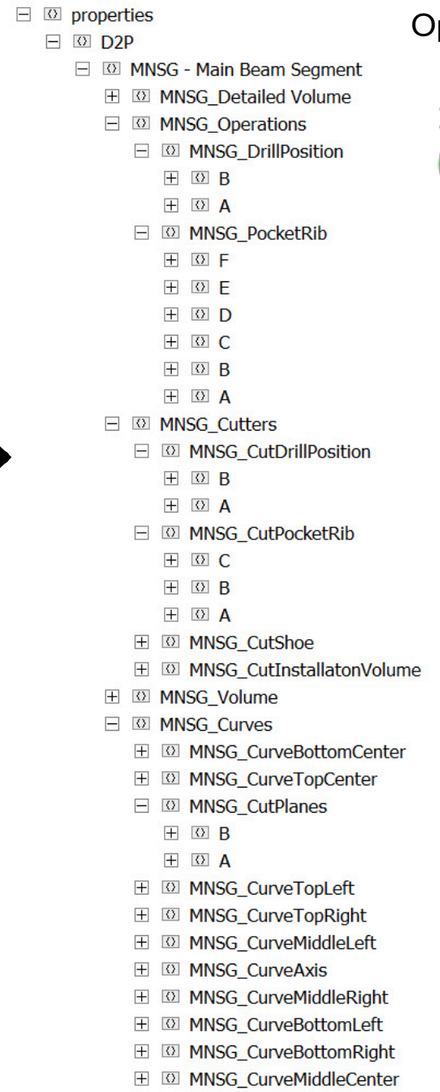

Open Format: JSON

mongoDB

Schema-based Experiments

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Key question:
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VIDEO PLACEHOLDER

Schema-based Experiments

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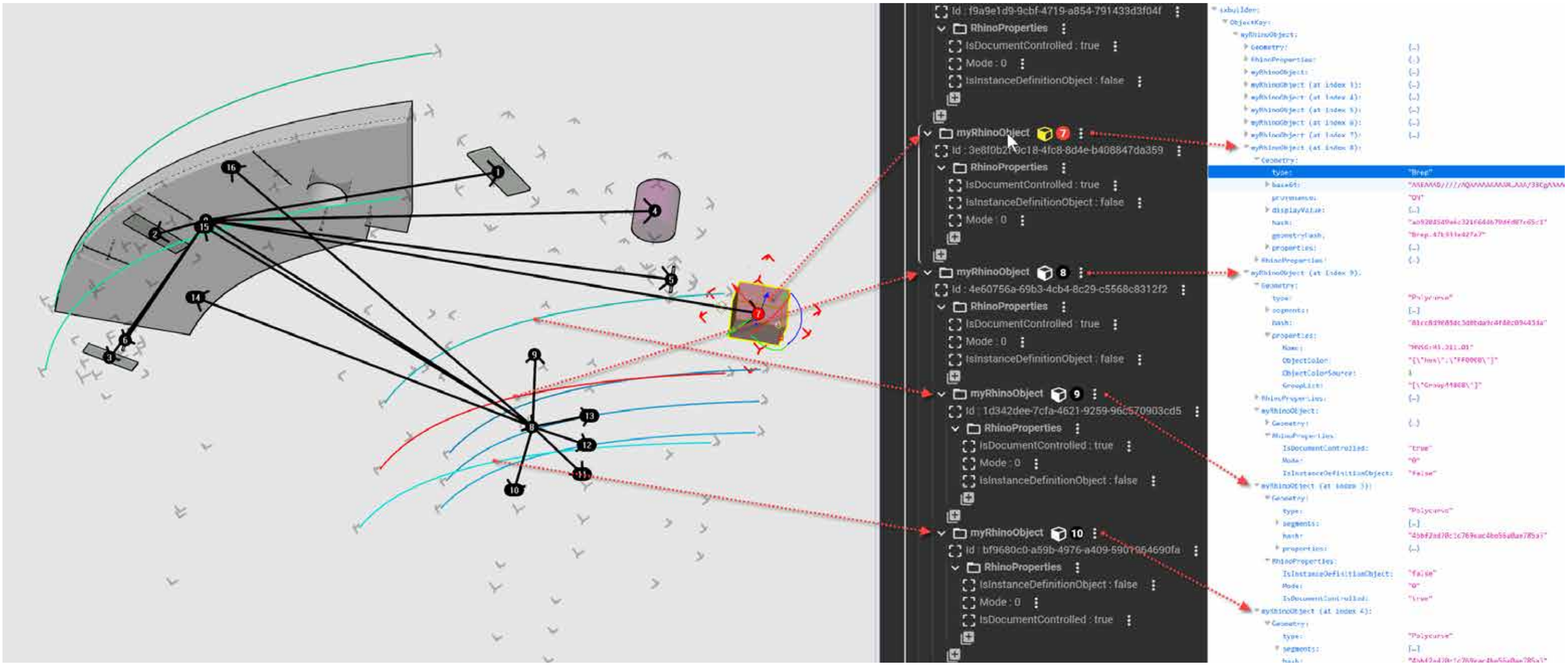
Rhino3D's Modelling Environment | **SchemaBuilder Interface** | **Serialized Objects (Speckle)**



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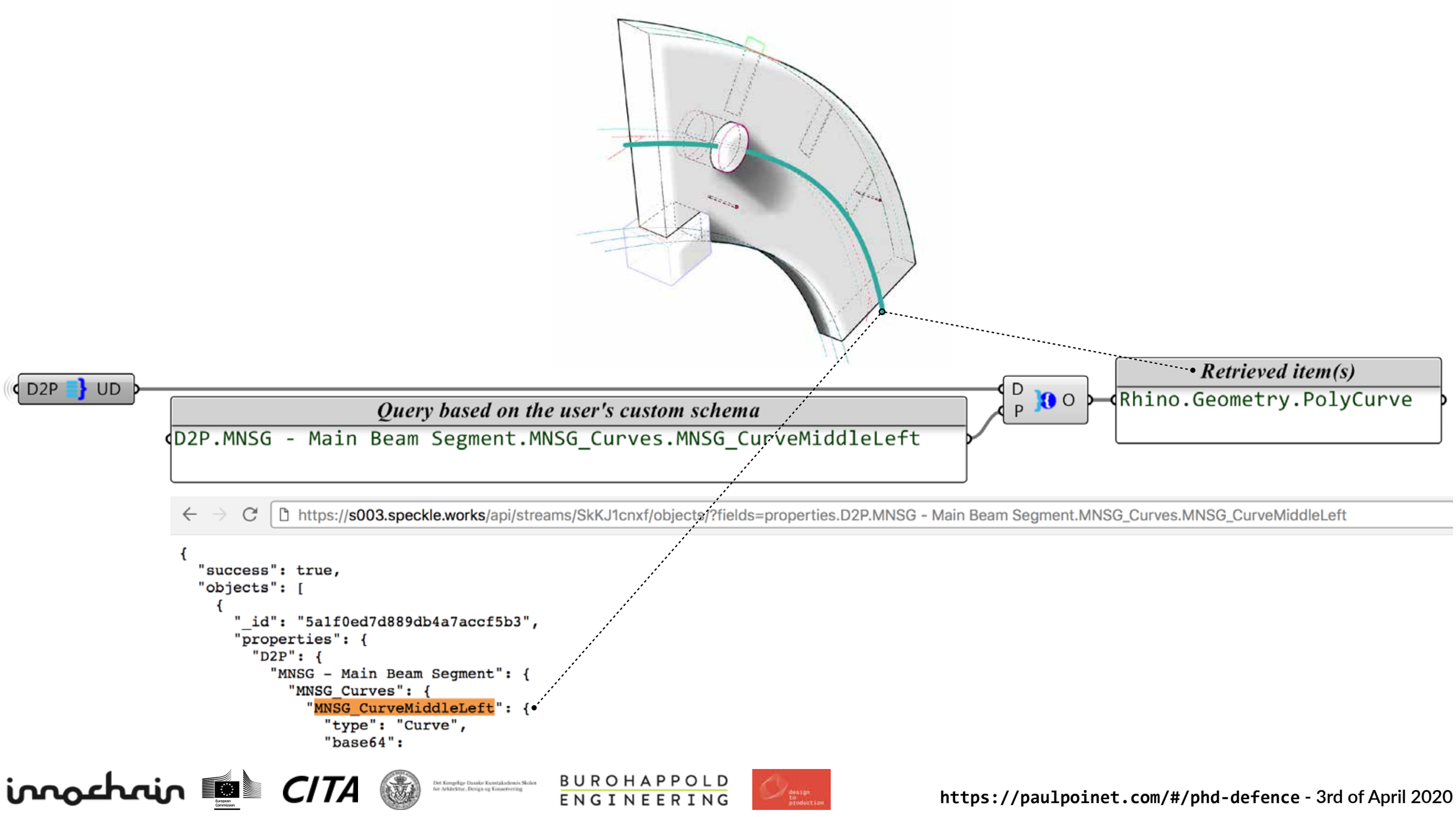


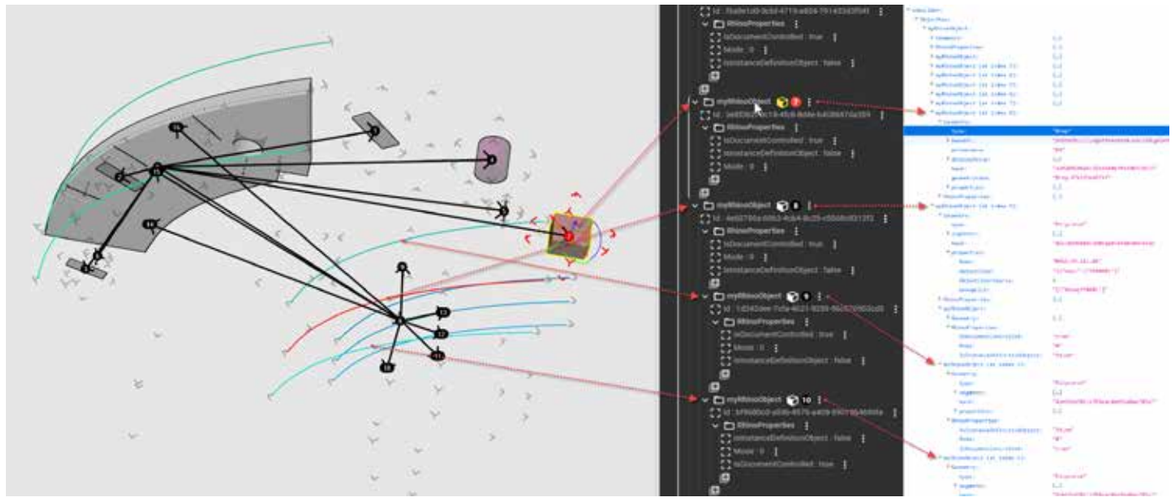
Schema-based Experiments

B7-B8 - Building & Transferring Hierarchies: SchemaBuilder

Key question:
"How can the end user share, access, track and modify at multiple scales data-rich objects sent and received from different trades within a common directory structure until completion of the building?"

Result

The present experiment demonstrated the possibility of **building a data rich hierarchy of objects and transfer it via Speckle to another Rhino/Grasshopper session**.



Limitations / link to the next experiment

However, the data exchange operates from and to the same software platform, Rhino3D. **The next experiment will investigate how to transfer a similar object across different host applications and adapt its schema accordingly**.

Cross-practice Collaboration Experiment

C1 - Sharing Custom Schemas via Speckle & BHoM:
A speculative scenario between BuroHappold and Design-to-Production

Key question:
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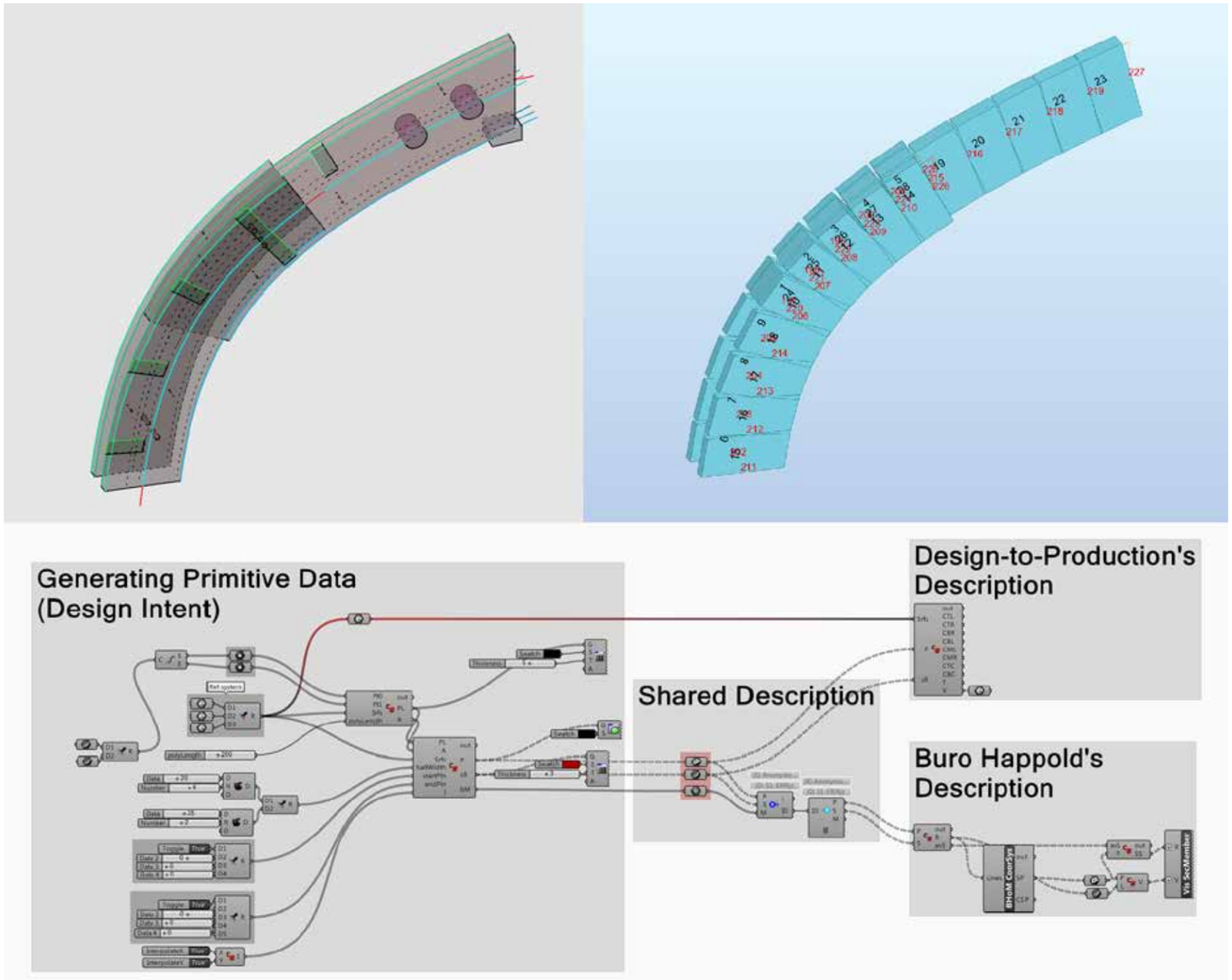

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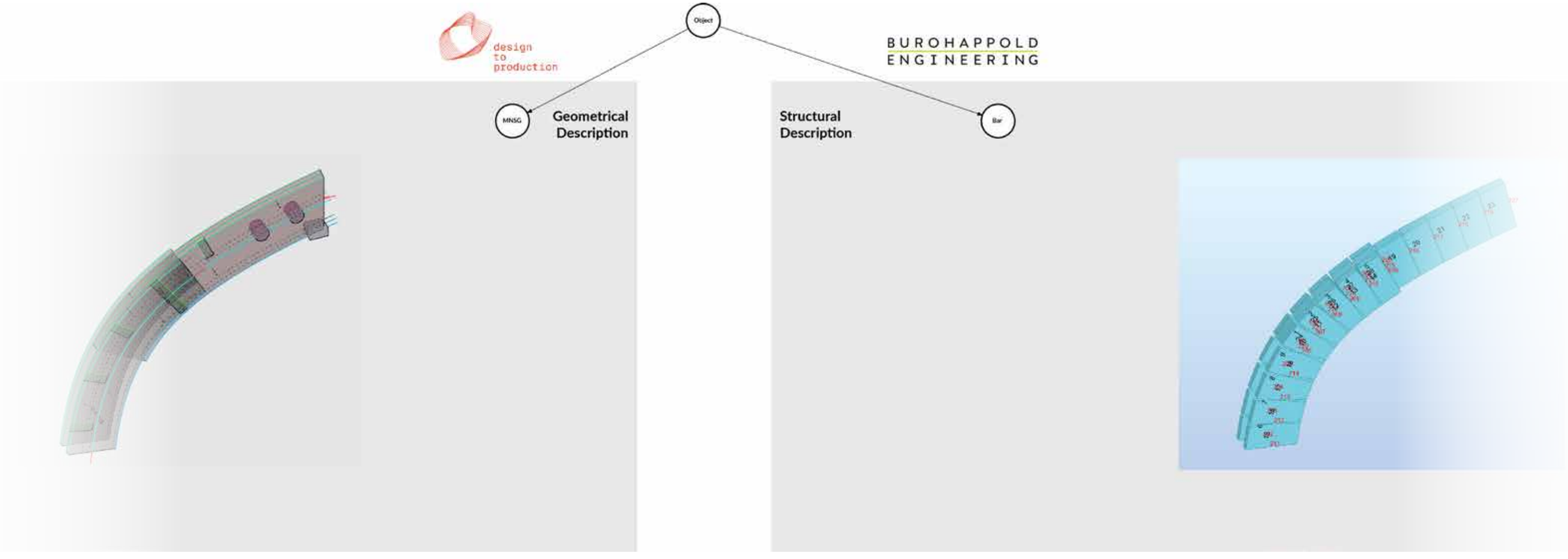

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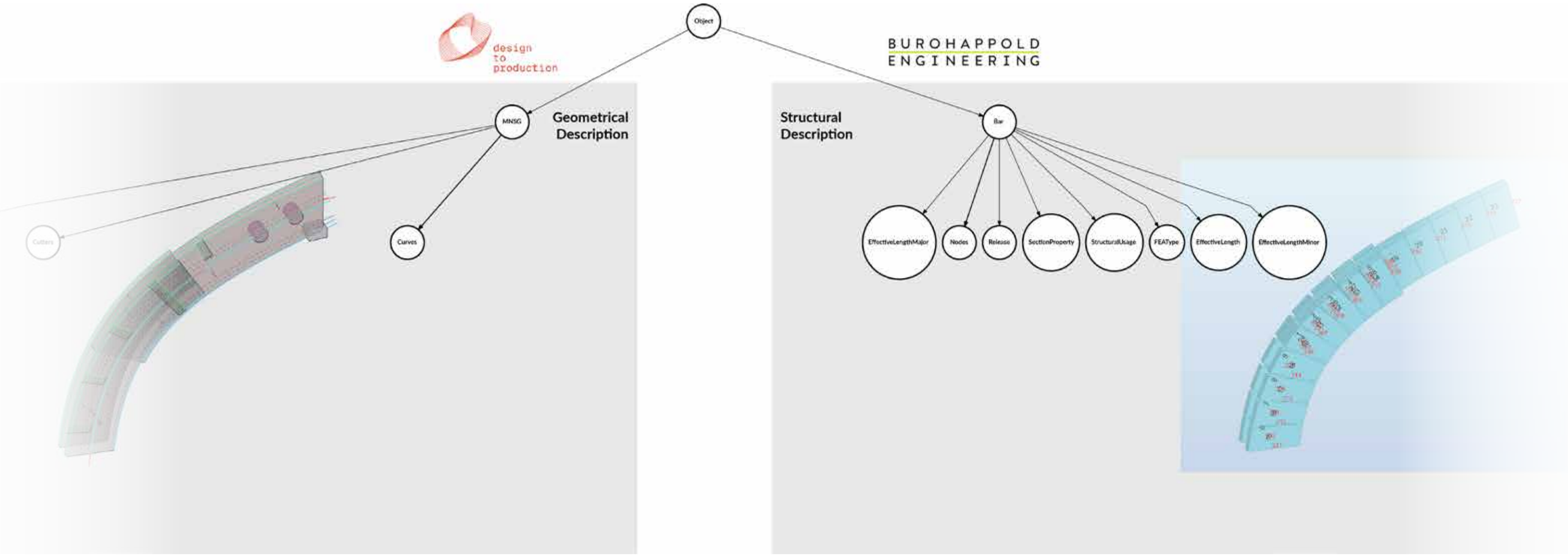

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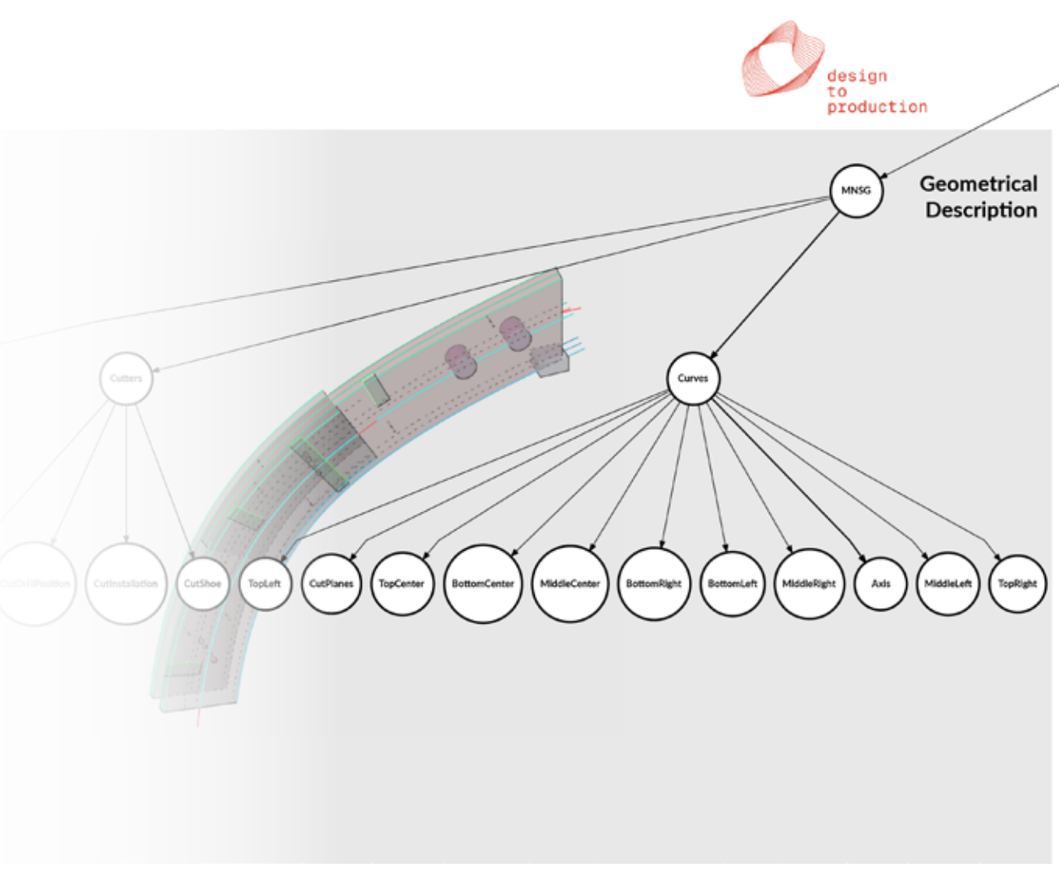

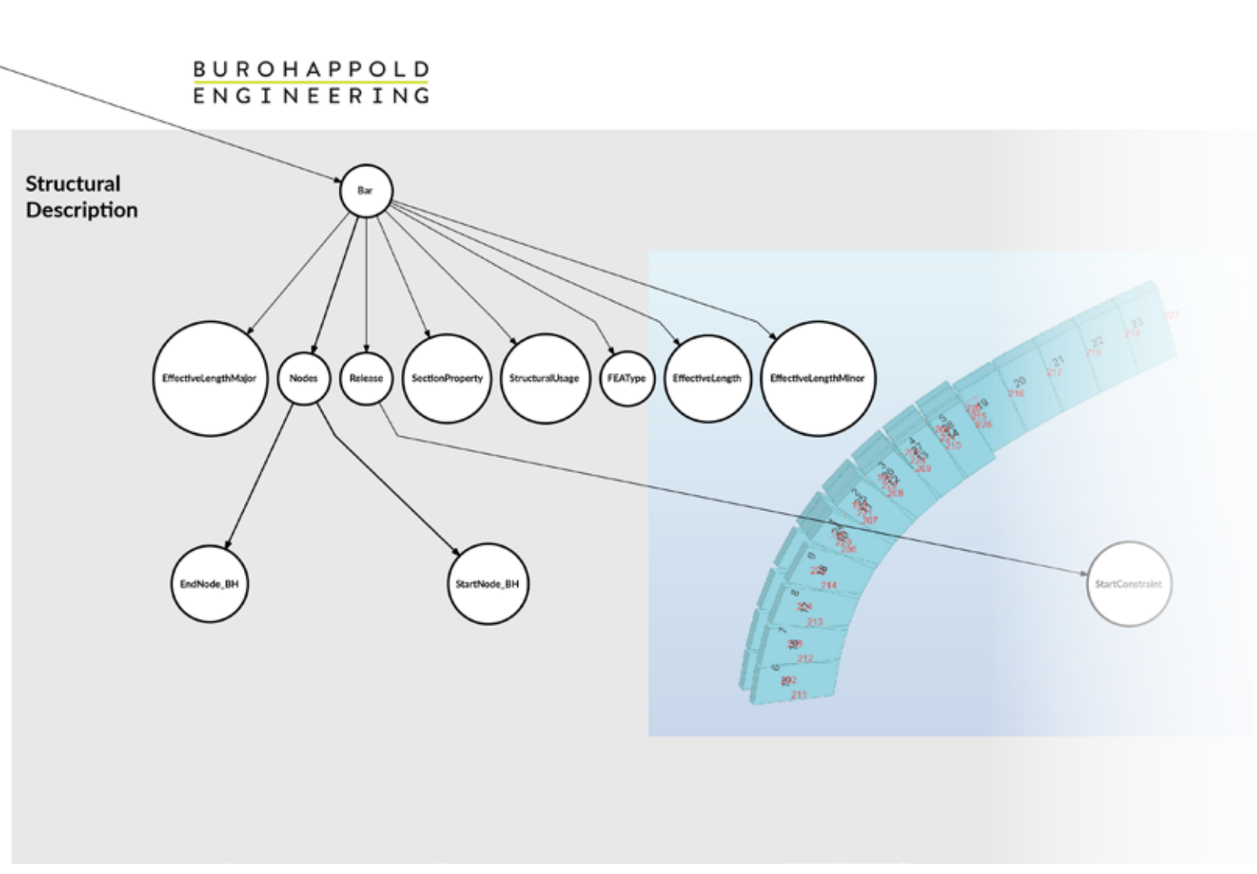

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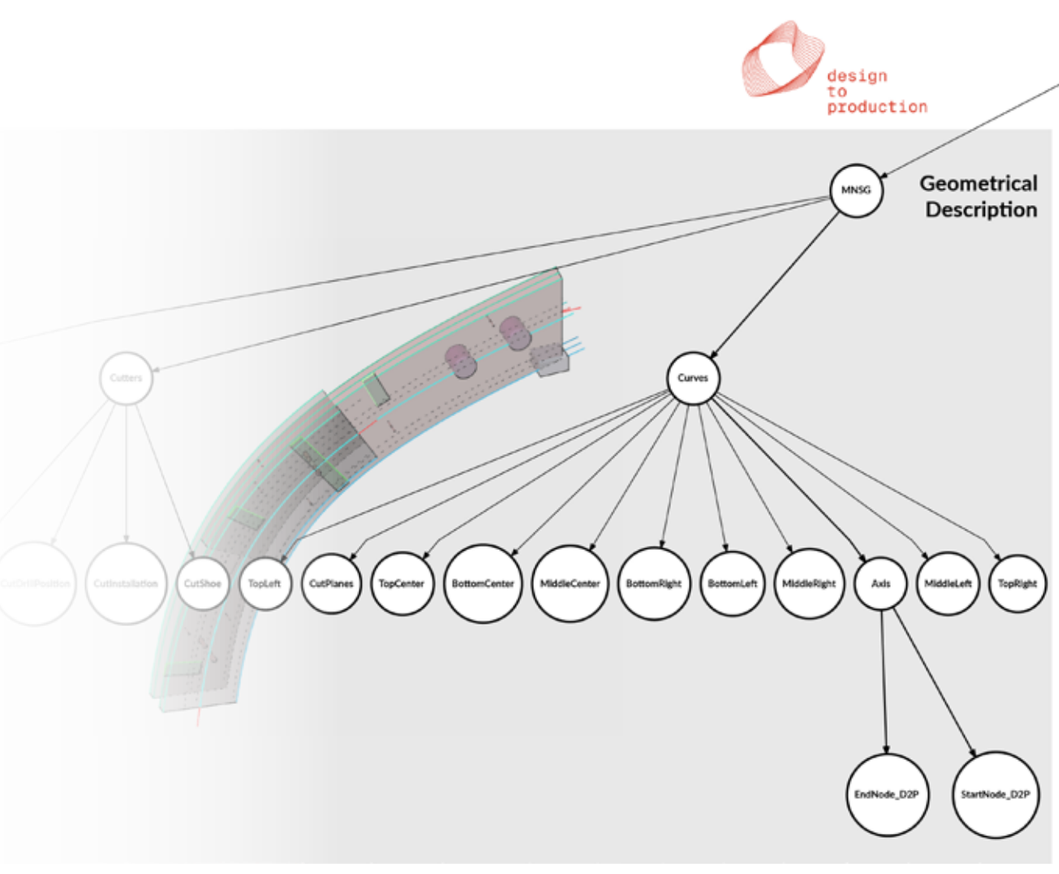

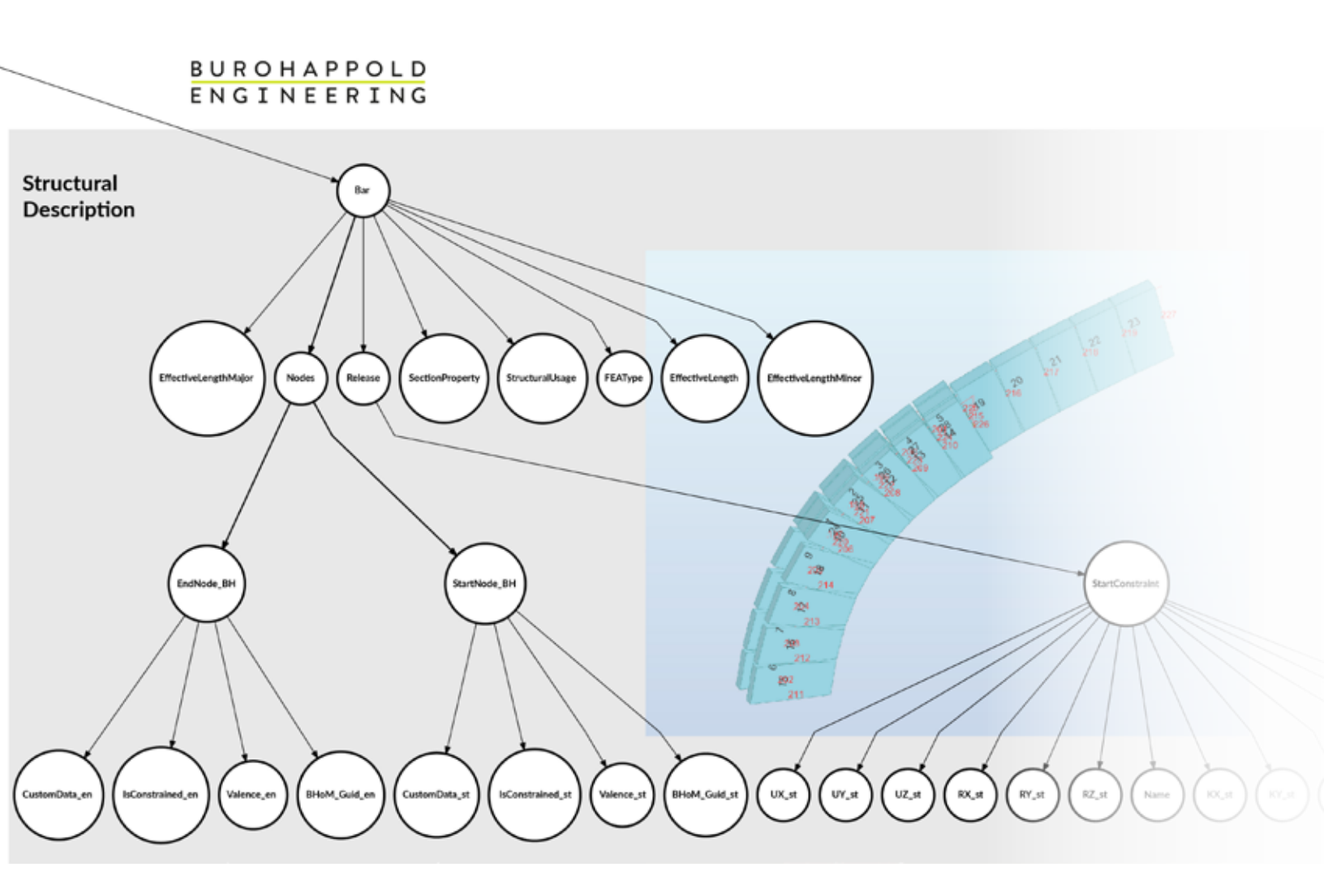

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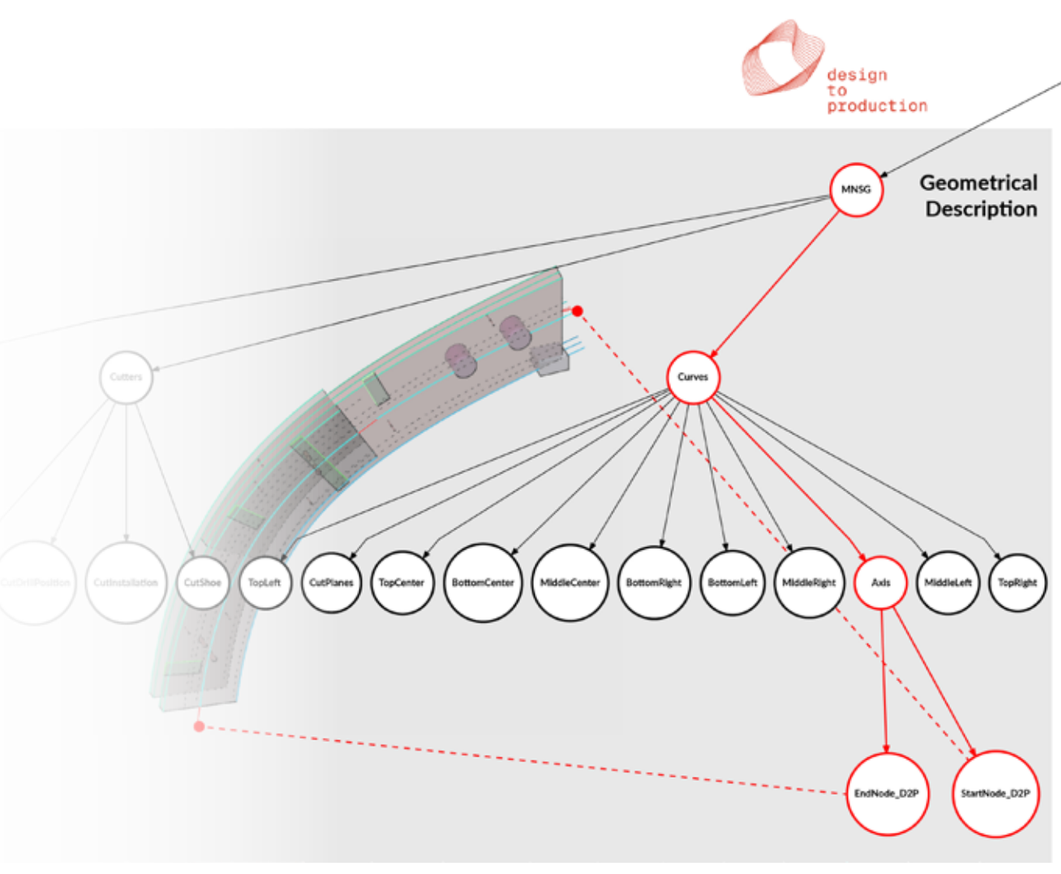

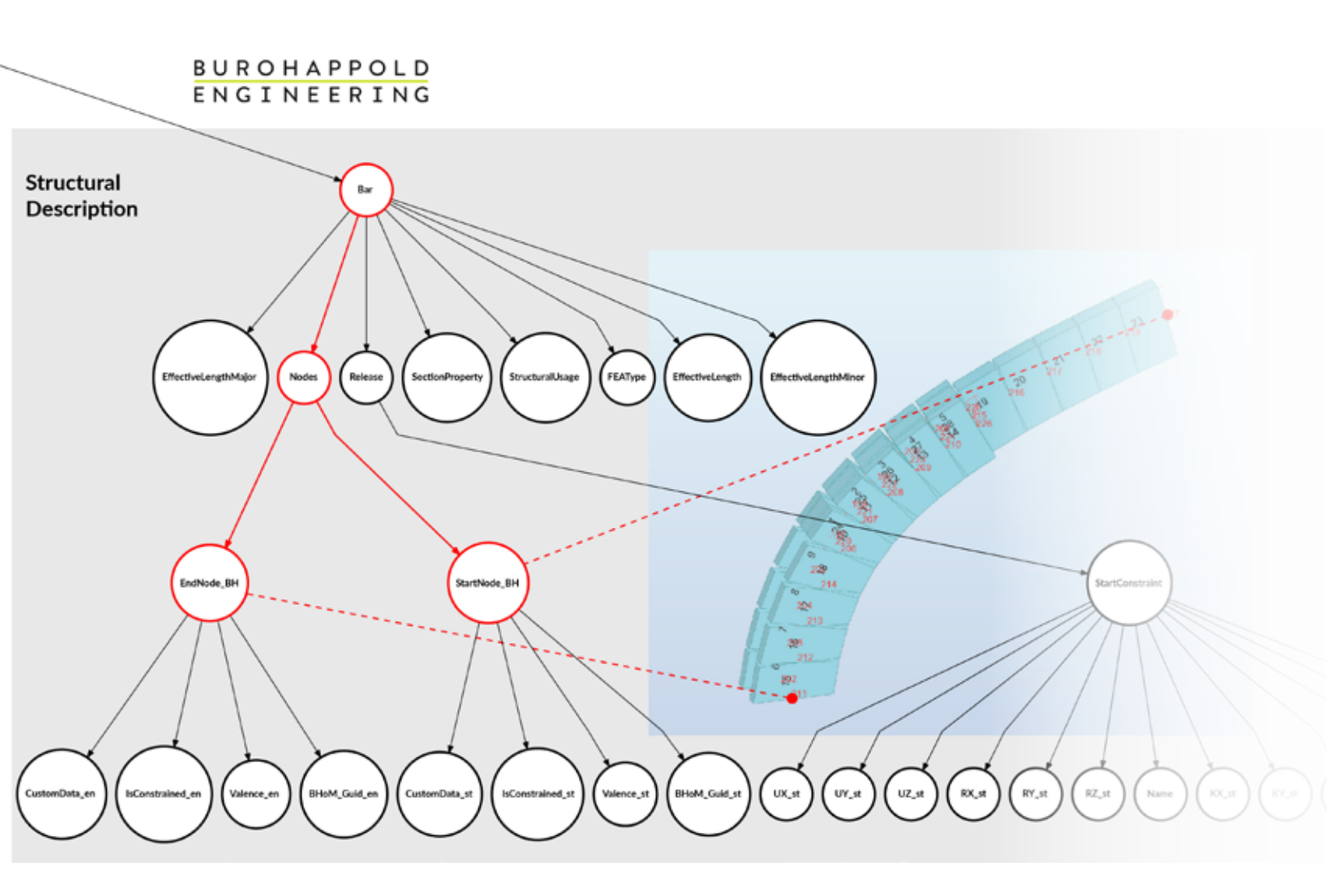

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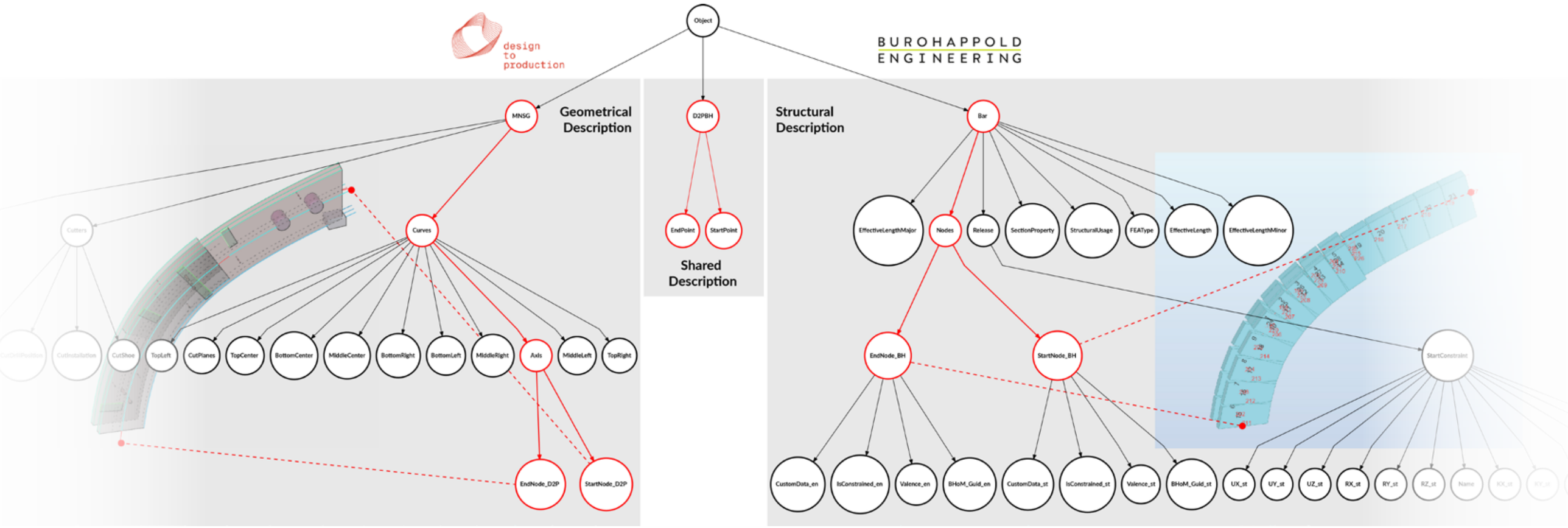

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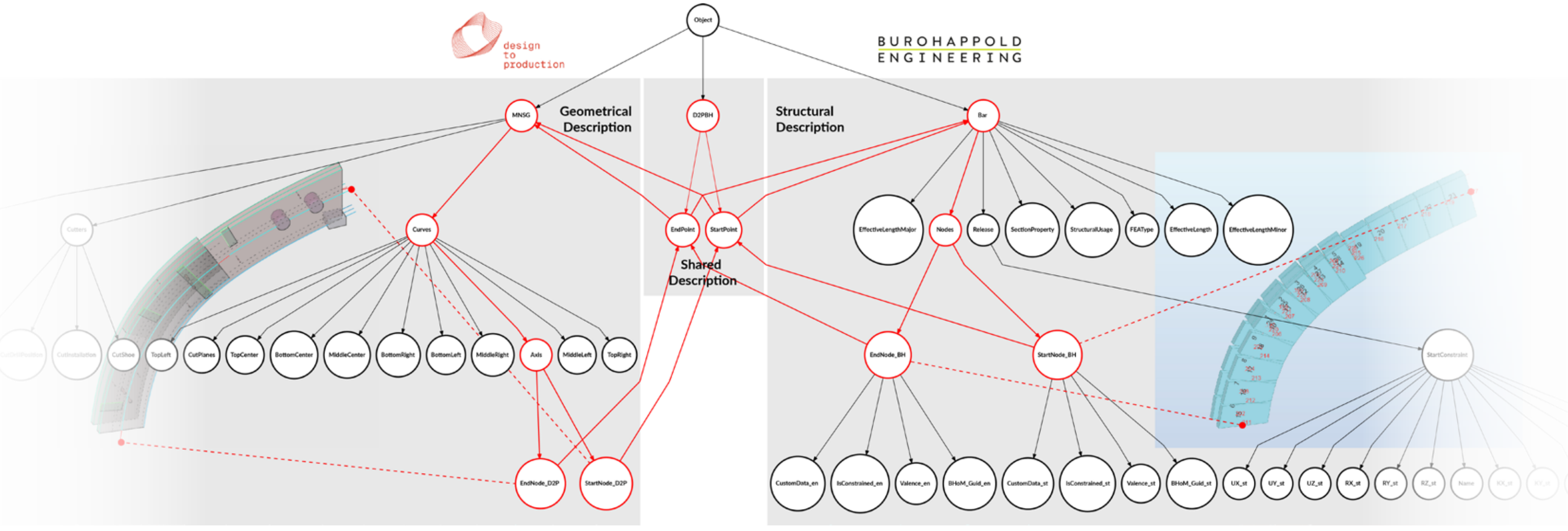

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VIDEO PLACEHOLDER

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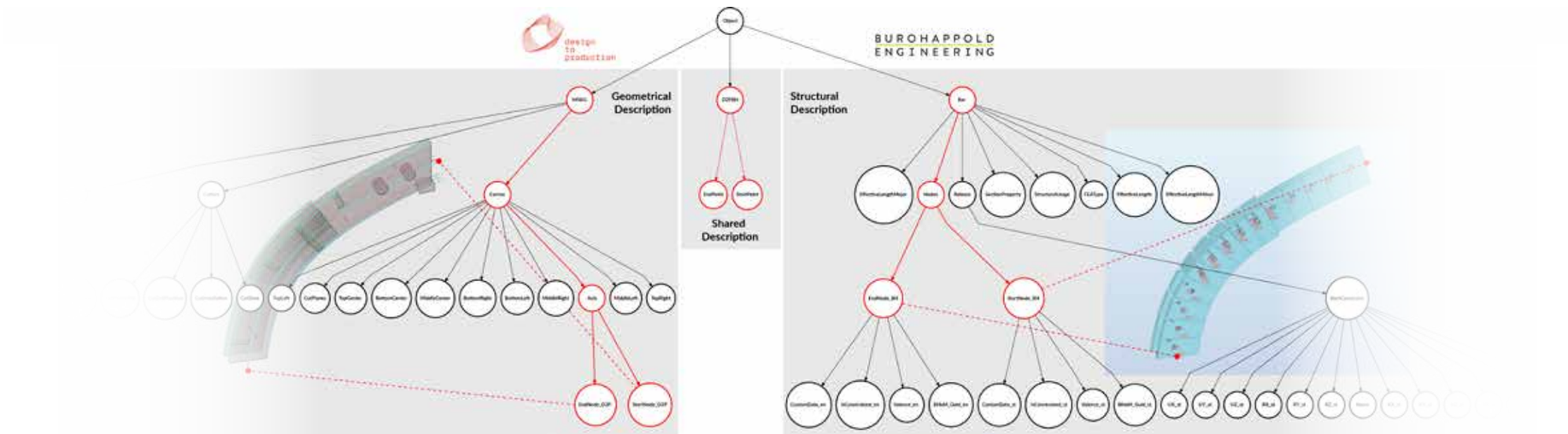
Result

This cross-practice collaboration experiment **hybridizes modelling-based and schema-based strategies to transfer data-rich geometrical information across trades and scales**, as part of the overall Multi-Scalar Modelling framework.

Limitations / link to the next experiment

Although successful, **the multiple schema-based experiments described so far focused on the local adaptive object schema** (SchemaBuilder). **Merging further this concept with the modelling-based strategies developed in the previous series of experiments would enable cross-practice collaboration at scale, in which multiple involved parties could seek to exchange multiple complex data schemas and (sub-)models throughout an entire project**. This principle was explored during the 2018 Simulation for Architecture + Urban Design (SimAUD) workshop.



Cross-practice Collaboration Experiment

C2 - SimAUD Workshop at TU Delft (2018): Open Collaborative Design, Simulation & Analysis Flows

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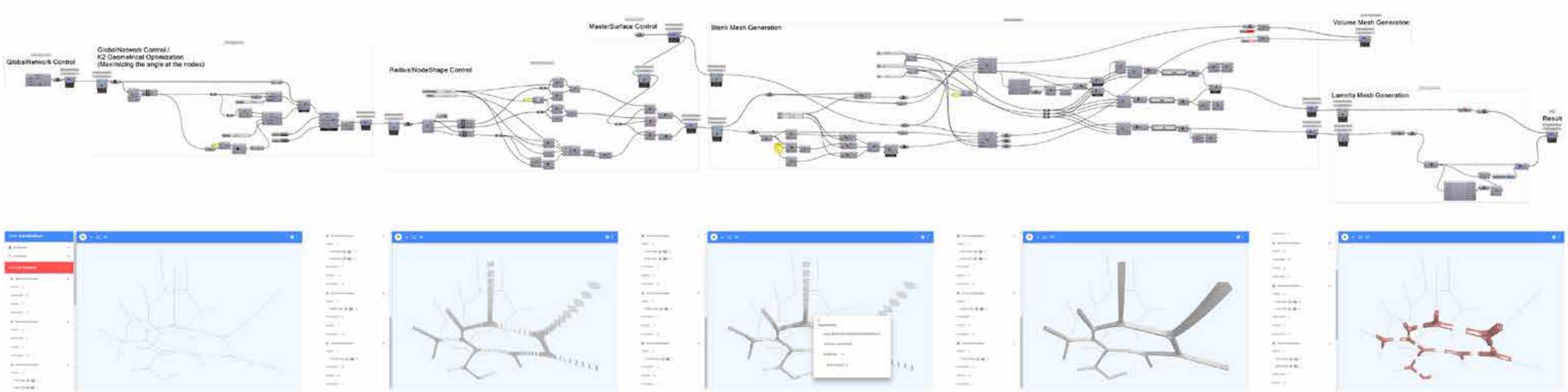
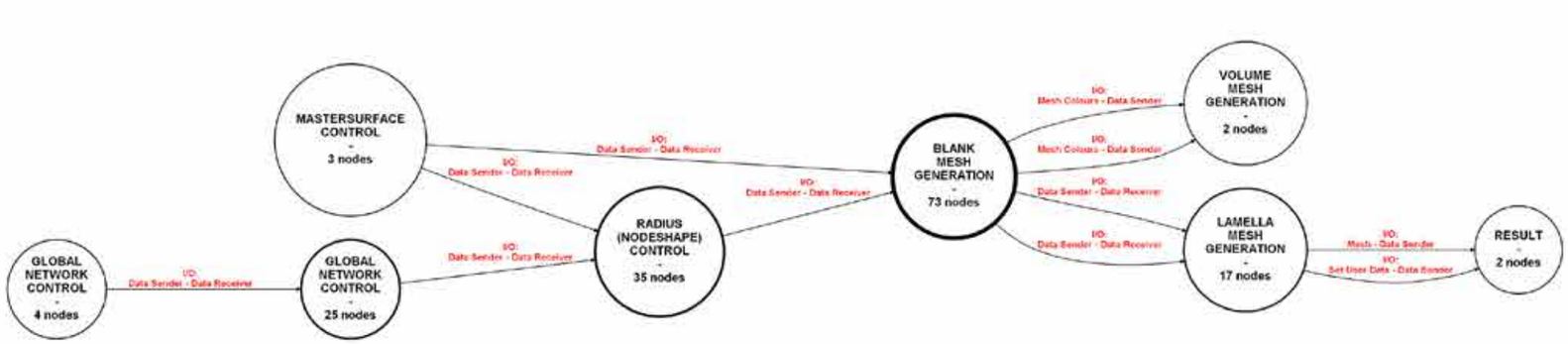
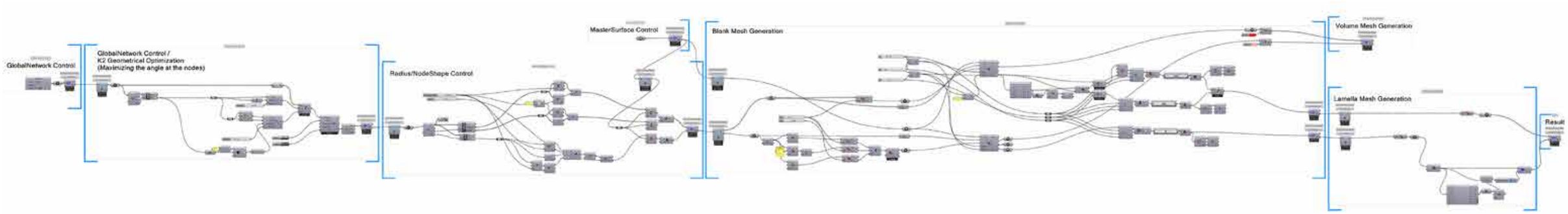


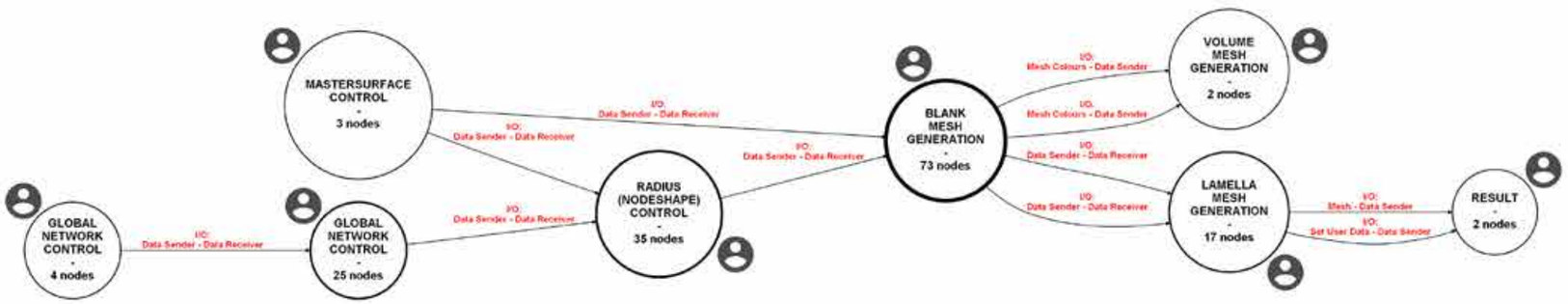


Cross-practice Collaboration Experiment

C2 - SimAUD Workshop at TU Delft (2018): Open Collaborative Design, Simulation & Analysis Flows

Key question:
"How can the end user share, access, track and modify at multiple scales data-rich objects sent and received from different trades within a common directory structure until completion of the building?"





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VIDEO PLACEHOLDER

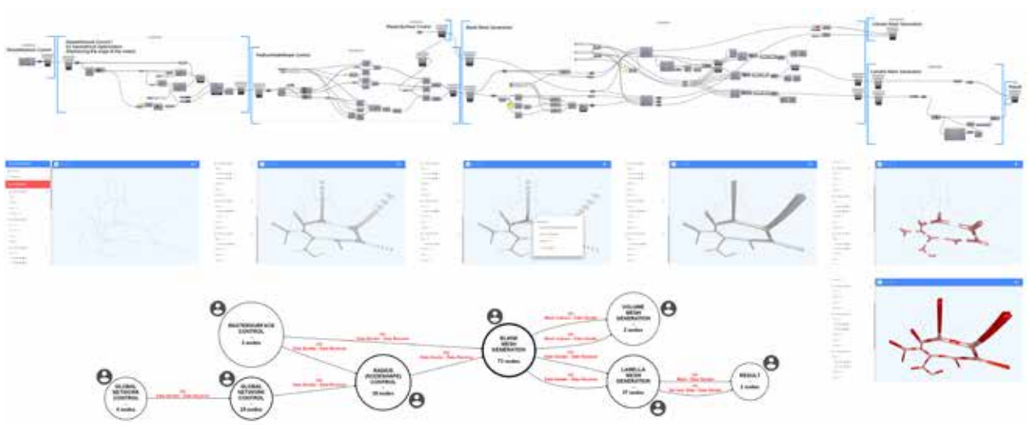
Cross-practice Collaboration Experiment

C2 - SimAUD Workshop at TU Delft (2018): Open Collaborative Design, Simulation & Analysis Flows

Key question:
"How can the end user share, access, track and modify at multiple scales data-rich objects sent and received from different trades within a common directory structure until completion of the building?"

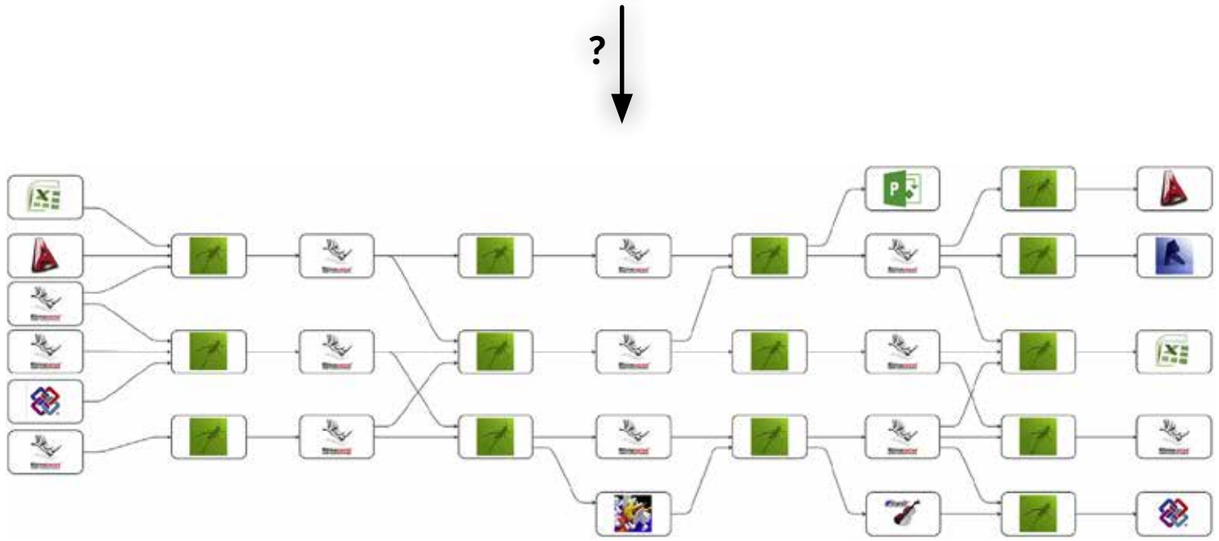
Result

The **shared workflow setup across the participants enabled them to communicate in a seamlessly manner across their respective design spaces**. Although segregation proves to be useful to separate the concerns in architectural design practice, **it does not mean that communication should be disabled. Instead, communication channels should be maintained with the possibility to enable them whenever the design users wish to stream data during the design process**.



Limitations

This experiment only tackled a design scale during a workshop. **The question remains open on how the system would behaved throughout a "real world" building design dataset** (e.g. the data flow elaborated by Front Inc. for the Morpheus Hotel).



Morpheus Hotel's project ecosystem of staged models and generating logic (Front Inc.)

6. Conclusion and Future Directions: Towards a Multi-scalar Paradigm for AEC

Conclusion & Future Directions

Answering the Research Questions

1. How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?

2. How can we keep track, add and modify data within a common directory structure until completion of the building?

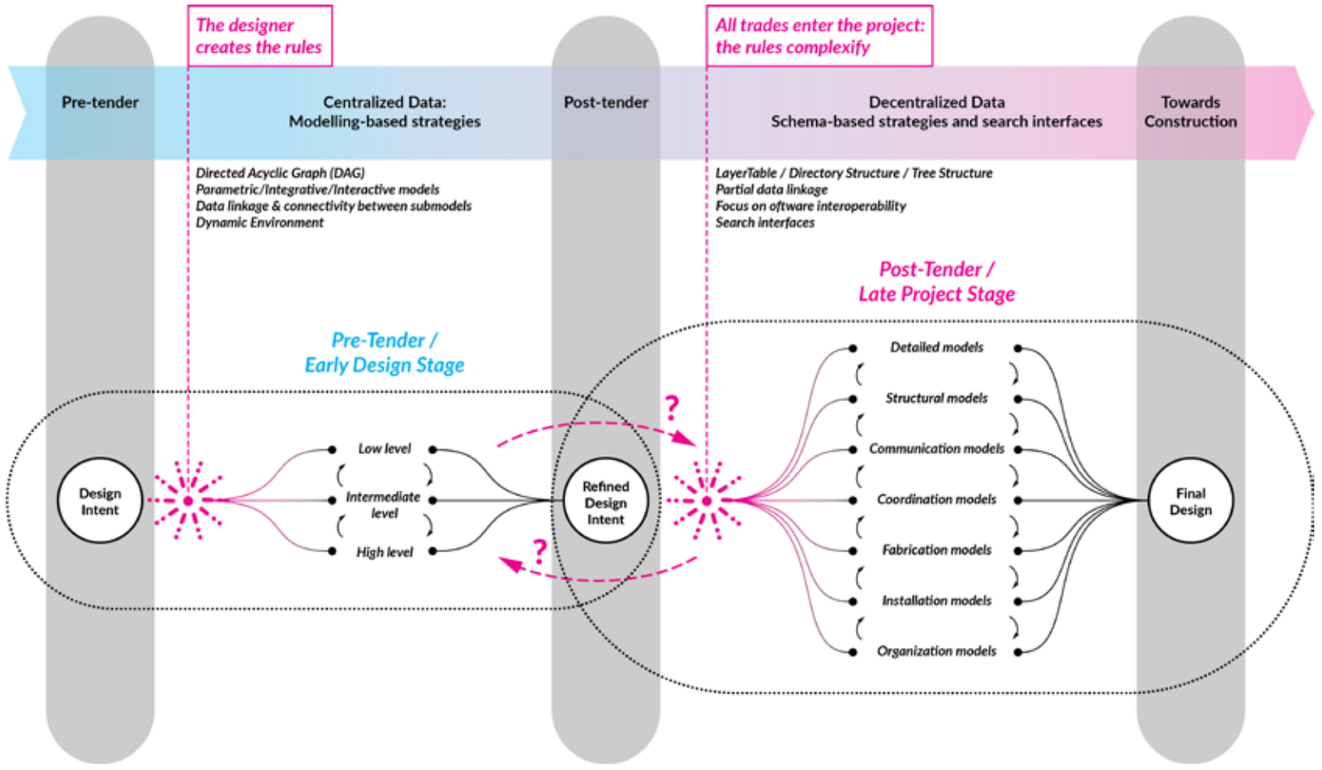
3. How would an ideal multi-scalar parametric AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which UI and UX concepts would be needed?

Conclusion & Future Directions

Answering the Research Questions

1. How can a Multi-Scalar Modelling framework allow the designer to work across different scales in order to take into account multiple constraints related to material, fabrication and structural performances during both early design and late stages?

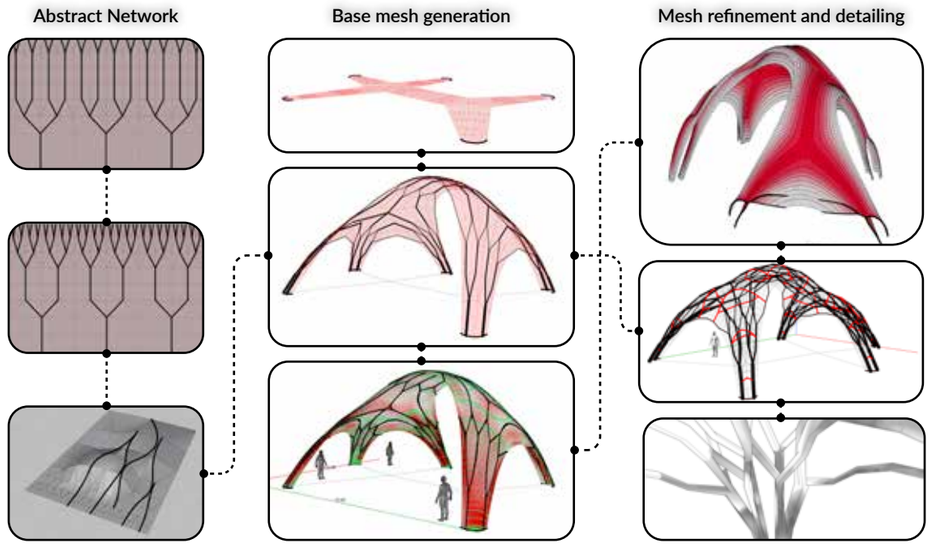
The further **hybridization of the modelling based strategies and custom software applications** (developed through the second series of schema-based experiments and search interfaces) constitutes the final Multi-Scalar Modelling framework for building design allowing for both integrative, **automated tasks at early stages** and more **direct data manipulation at later stages**.

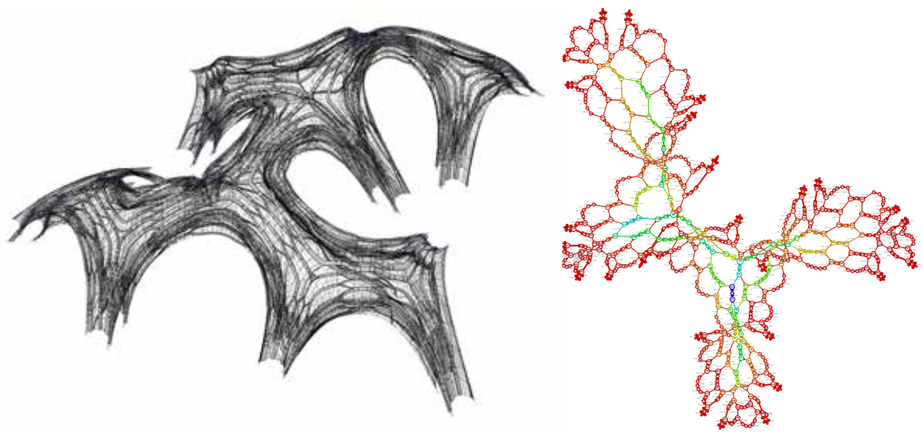


Conclusion & Future Directions

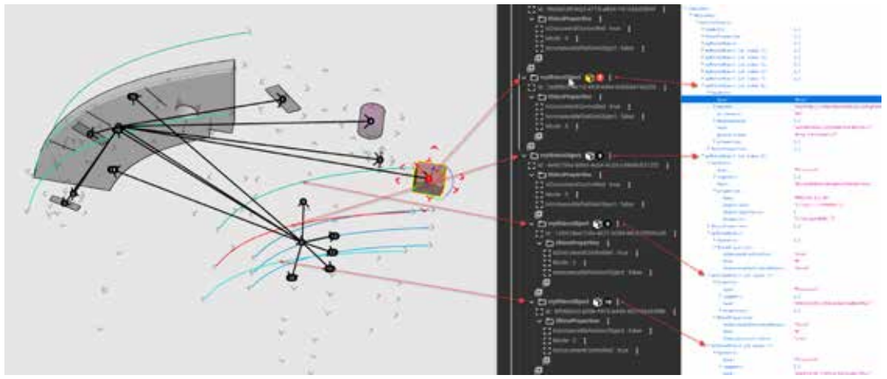
Mapping and Reflecting upon the Experiments - Early Design Stages to Late Stages

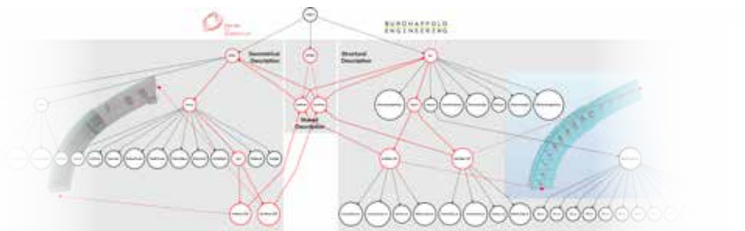
Early-stage design strategies
- Graph Modelling
- “Skeleton models”





Object Level
- Building, assembling and sharing schemas
- Querying objects



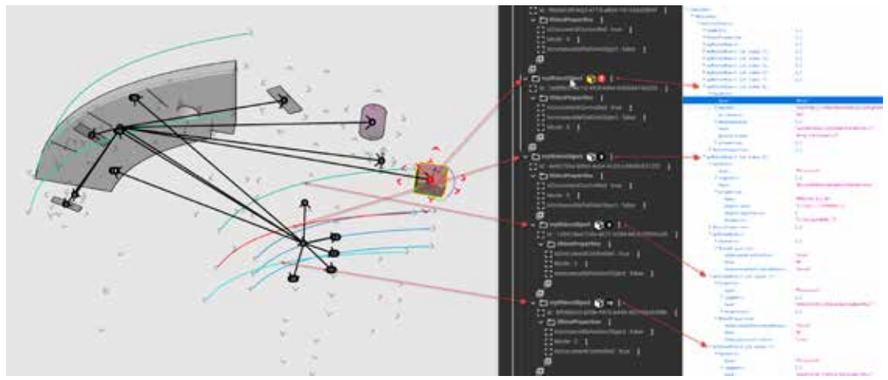


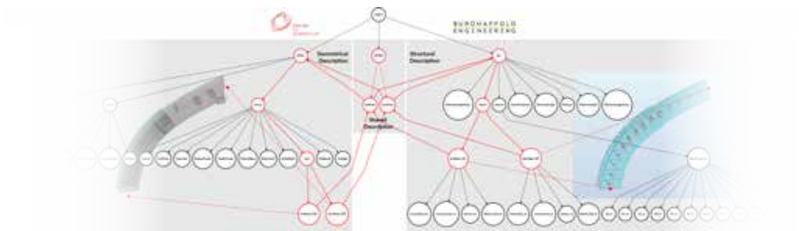
Conclusion & Future Directions

Mapping and Reflecting upon the Experiments - Late Stages

Object Level

- Building, assembling and sharing schemas
- Querying objects



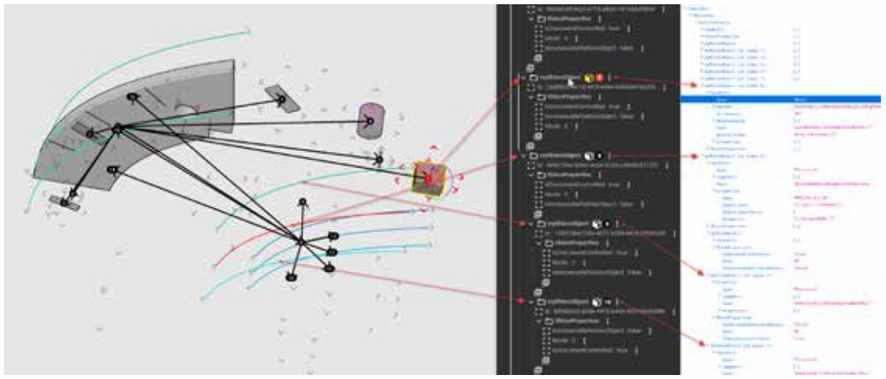


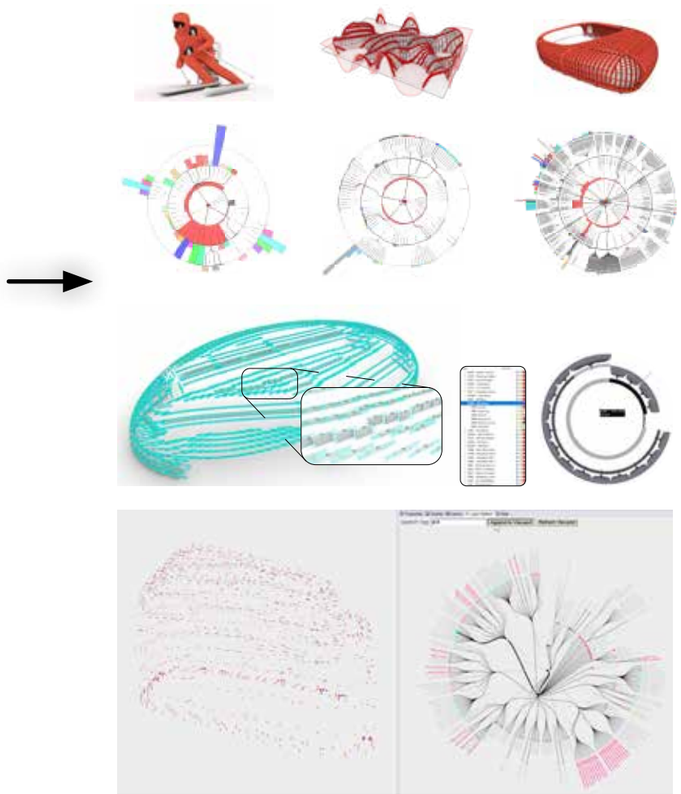
Conclusion & Future Directions

Mapping and Reflecting upon the Experiments - Late Stages

Object Level
- Building, assembling and sharing schemas
- Querying objects

Model Level
- Leveraging, visualizing, querying, navigating through large datasets





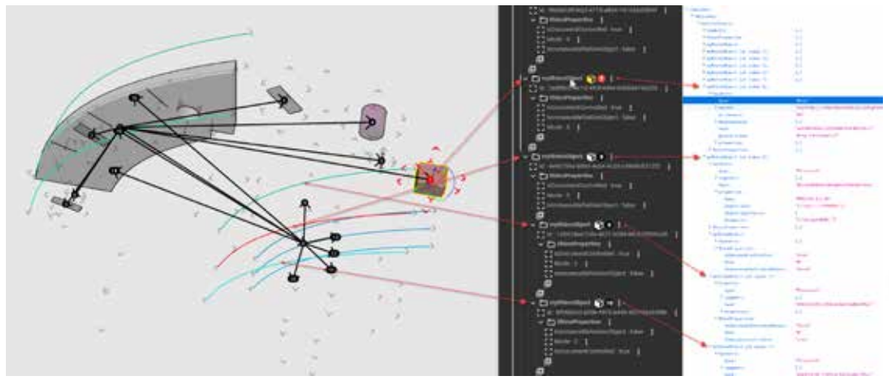
Conclusion & Future Directions

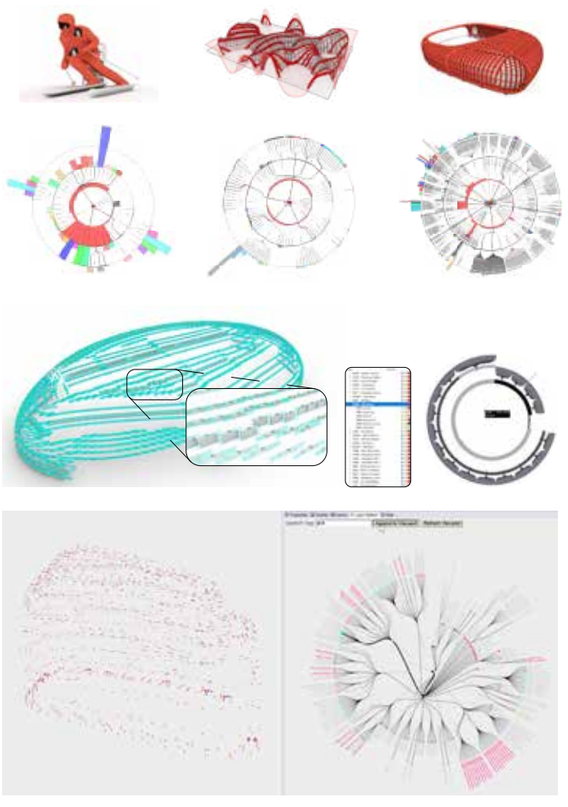
Mapping and Reflecting upon the Experiments - Late Stages

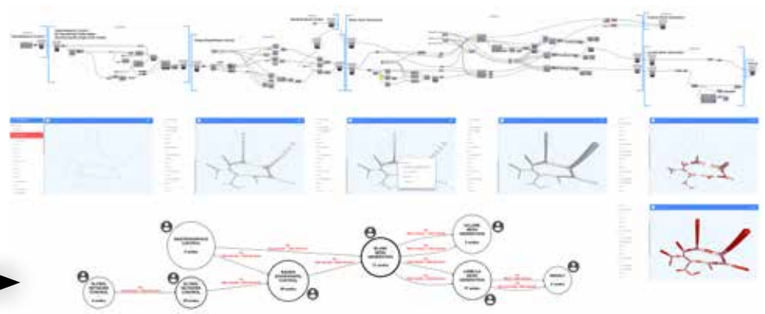
Object Level
- Building, assembling and sharing schemas
- Querying objects

Model Level
- Leveraging, visualizing, querying, navigating through large datasets

Project Level
- Tracking data flows
- Linking multiple scales





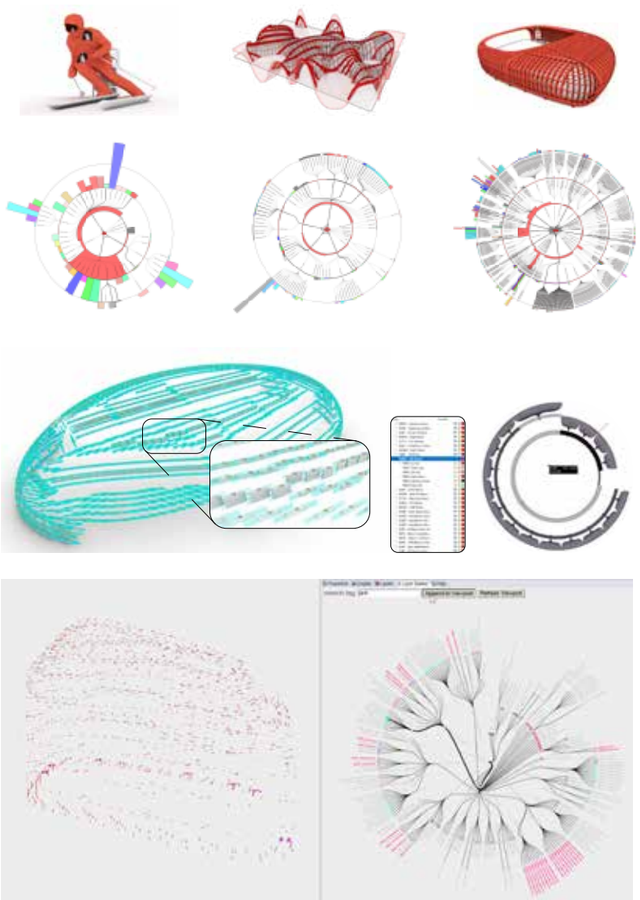


Conclusion & Future Directions

Answering the Research Questions

2. How can we keep track, add and modify data within a common directory structure until completion of the building?

Developed through the present thesis work, *LayerFootprint* allowed to **visualize complex hierarchical data sets**, *LayerExplorer* and *LayerStalker* **enabled the user to visualize, navigate through complex schemas in a more sustainable way**, and *SchemaBuilder* enabled to **build data-rich, custom geometrical data sets** that could be directly shared and queried through the open-source Speckle platform, from and to multiple Rhino3D documents. Although the mentioned "common directory structure" has not been developed independently through the present research work, the theoretical Multi-Scalar Modelling framework has been partly demonstrated through the use of the open-source communication platform Speckle. It is suggested that the underlying object infrastructure of the Multi-Scalar Modelling framework should be open-source.



Conclusion & Future Directions

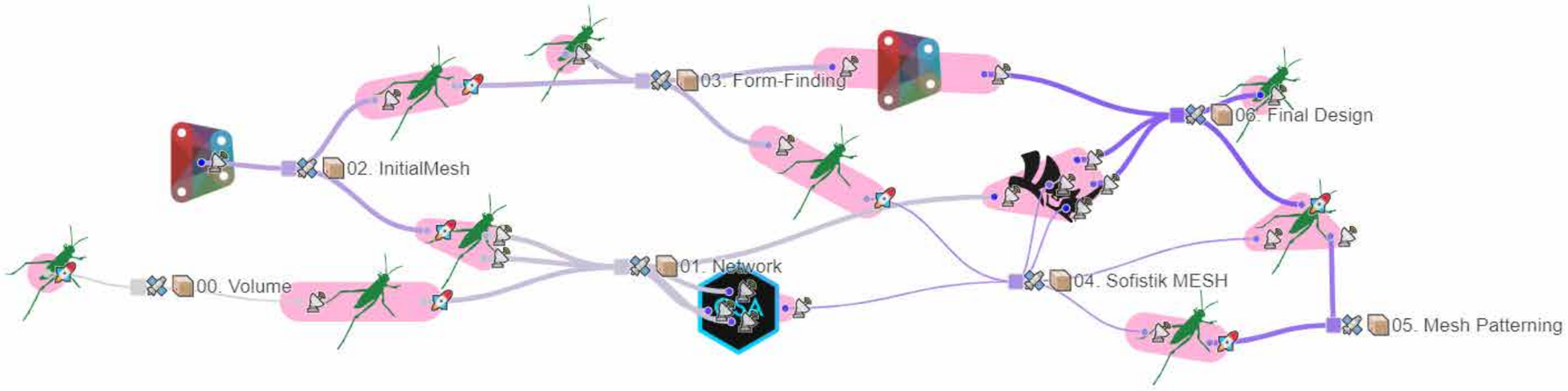
Answering the Research Questions

3. How would an ideal multi-scalar parametric AEC-model look like and which requirements would it have to fulfill all user's requests? How could the multi-scalar model be interacted and which UI and UX concepts would be needed?

The integration of the developed prototypical applications within a common directory structure or open-source communication platform would partly shape the ideal Multi-Scalar Modelling framework for AEC. However, as user requests might change and evolve over time, it is **difficult to give a clear picture of the final developed interface that would be gradually improved before becoming more and more crystallized**.

Conclusion & Future Directions - AEC Delta Mobility Project - InnovateUK

Perspective - towards further software integration



SpeckleViz maps dataflows within Speckle: https://speckle.systems/docs/web/speckleviz