

063-0605-22L

Computational Structural Design I

Computational Graphic Statics

Dr. Lluís Enrique

Block Research Group (Prof. Dr. Philippe Block)

HS2022

Week 4 Friday, October 14th

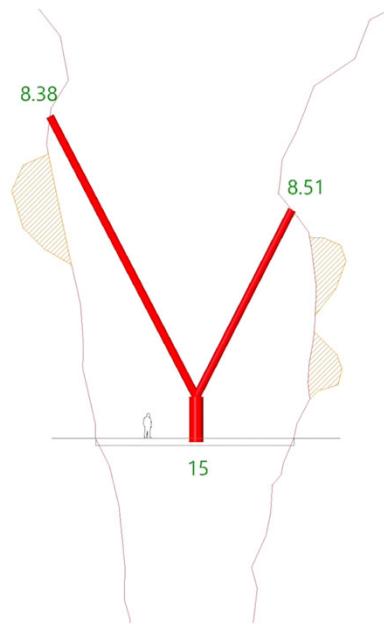
9:45 – 10:30 Recap of last week's exercise
[**Lecture: Computational Graphic Statics**](#)

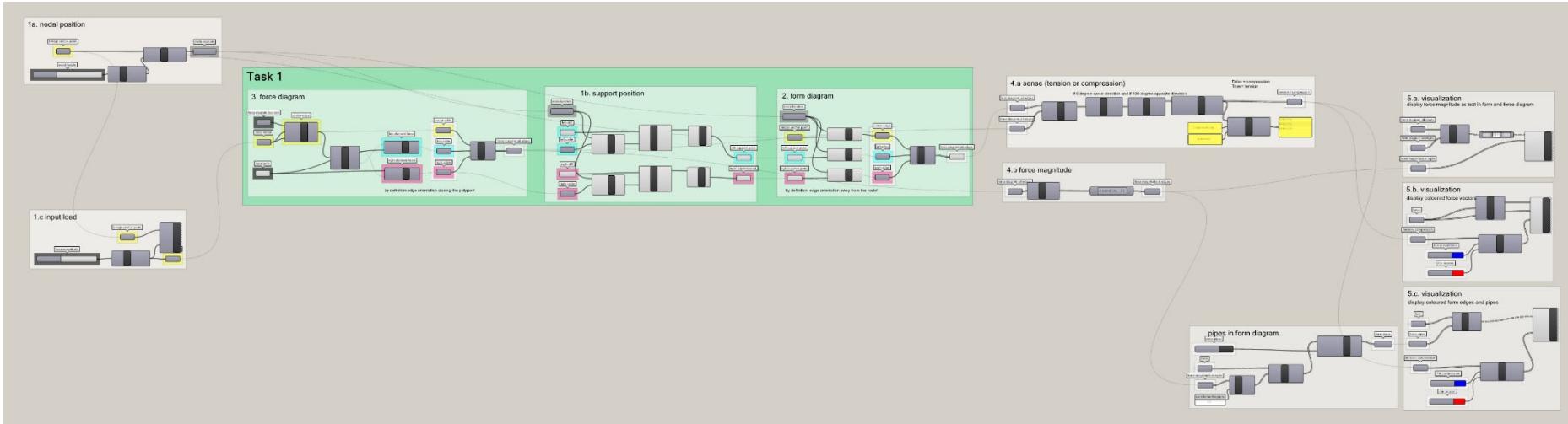
10:30 – 10:45 Break

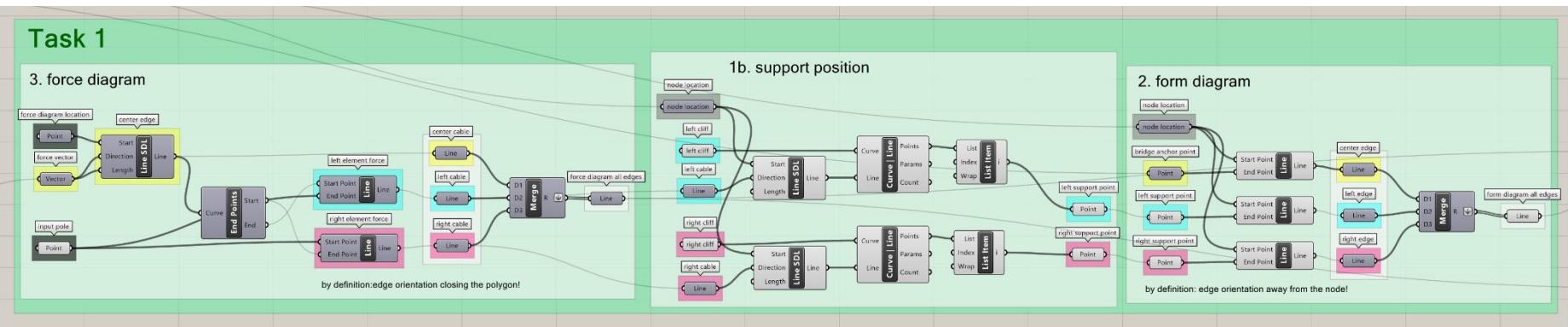
10:45 – 11:30 [**Tutorial: Procedural graphic statics II**](#)

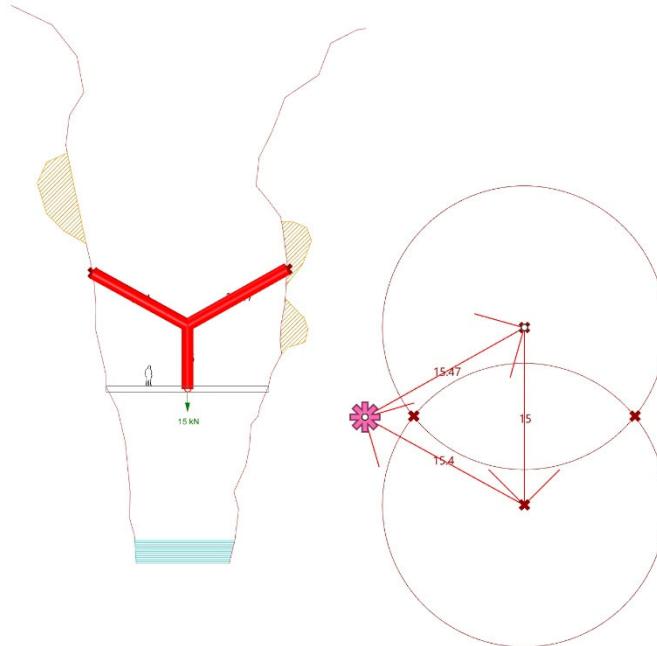
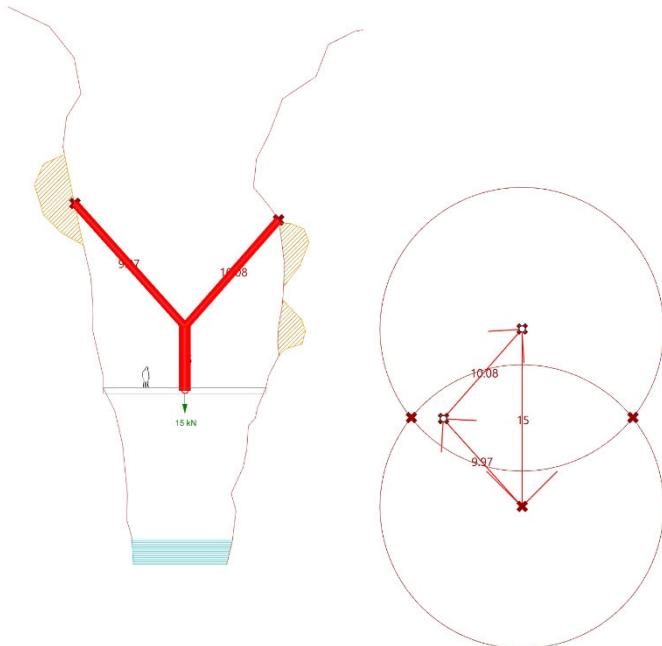
11:30 – 11:45 Break

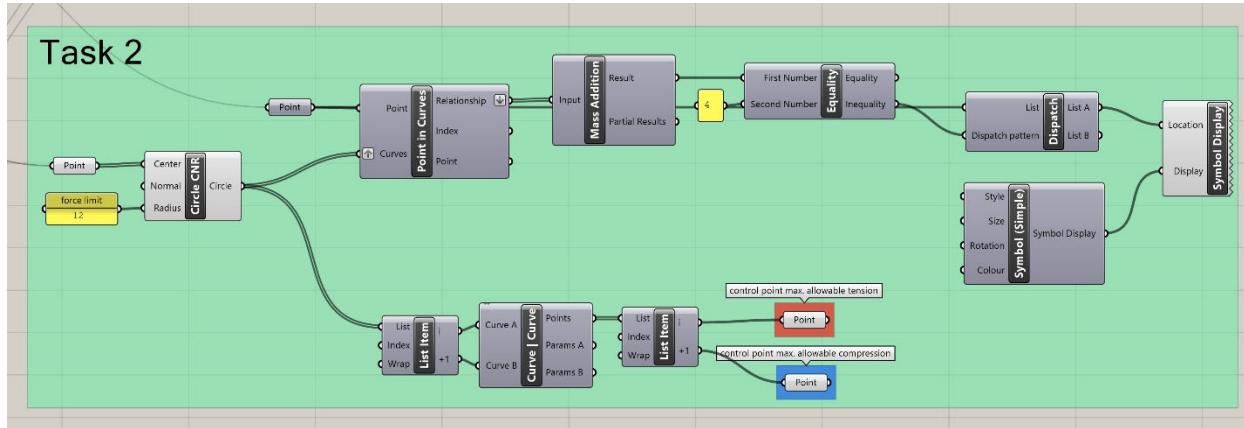
11:45 – 12:30 [**Tutorial: Procedural graphic statics II**](#)

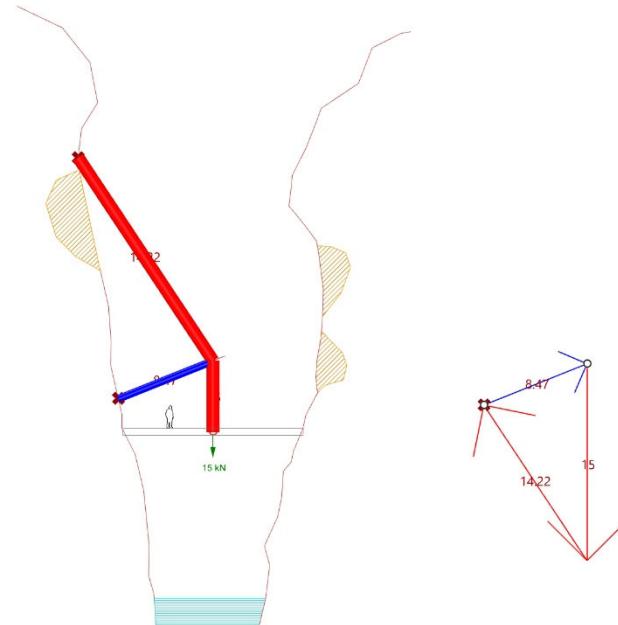


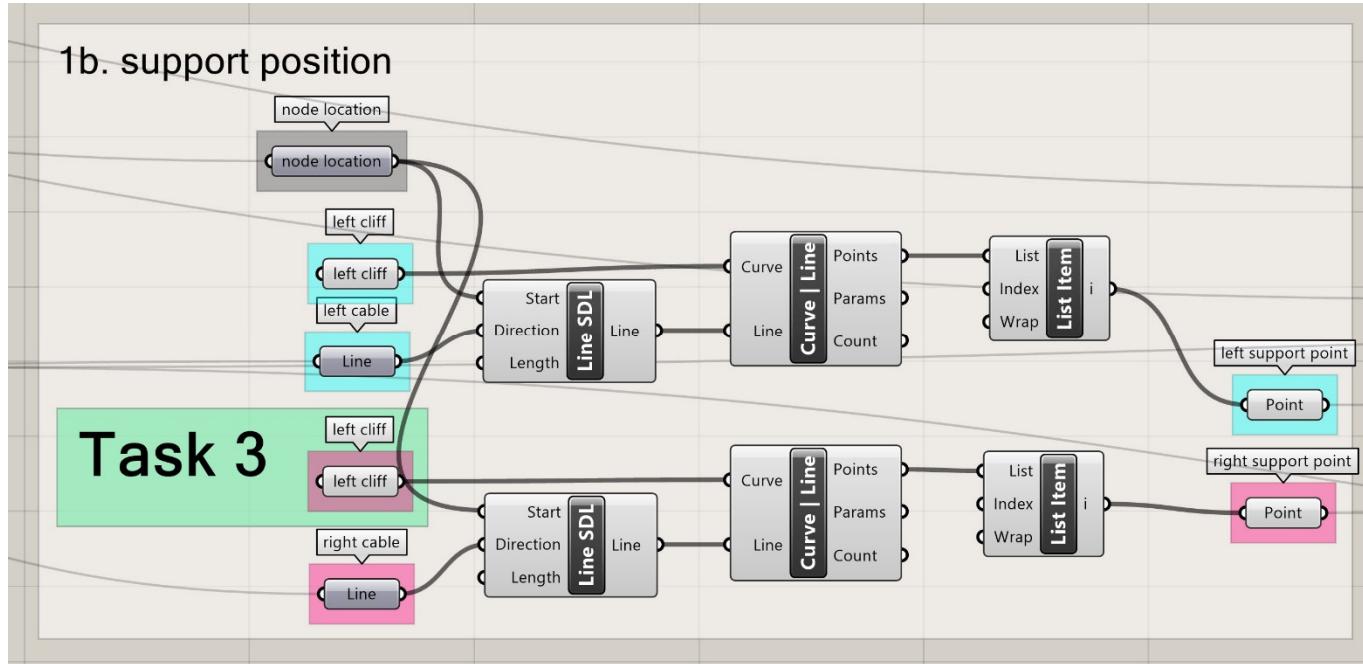


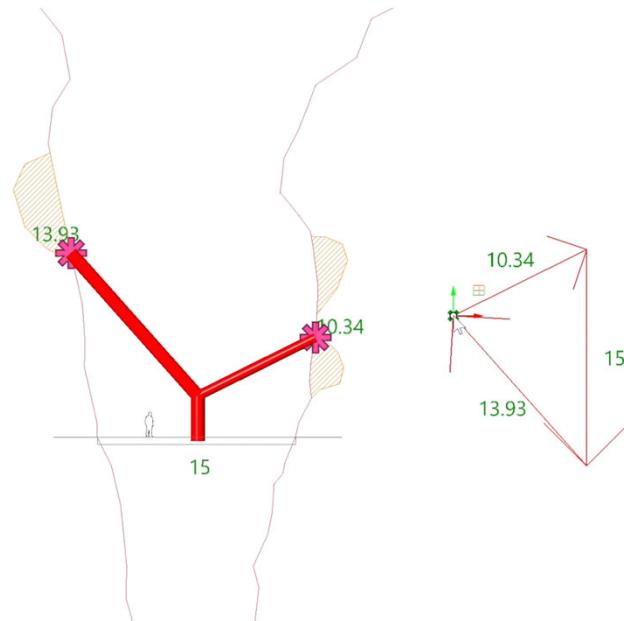


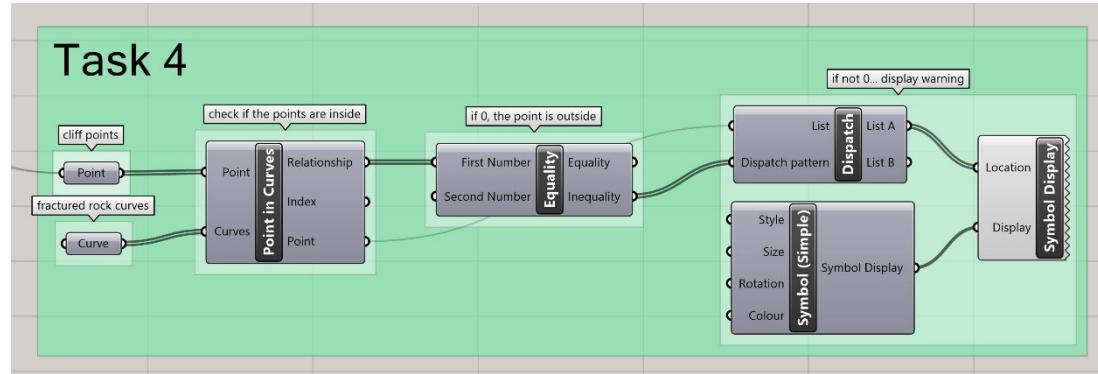


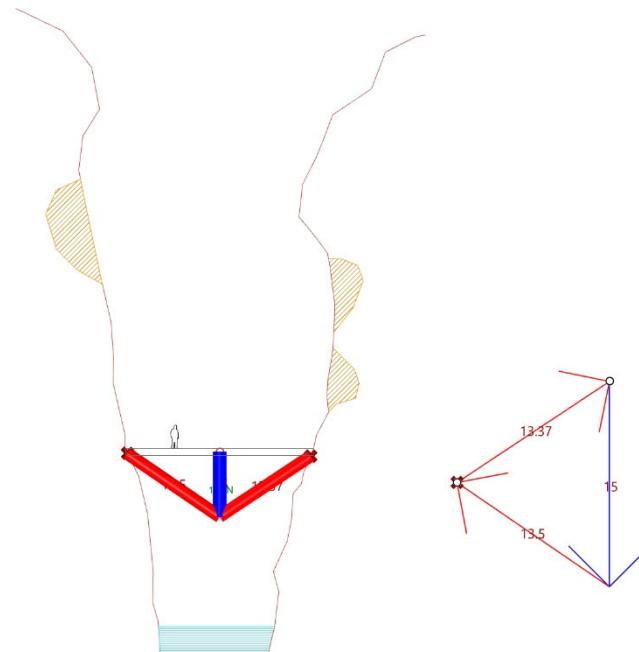
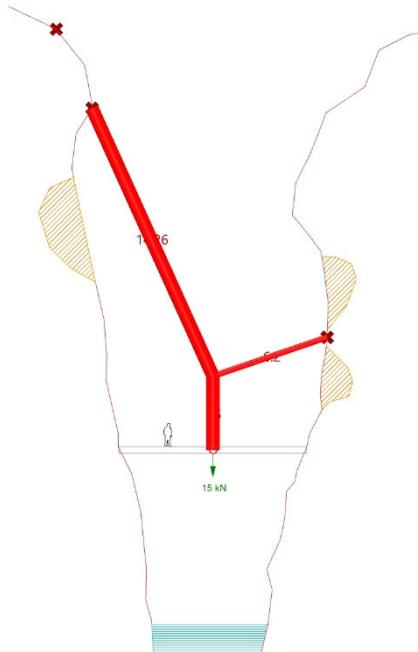




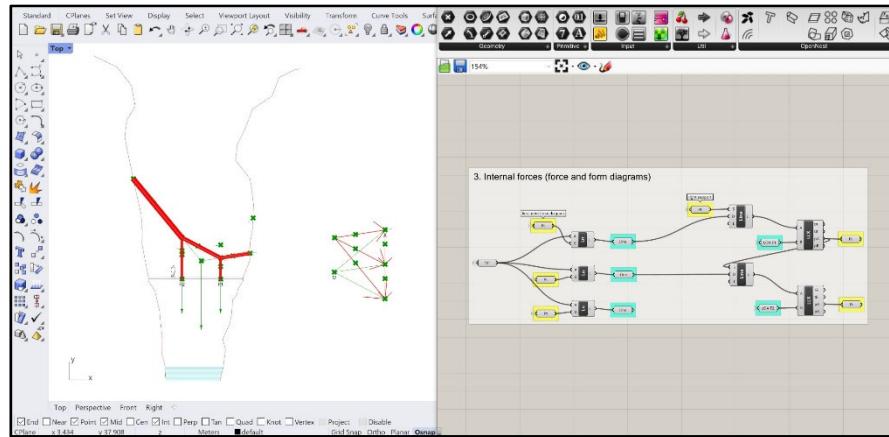
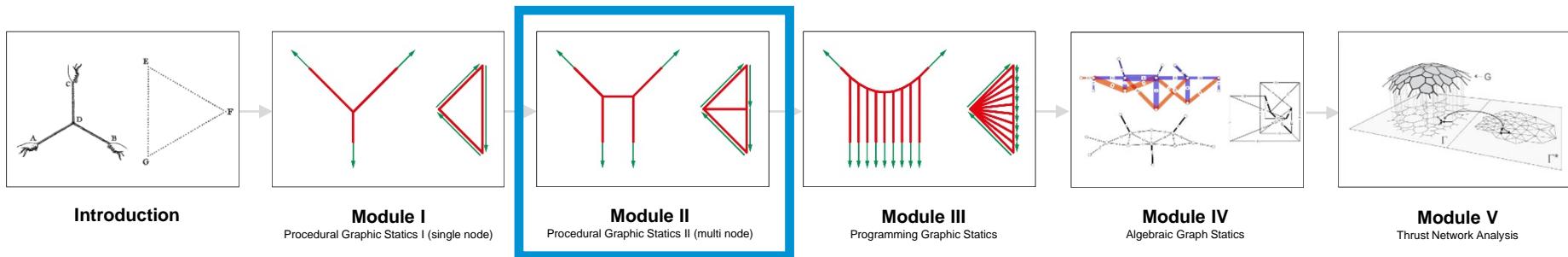








Typology	Topic	Module	Week		Topic	Lead
cables & arches	Introduction		Week 1 (23/9)	Lecture	Introduction to graphic statics	Dr. Lluis Enrique
				Tutorial	Introduction to Rhino and Grasshopper	
				Work session	graphic statics + Grasshopper	
			Week 2 (30/9)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique
				Tutorial	Algorithmic design & thinking	
	Procedural GS (Grasshopper)			Work session	Single node bridge in Grasshopper	
		Week 3 (7/10)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique	
			Tutorial	Computational graphic statics		
			Work session	Multi-node bridge in Grasshopper		
		Week 4 (14/10)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique	
			Tutorial	Multi-node bridge in Grasshopper		
		Week 5 (21/10)	Work session	Multi-node bridge in Grasshopper		
Week 6: Seminar week						
cables & arches	Procedural GS (Python)		Week 7 (4/11)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique
				Tutorial	Programming	
			Week 8 (11/11)	Work session	Multi-node bridge in Python	
trusses	AGS		Week 9 (18/11)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique
				Tutorial	Algebraic Graph Statics (AGS)	Dr. Lluis Enrique
			Week 10 (25/11)	Work session	Interactive Graphic Statics (IGS)	Chaoyu Du
shells	TNA		Week 11 (02/12)	Lecture	Quick recap of last week's exercise	Dr. Lluis Enrique
				Tutorial	Thrust Network Analysis (TNA)	Dr. Lluis Enrique
			Week 12 (09/12)	Work session	RhinoVault 2 (rv2)	Selina Bitting
					Shell design using rv2	



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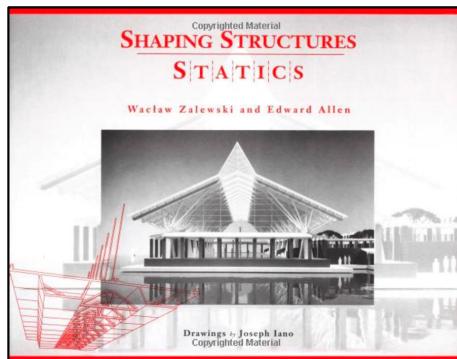


Computational Graphic Statics

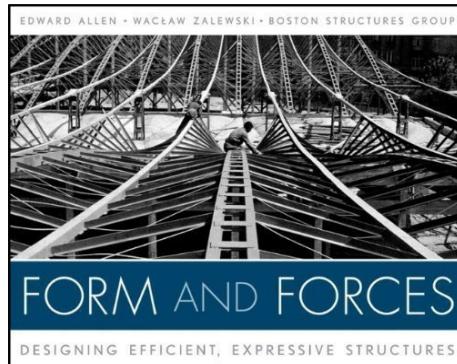
Friday, October 14th, 2022

Dr. Lluís Enrique

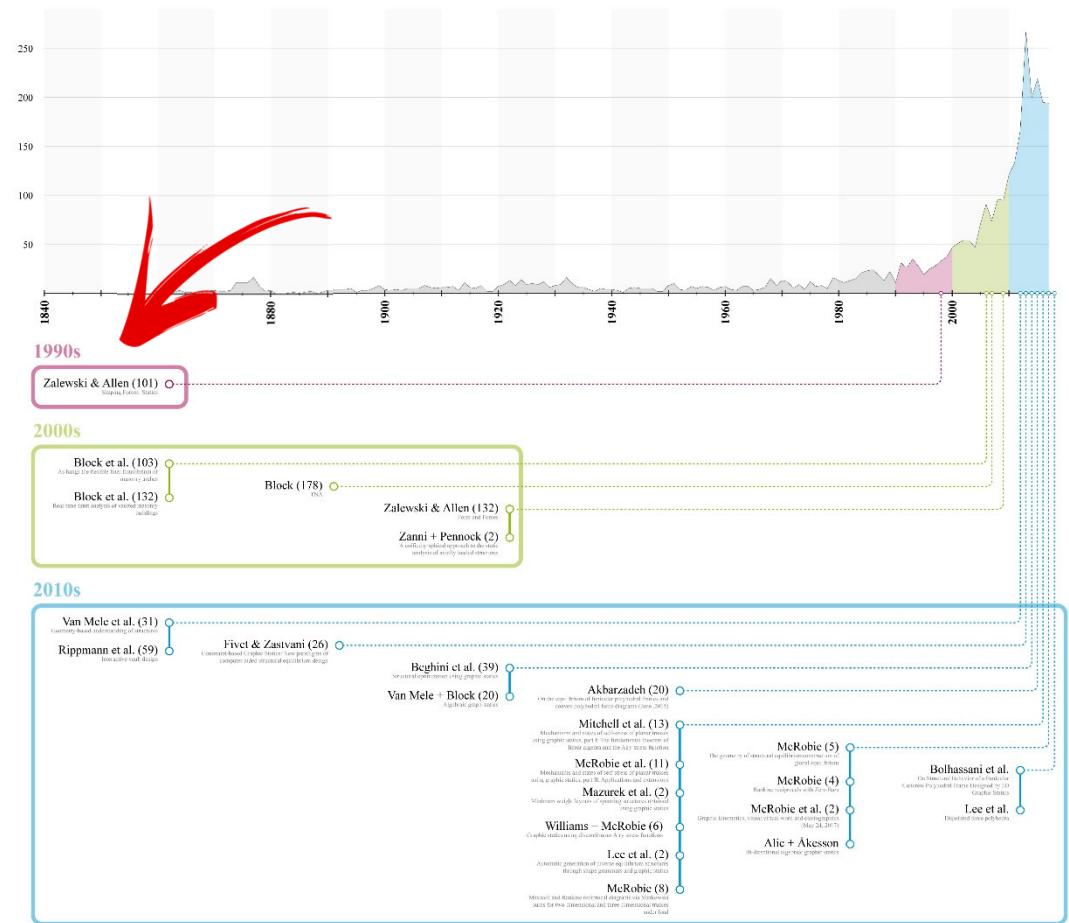
Graphic Statics

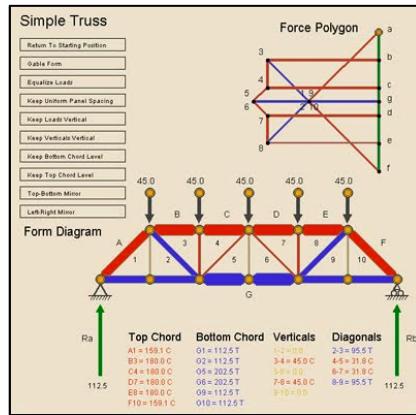


Shaping Structures



Form and Forces

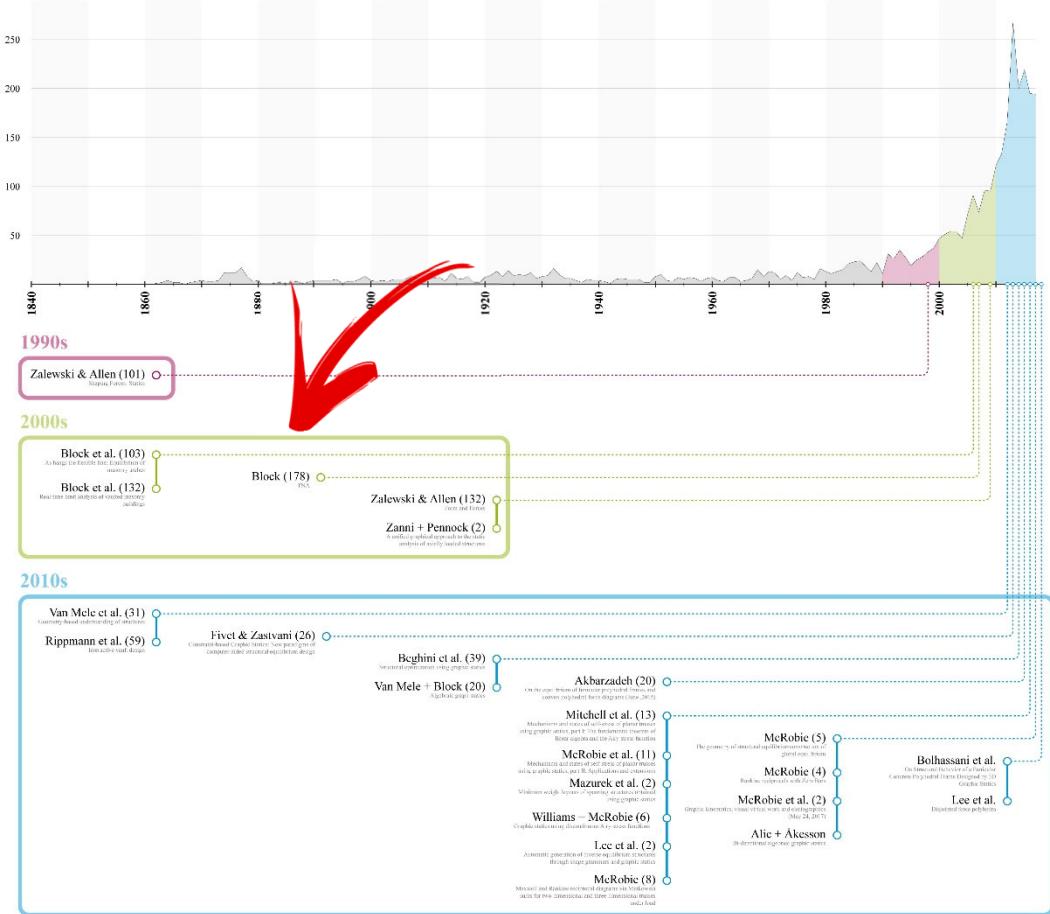


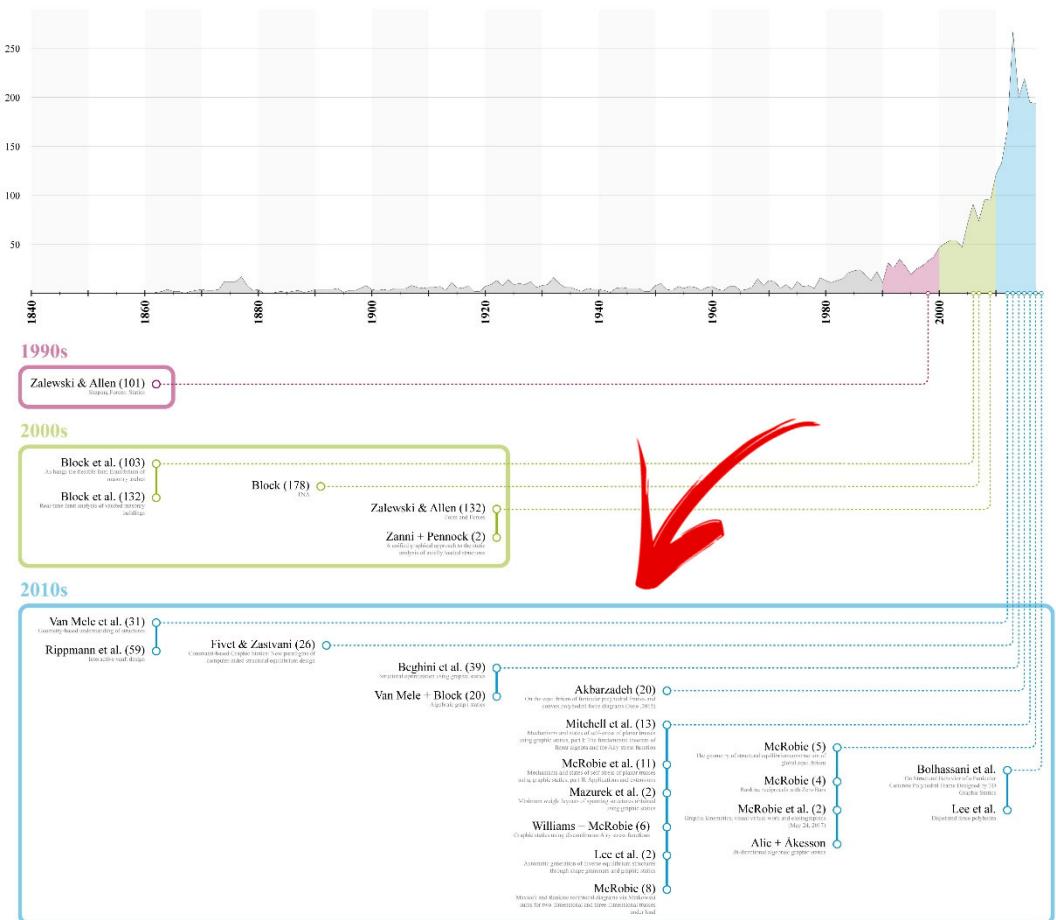


Active Statics
reenwold and Allen (2003)

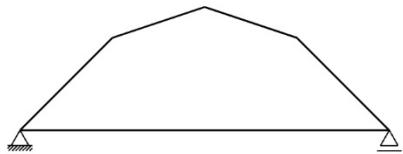
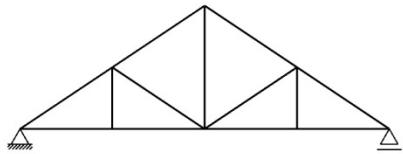


InteractiveTHRUST

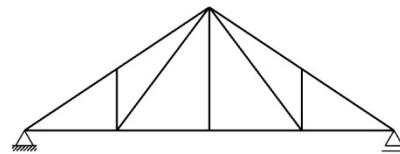
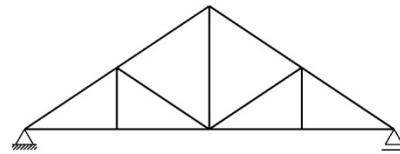




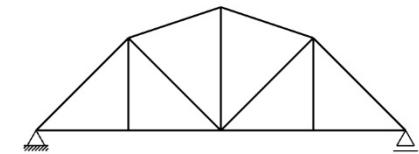
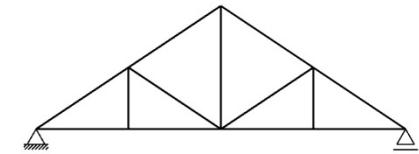
Typology



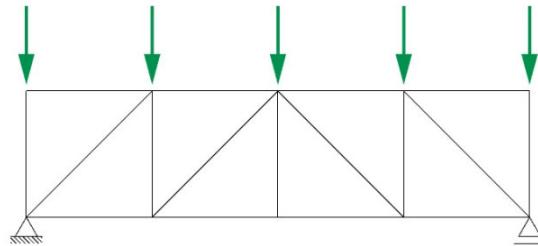
Topology



Geometry



Analysis



Input:

- Loads
- Supports
- Geometry

→ Trusses
3D trusses



Form-finding



Input:

- Loads
- Supports

→ Cables
Arches
Arch-cables
Cable nets
Shells



Analysis

Interactive drawings

Algebraic graph(ic) statics (AGS)

Bi-directional AGS

Vector-based Graphic Statics (VGS)

Form-finding

Interactive drawings

Constrained form-finding

Thrust Network Analysis (TNA)

3D Graphic Statics (3GS)

Subdivision

Shape grammars

Combinatorial Equilibrium Modelling (CEM)

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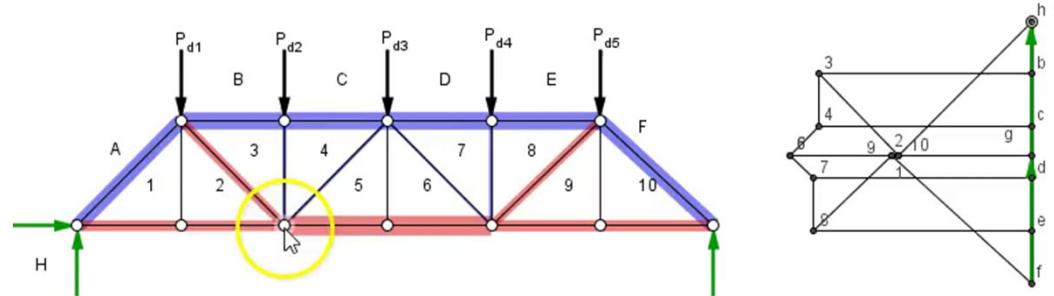
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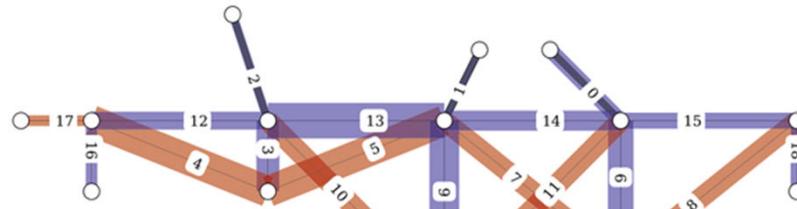
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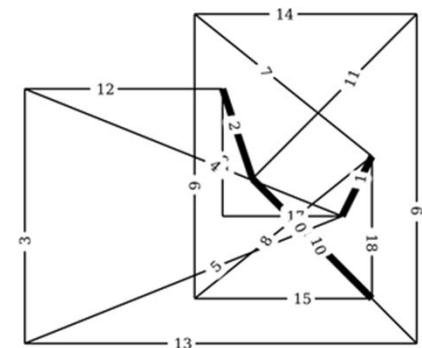
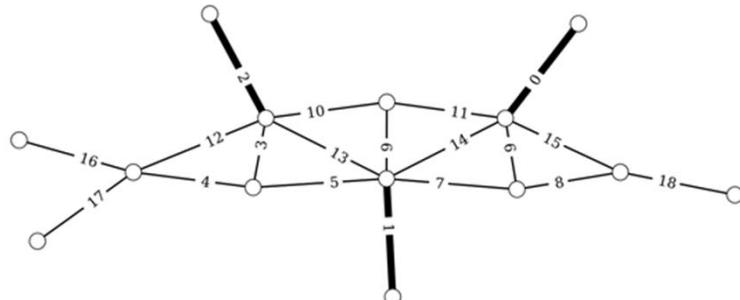
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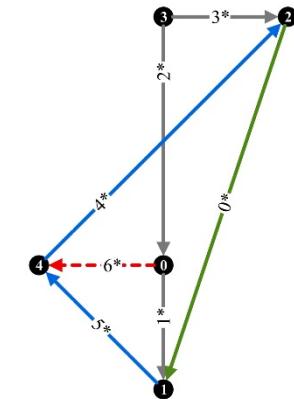
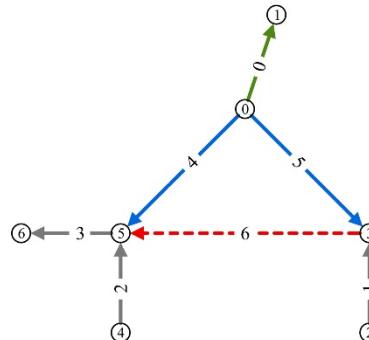
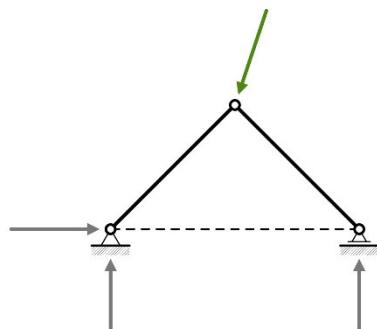
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Form diagram



Form diagram as a graph



Force diagram

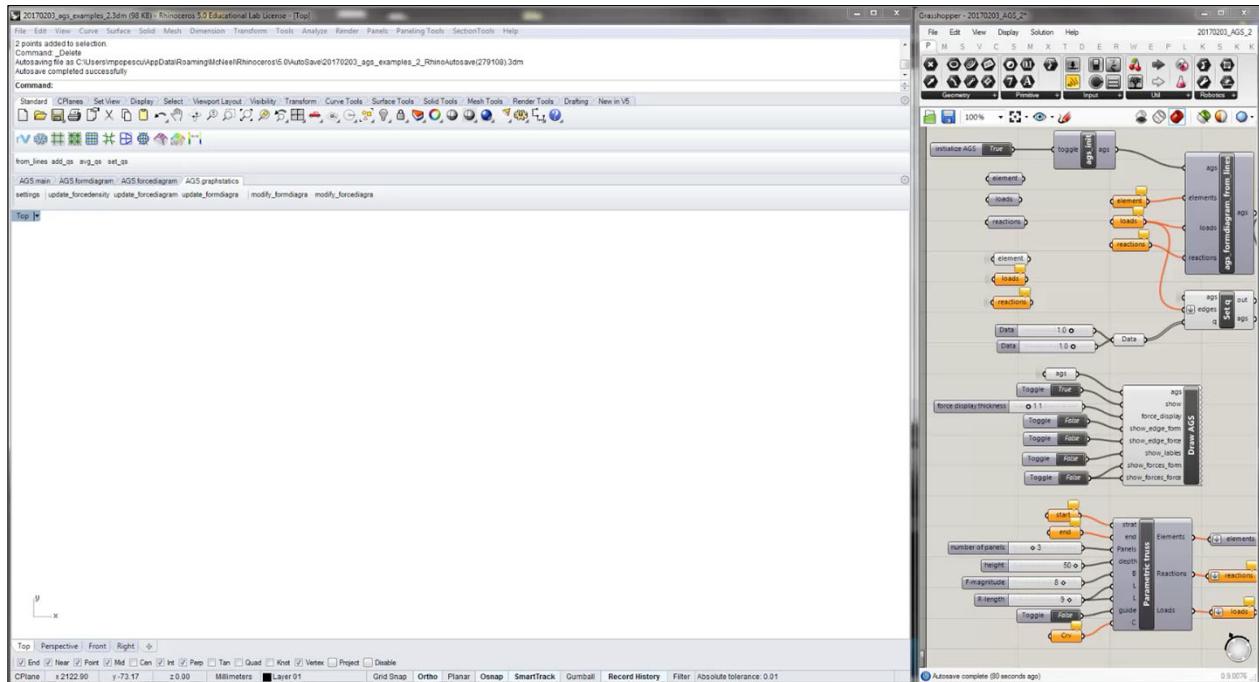
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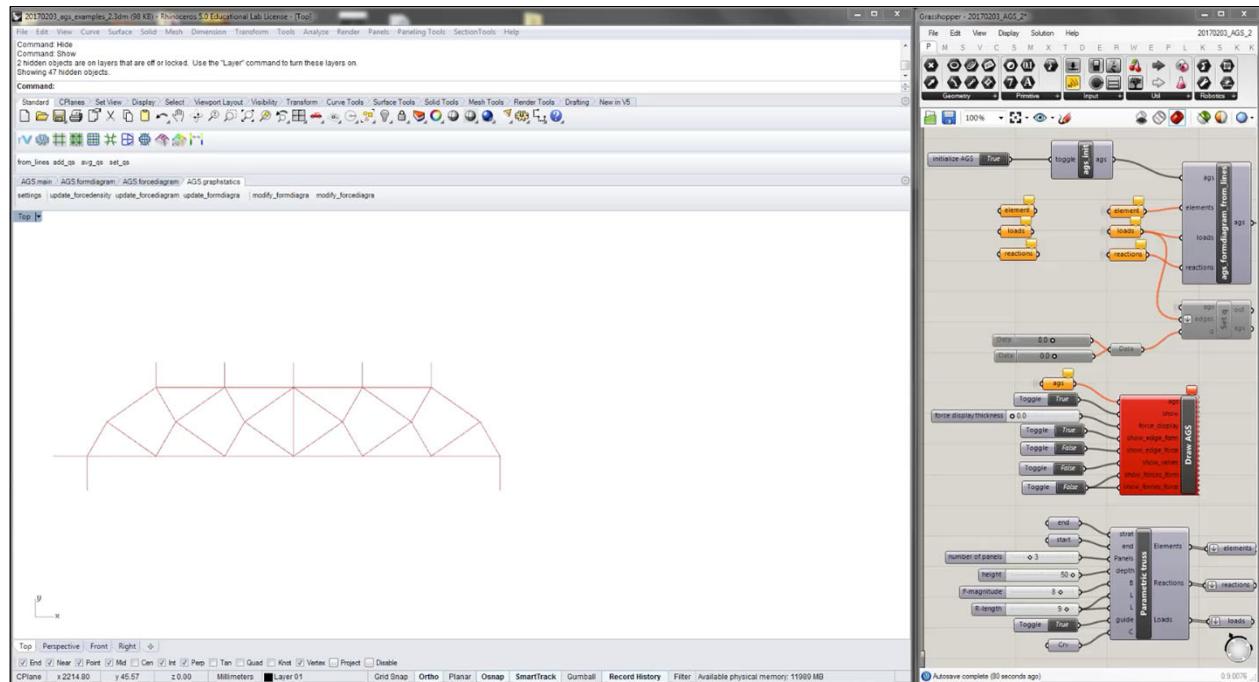
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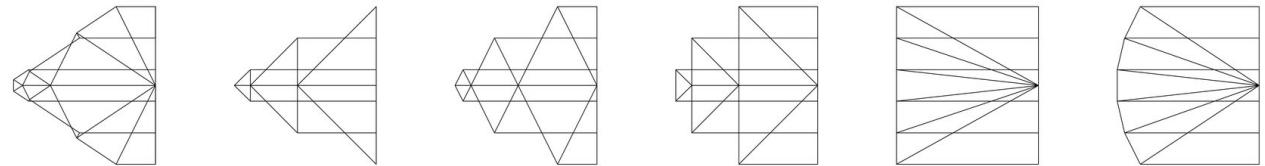
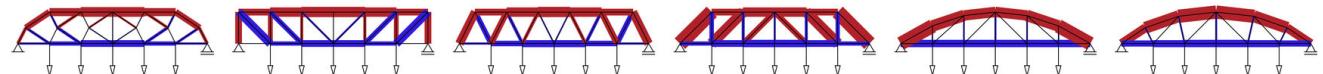
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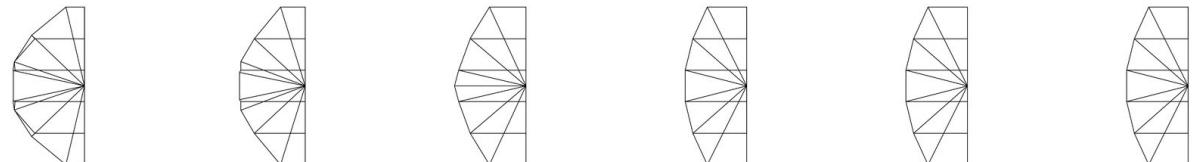
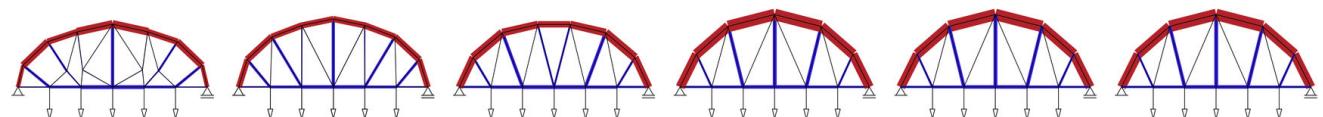
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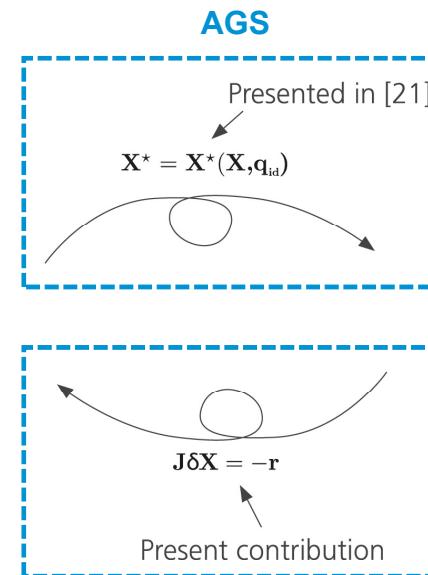
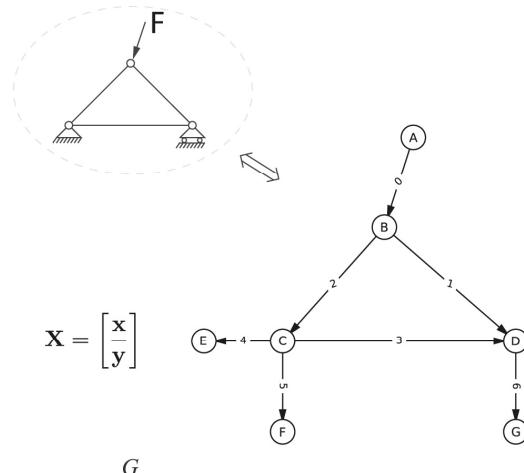
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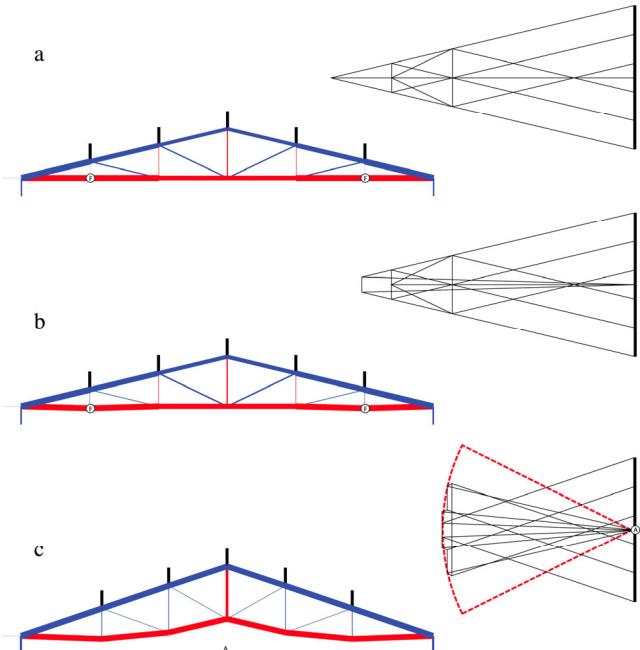
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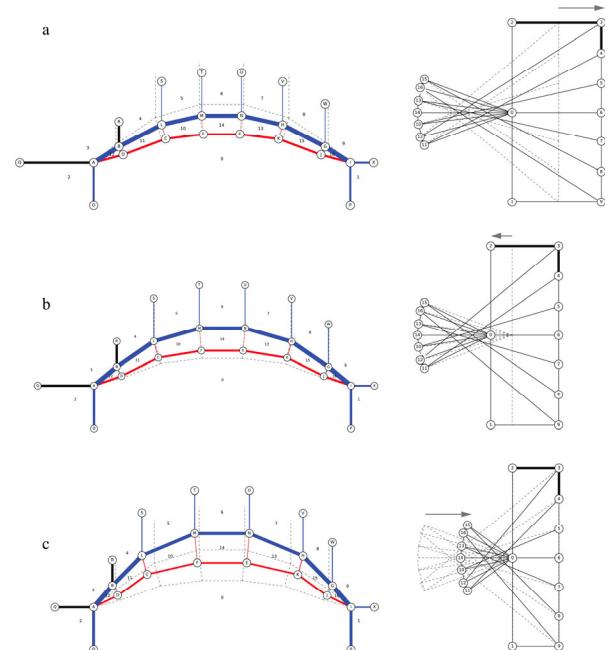
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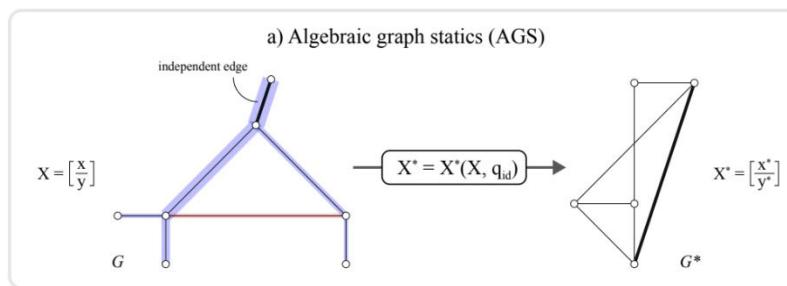
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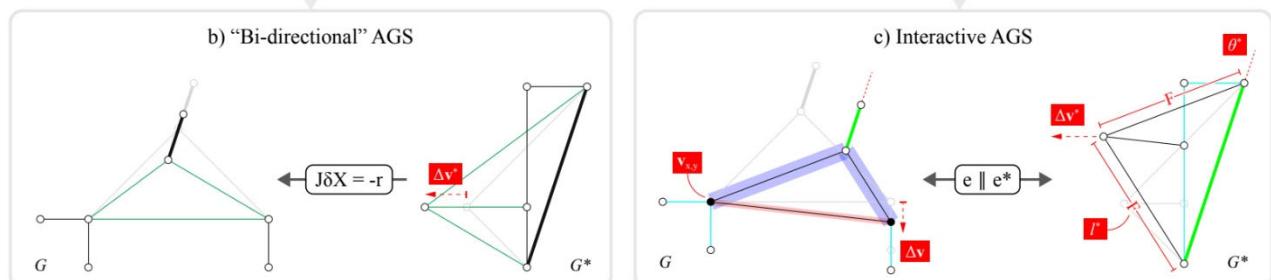
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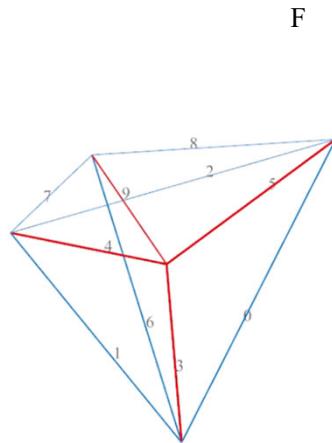
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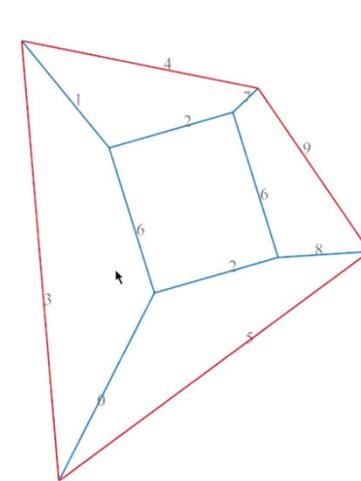
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3D form diagram



vector-based
3D force diagram

F^{**}

— tension
— compression

Analysis

Interactive drawings

Algebraic graph(ic) statics (AGS)

Bi-directional AGS

[Vector-based Graphic Statics \(VGS\)](#)



F

F*

Form-finding

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Constrained form-finding

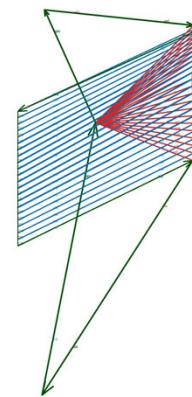
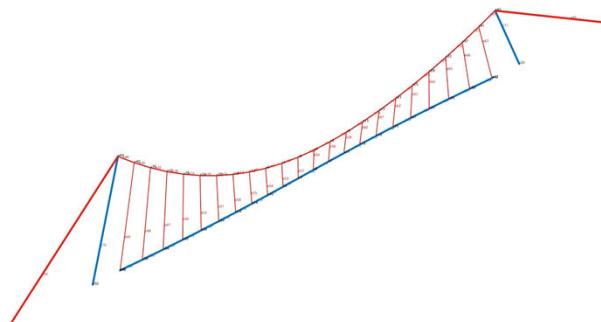
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— tension
— compression

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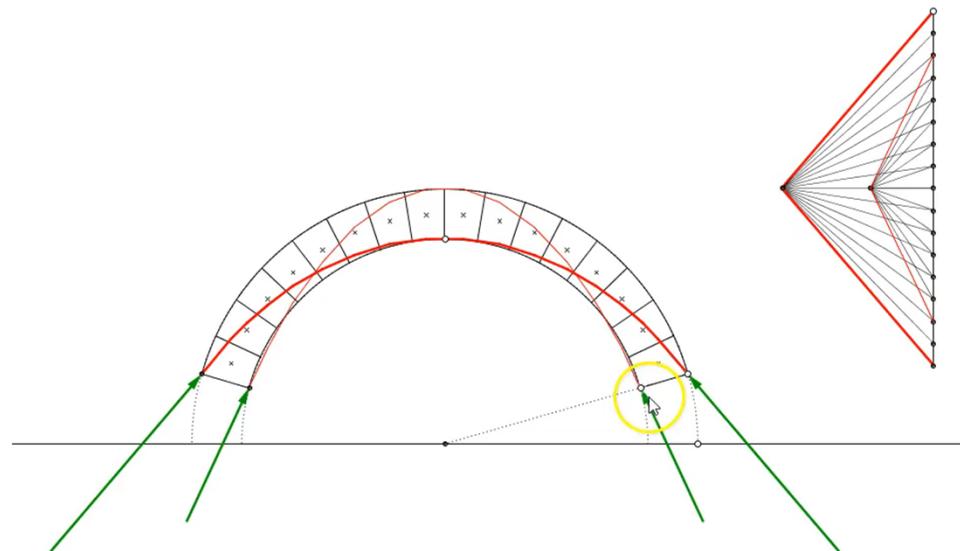
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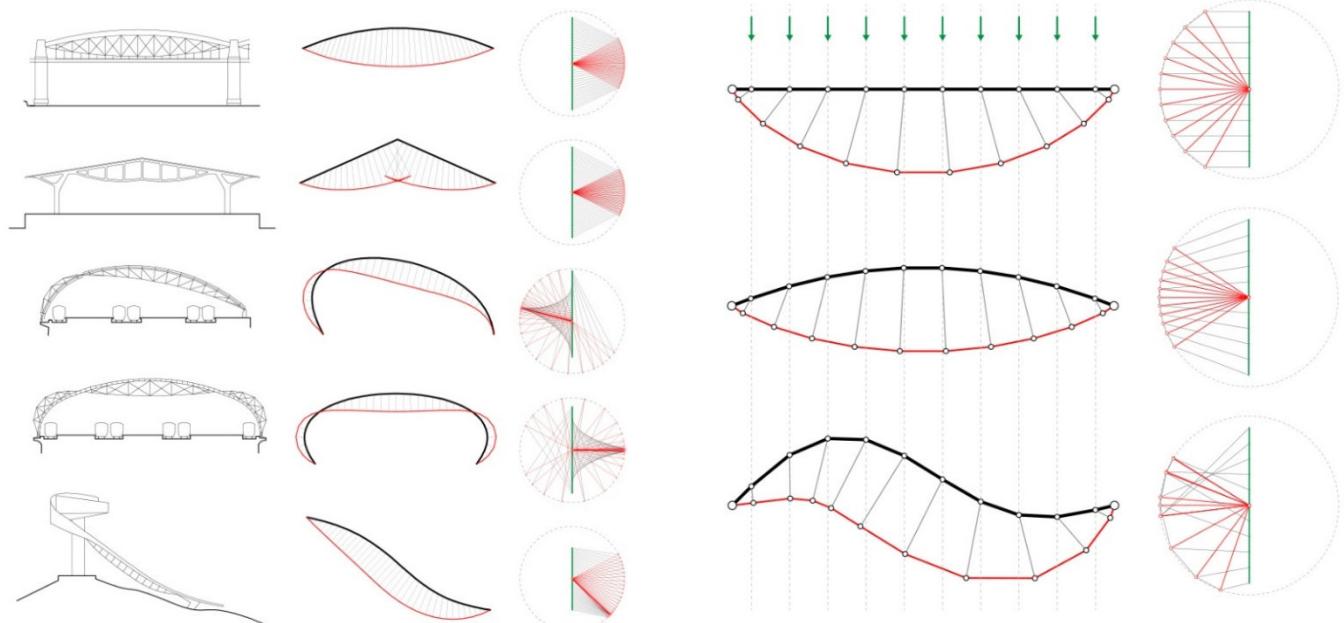
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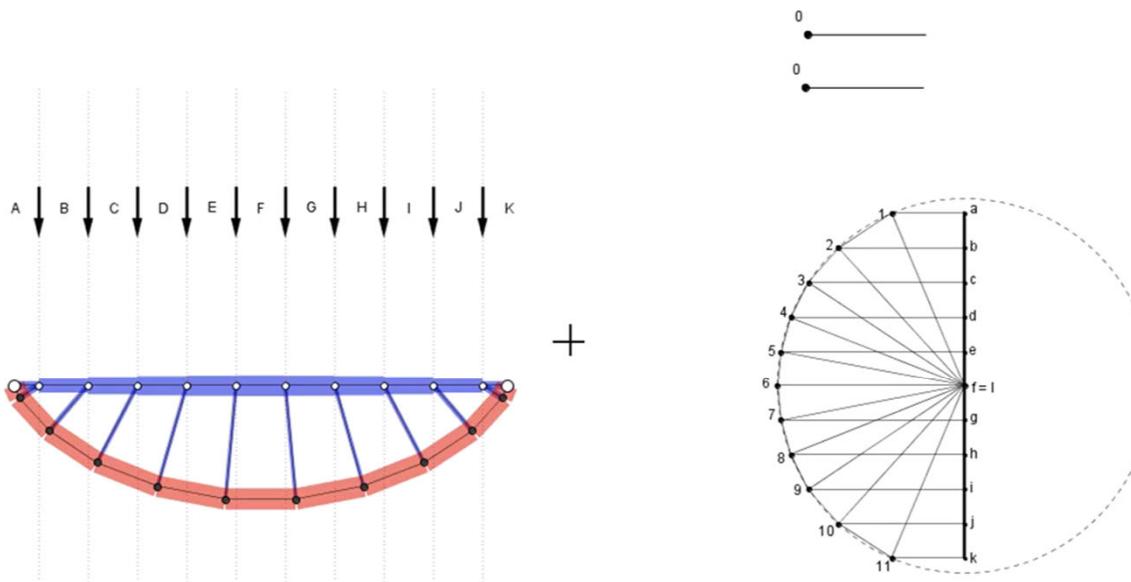
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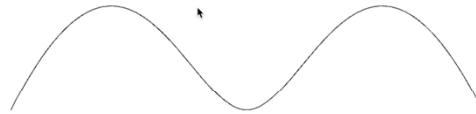
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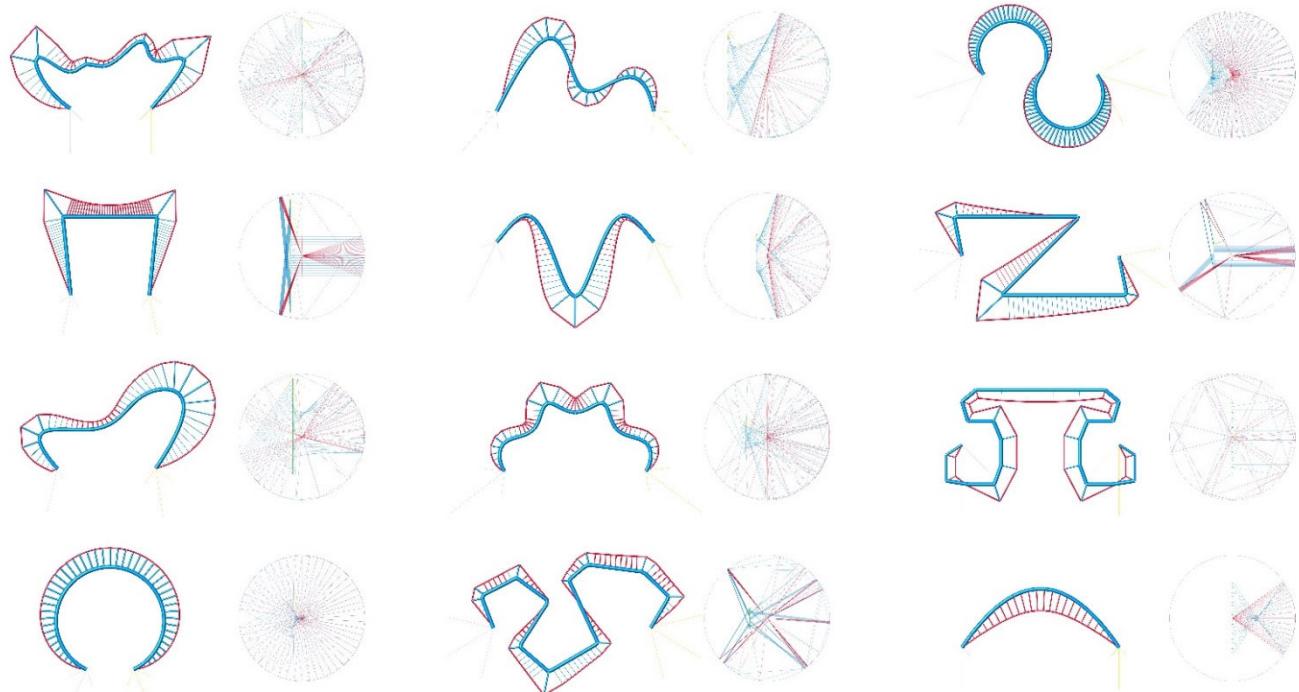
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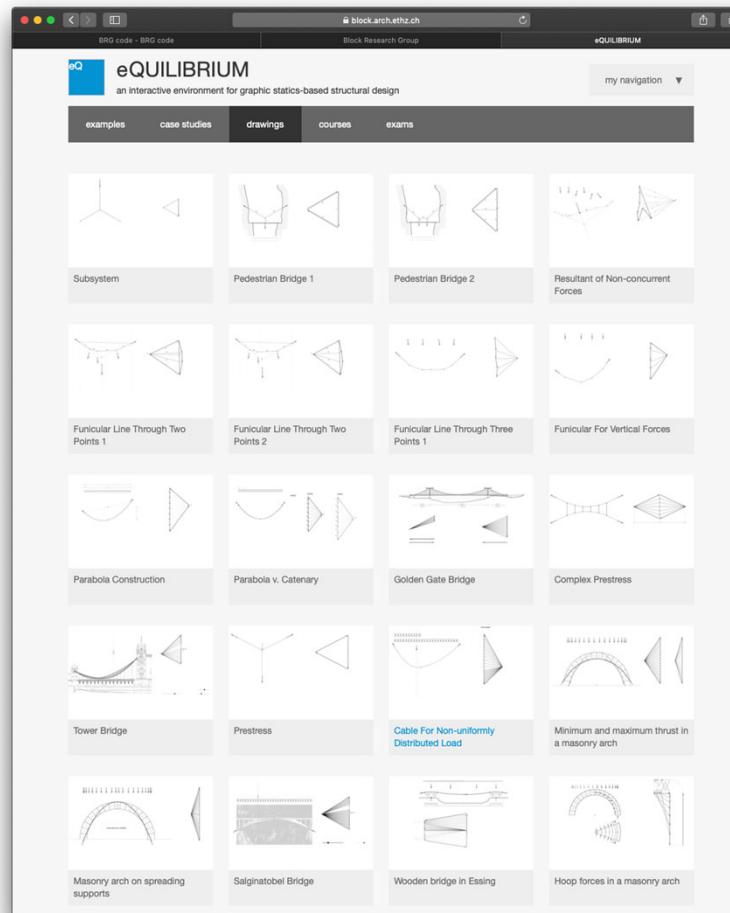
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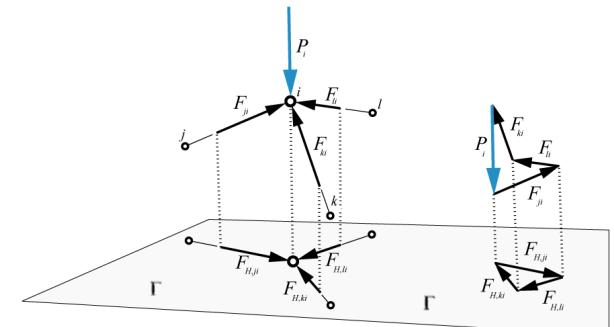
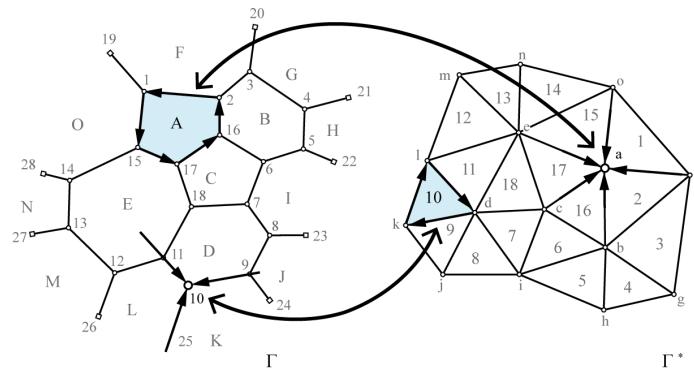
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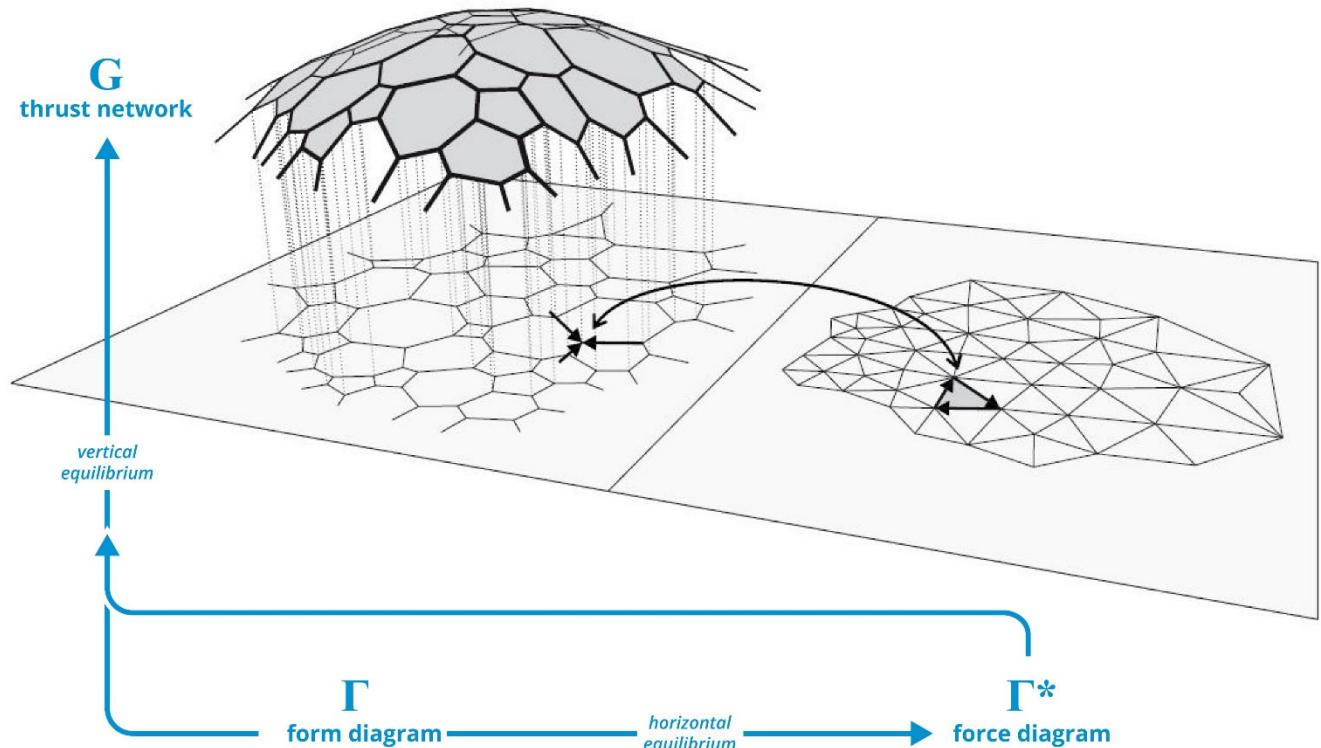
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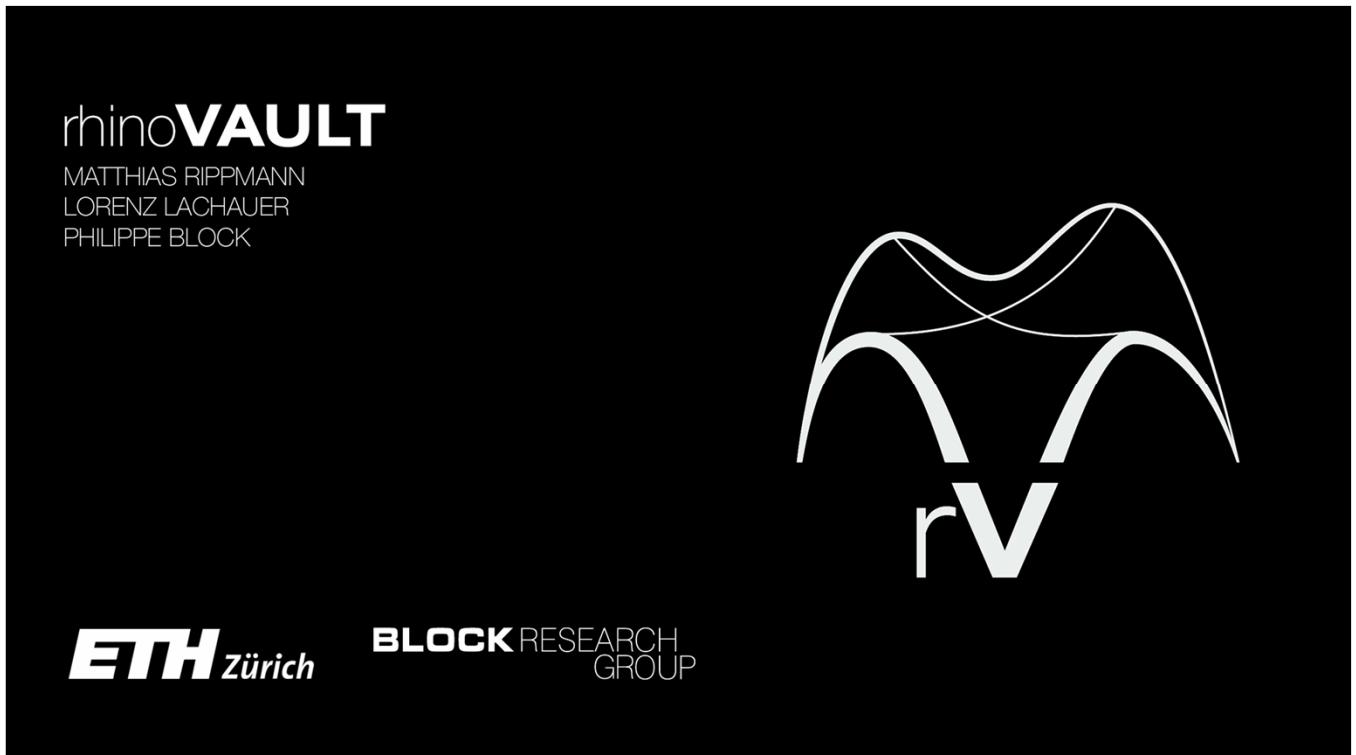
[Thrust Network Analysis \(TNA\)](#)

3D Graphic Statics (3GS)

Subdivision

Shape grammars

Combinatorial Equilibrium Modelling (CEM)



Analysis

Interactive drawings

Algebraic graph(ic) statics (AGS)

Bi-directional AGS

Vector-based Graphic Statics (VGS)

Form-finding

Interactive drawings

Constrained form-finding

[Thrust Network Analysis \(TNA\)](#)

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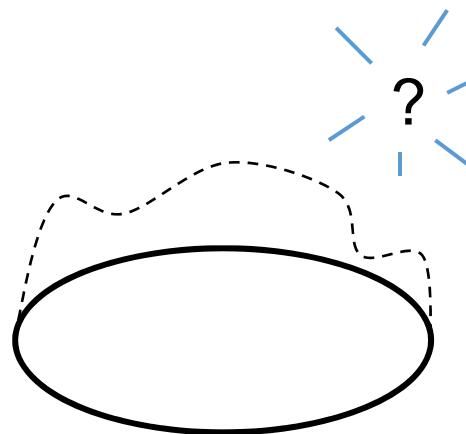
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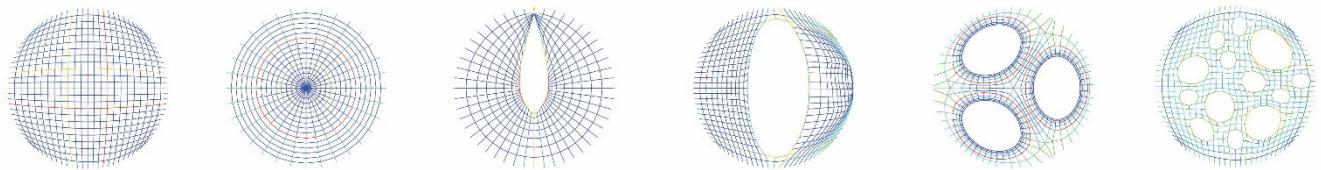
[Thrust Network Analysis \(TNA\)](#)

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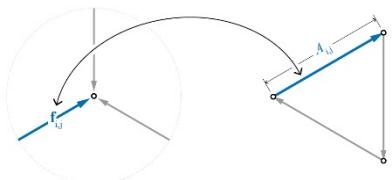
Thrust Network Analysis (TNA)

3D Graphic Statics (3GS)

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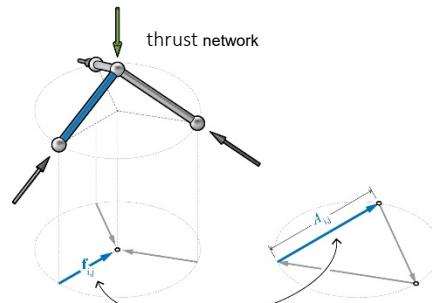
Combinatorial Equilibrium Modelling (CEM)



form diagram

force diagram

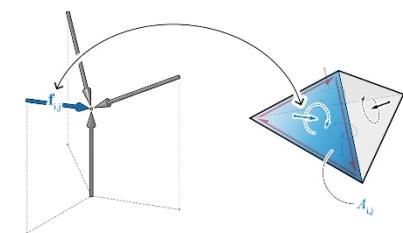
2D



form diagram

force diagram

2.5D



form diagram

force diagram

3D

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Vector-based Graphic Statics (VGS)

Form-finding

Interactive drawings

Constrained form-finding

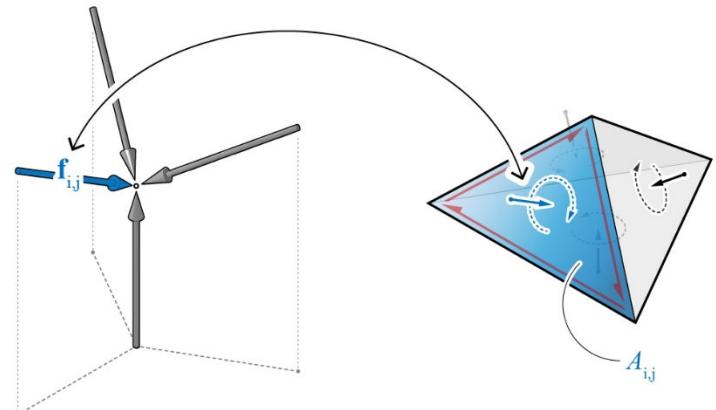
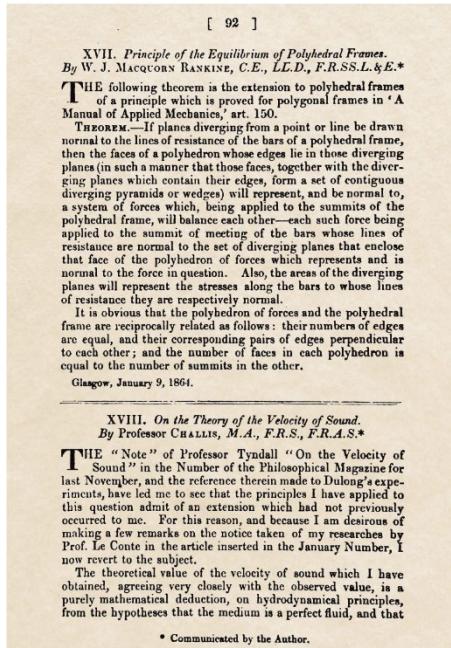
Thrust Network Analysis (TNA)

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Combinatorial Equilibrium Modelling (CEM)



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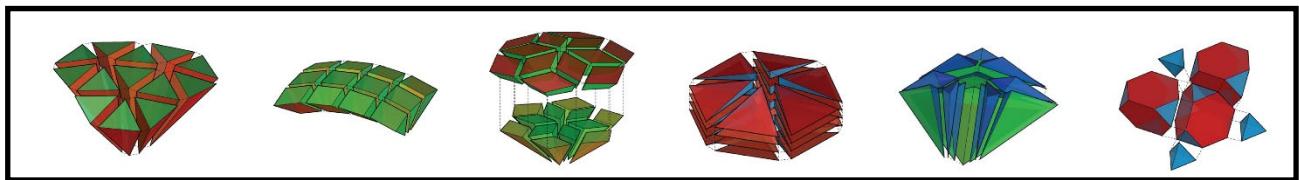
Interactive drawings

Algebraic graph(ic) statics (AGS)

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Polyhedral force diagram



Form-finding

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Polyhedral form diagram



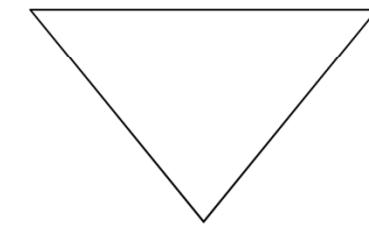
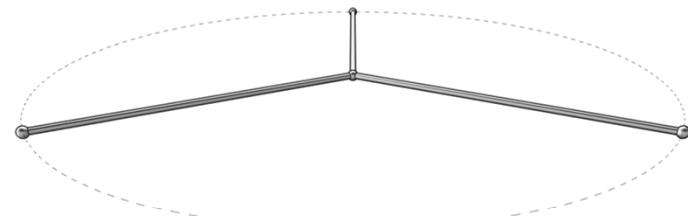
Analysis

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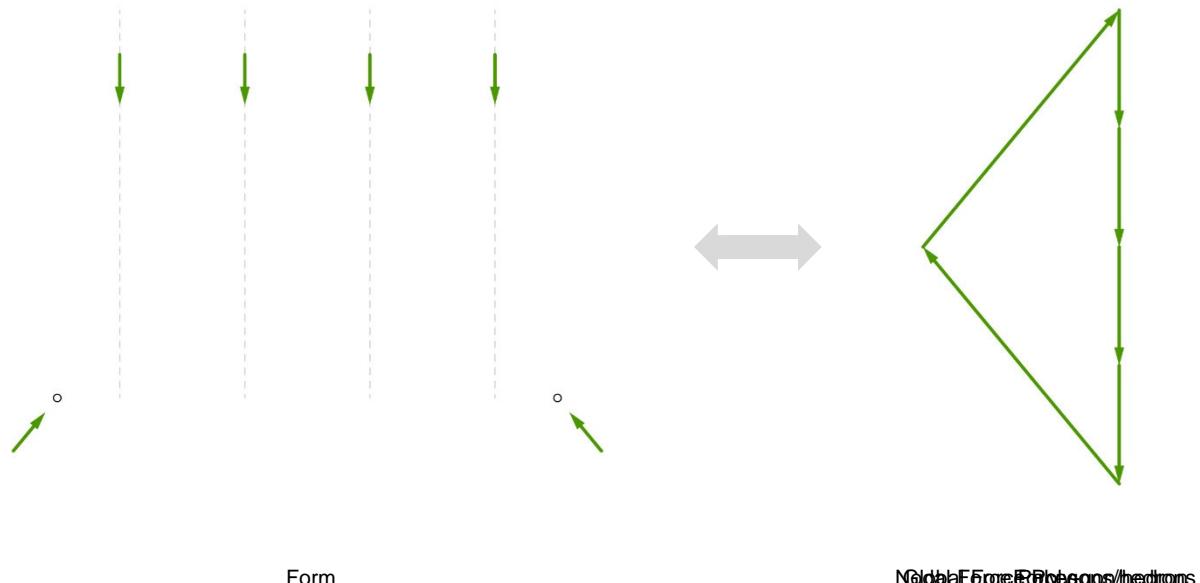
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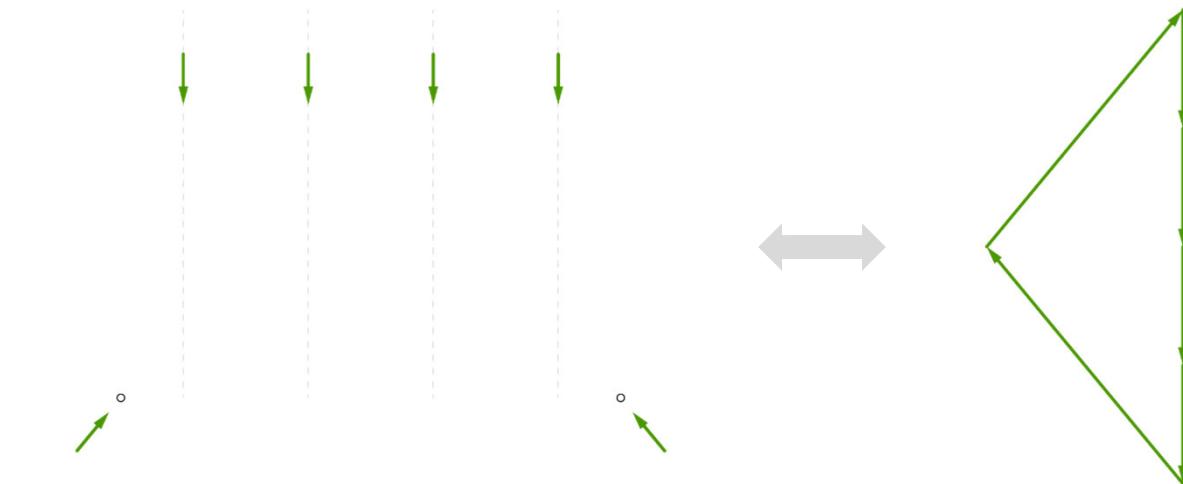
Thrust Network Analysis (TNA)

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Subdivision of Global Force Polyhedron

Equilibrated Structure

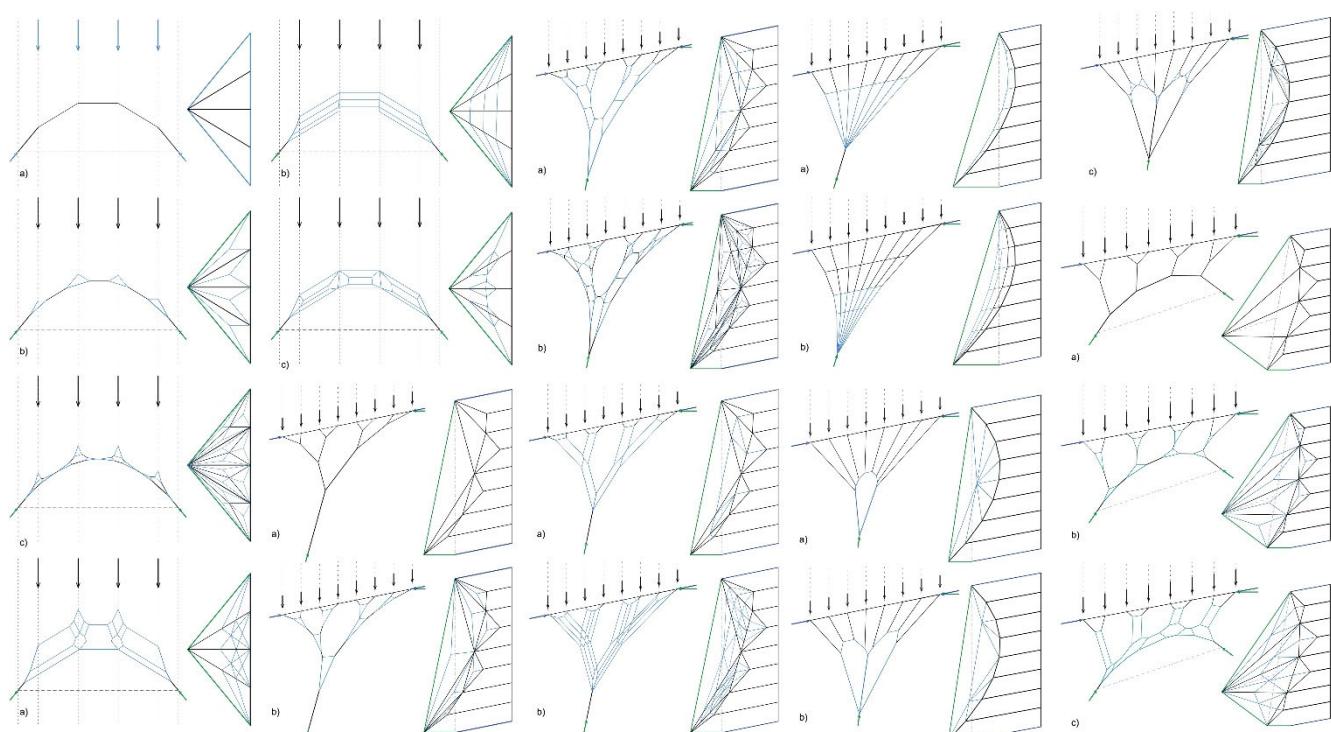
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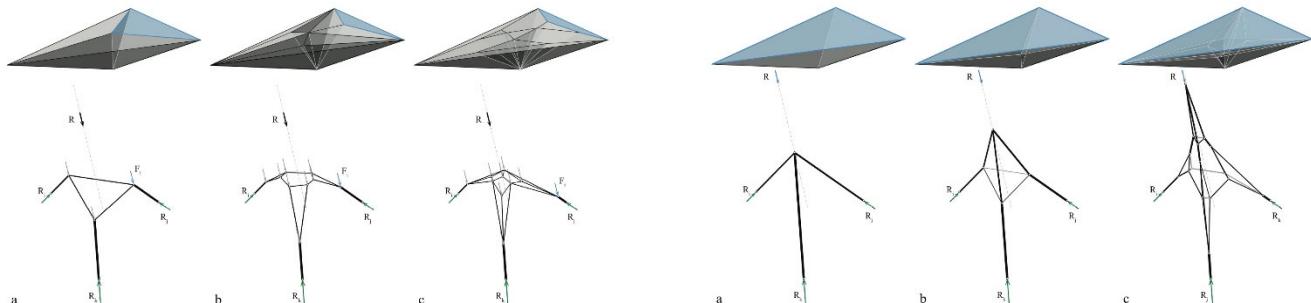
Thrust Network Analysis (TNA)

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Subdivision of a Face

Subdivision of Cells

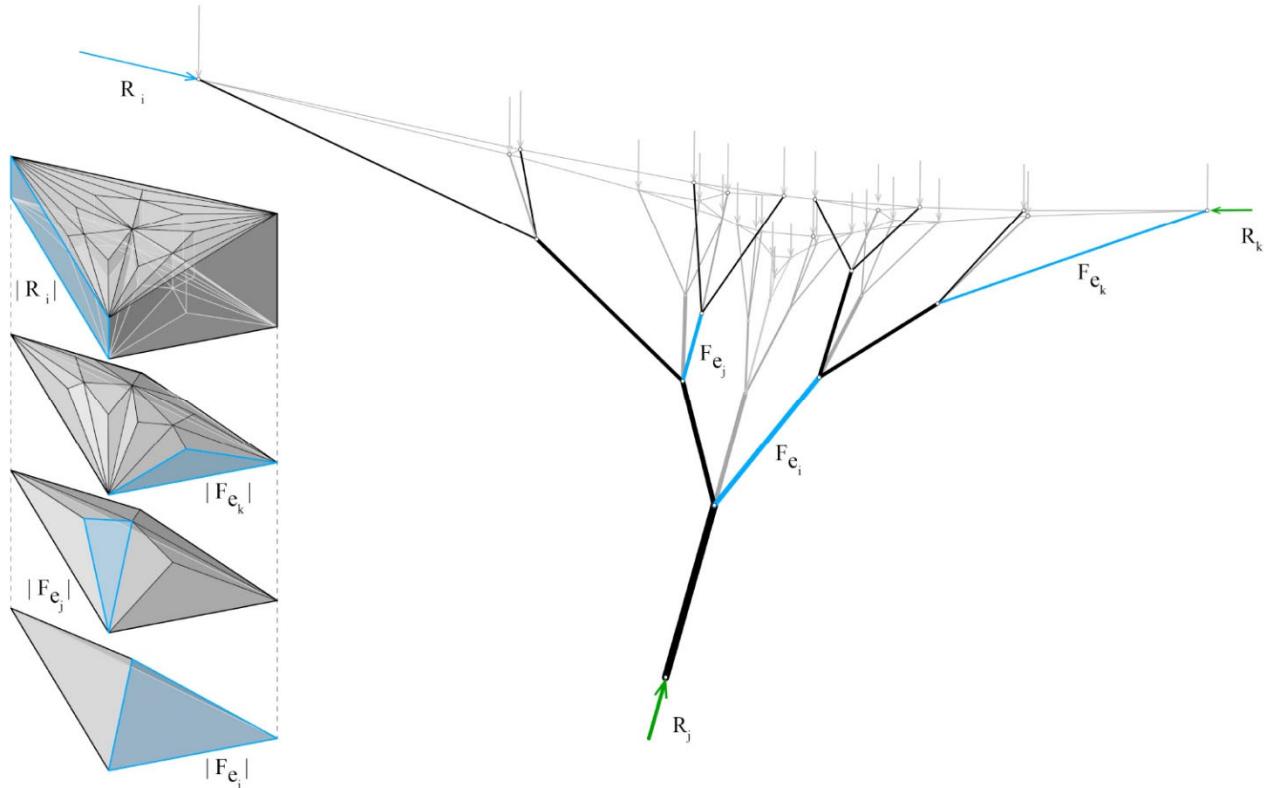
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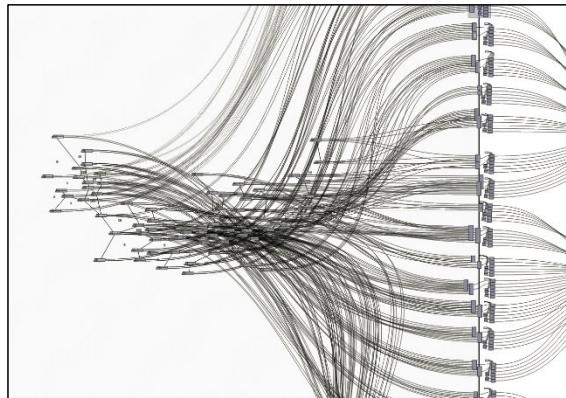
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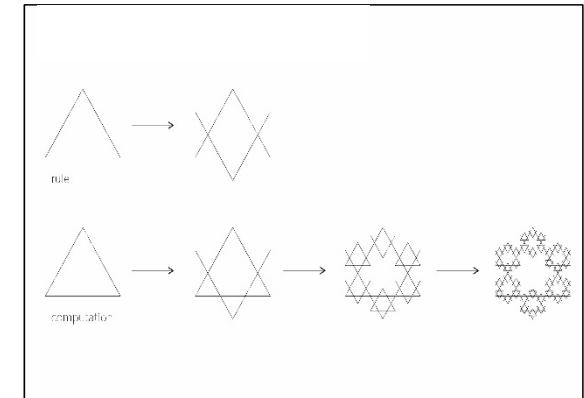
Combinatorial Equilibrium Modelling (CEM)

Parametric Design Space

NUMERICAL PARAMETERS are defined ...

to

... DESCRIBE & MODIFY geometries.



Grammatical Design Space

ACTIONS & OPERATIONS (RULES) are defined ...

to

... GENERATE geometries.

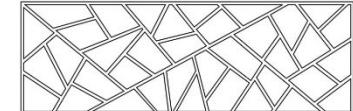
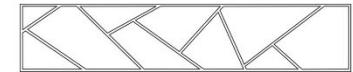
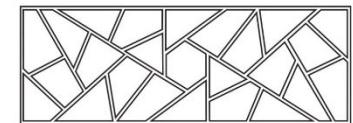
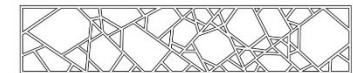
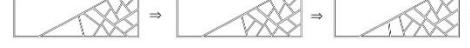
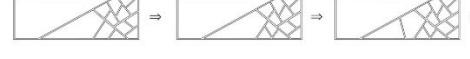
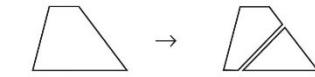
Analysis

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Vector-based Graphic Statics (VGS)



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Constrained form-finding

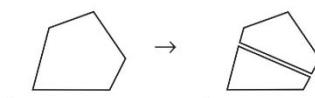
Thrust Network Analysis (TNA)

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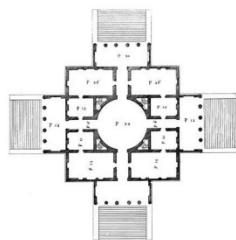
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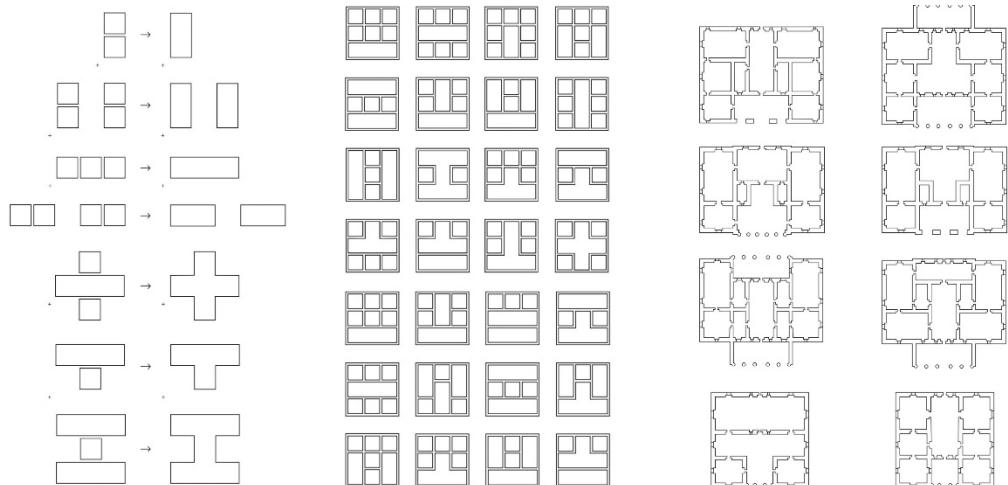
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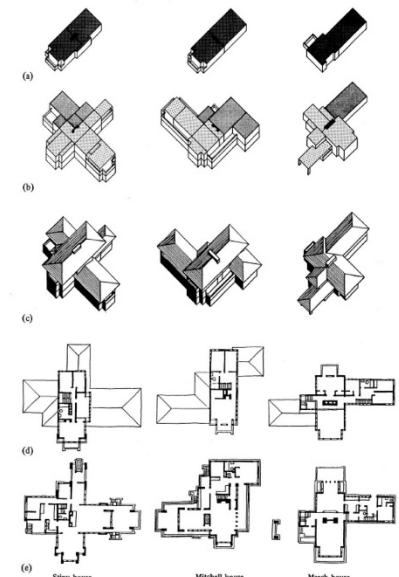
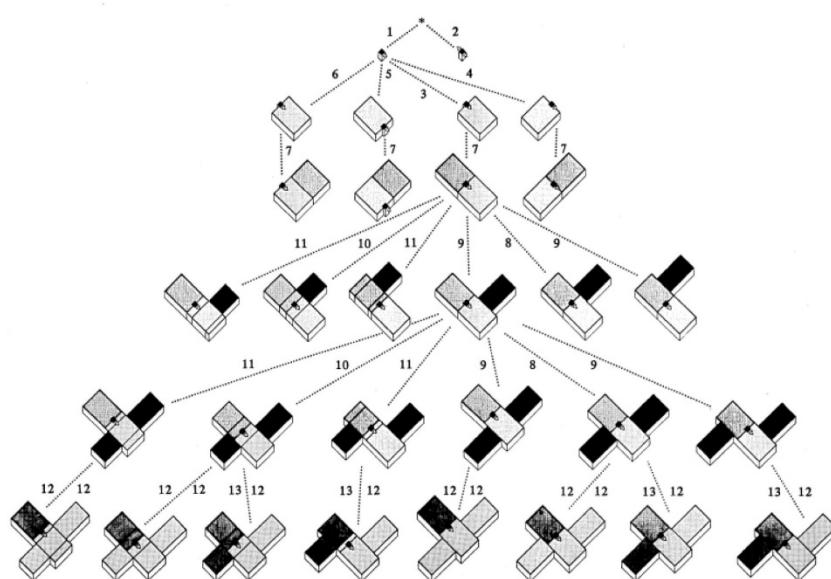
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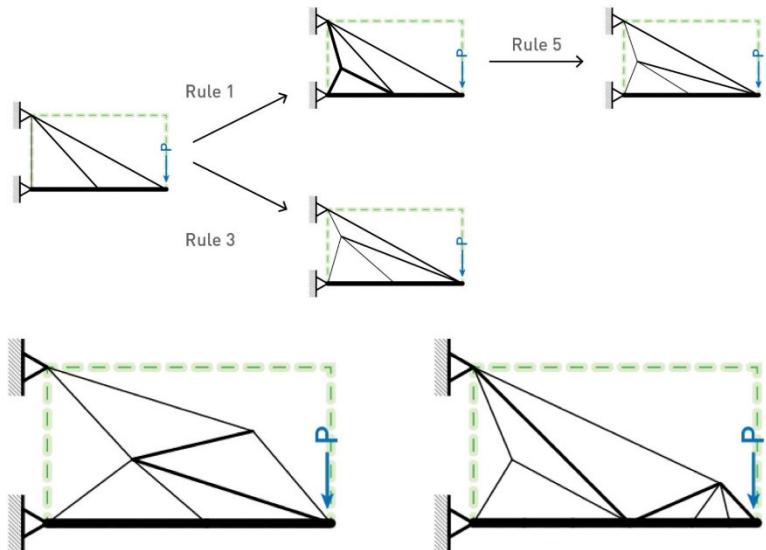
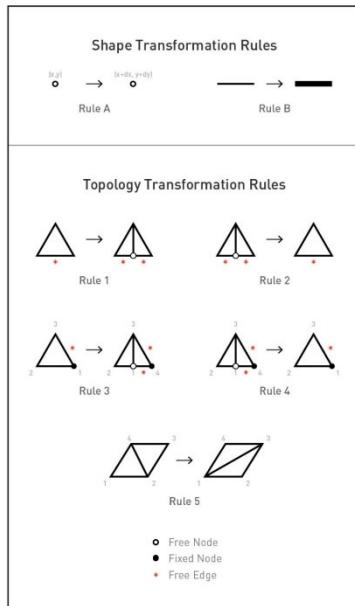
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Original Work by Shea & Cagan (1999) • Redrawn &

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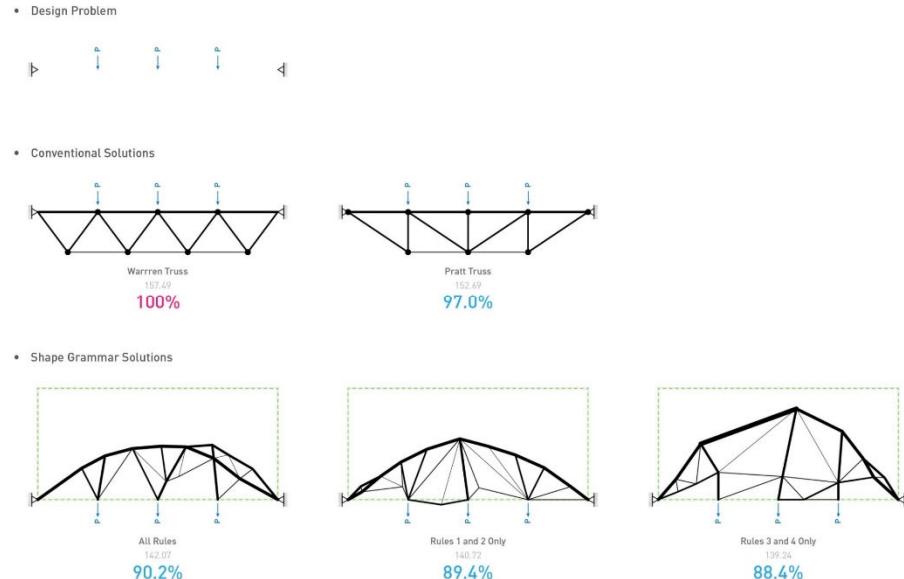
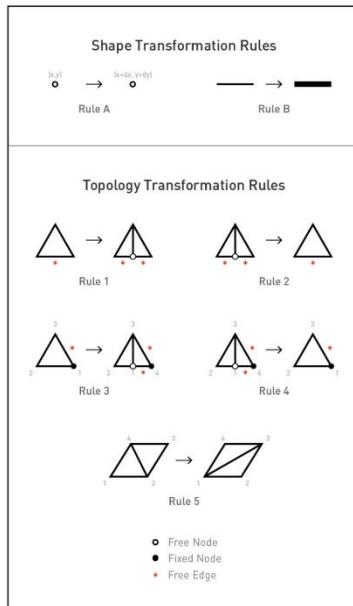
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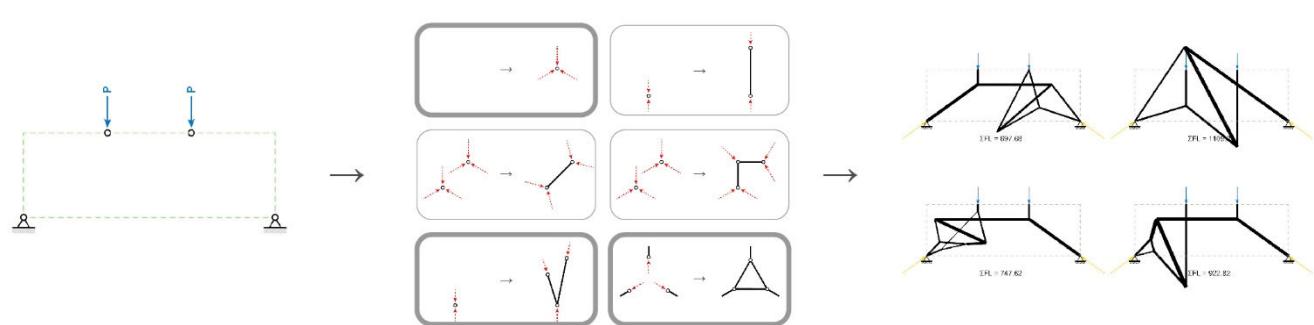
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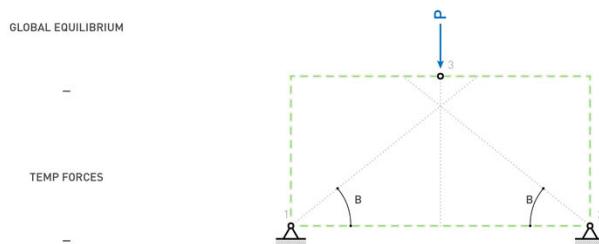
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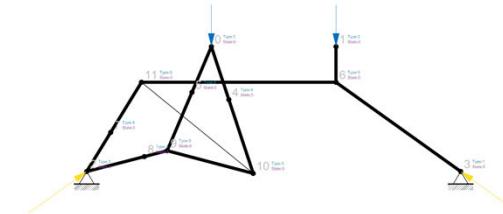
Shape grammars

Combinatorial Equilibrium Modelling (CEM)

Force Diagrams of Every Node



The Design



Evaluation Metric

ID : 0004E
 $\Sigma F_L = 673.61$
 $\Sigma L = 126.38$
 $\Sigma \# = 13$

Length: [1.0, 10.0, 100.0]
 Rule 2: 25%
 Rule 3: 25%
 Rule 4: 25%
 Rule 5: 25%

Rule Info

RULE HISTORY
 1. "Rule 0: START" applied at Node 2
 2. "Rule 3: Split Node" applied at Node 0
 3. "Rule 5: Connect via Projection" applied at Node 4
 4. "Rule 5: Connect via Projection" applied at Node 1
 5. "Rule 3: Split Node" applied at Node 2
 6. "Rule 5: Connect via Projection" applied at Node 2
 7. "Rule 5: Connect via Projection" applied at Node 8
 8. "Rule 6: System Close" applied at Node 4
 9. "Rule 6: System Close" applied at Node 6

Rule History

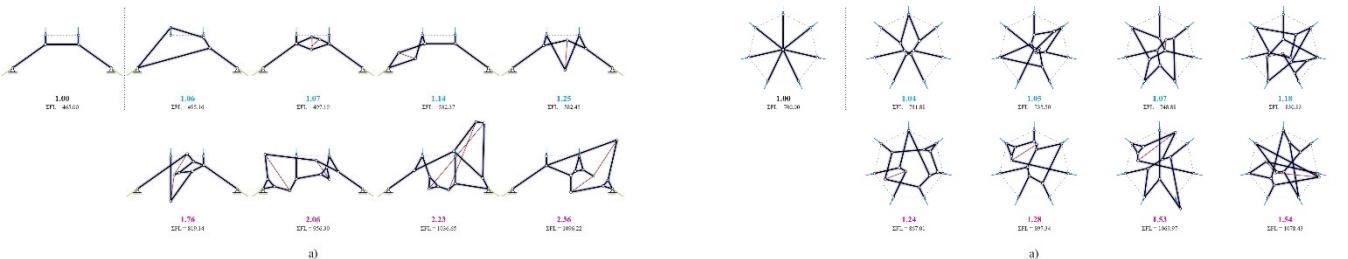
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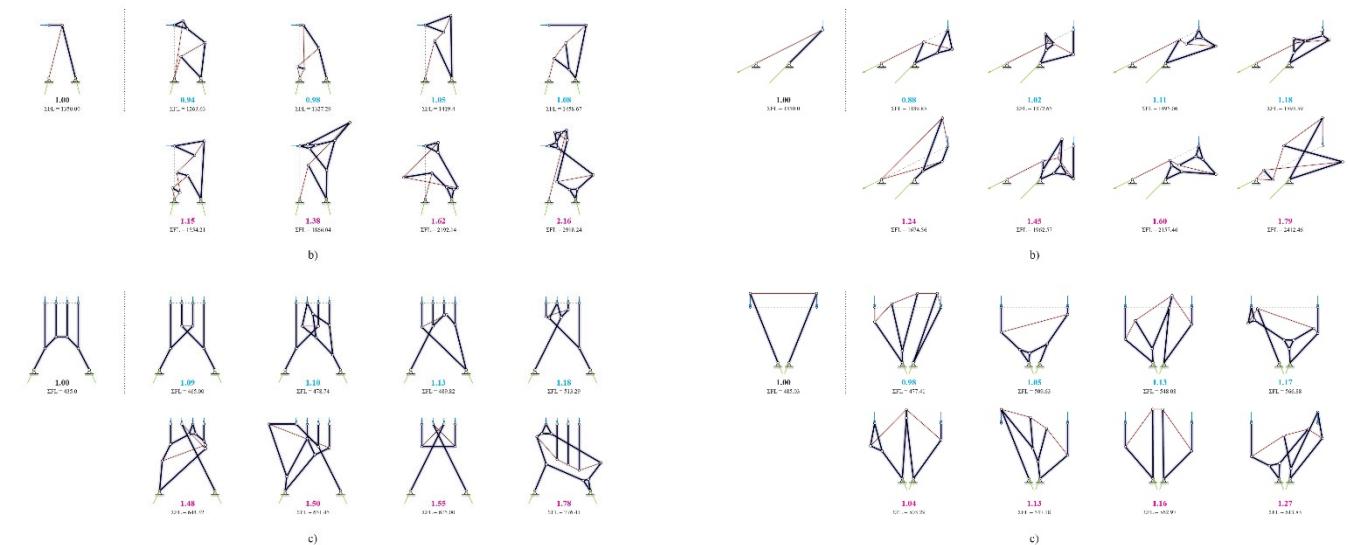
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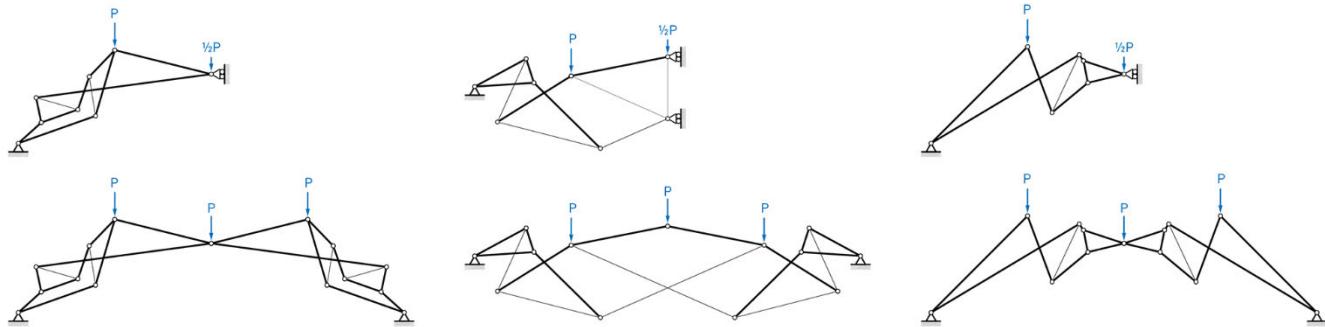
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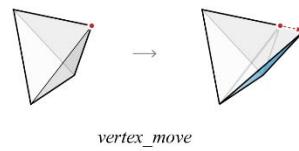
3D Graphic Statics (3GS)

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Shape grammars

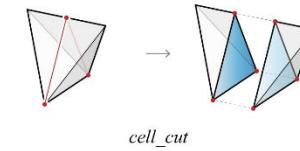
Combinatorial Equilibrium Modelling (CEM)

Modification



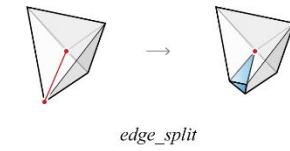
vertex_move

Decomposition

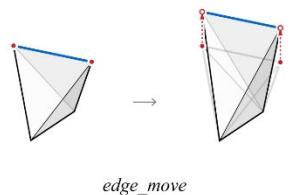


cell_cut

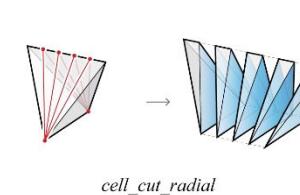
Transformation



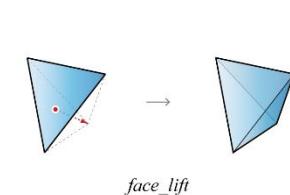
edge_split



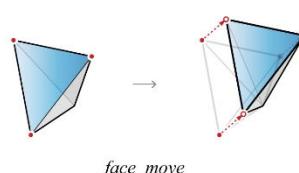
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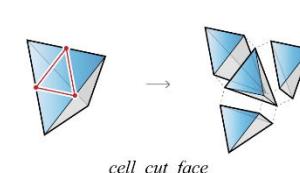
cell_cut_radial



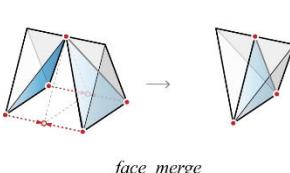
face_lift



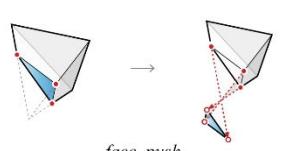
face_move



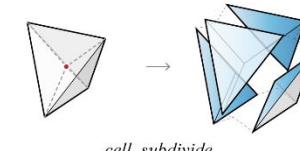
cell_cut_face



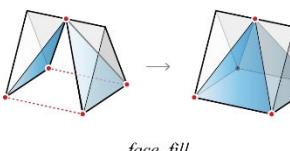
face_merge



face_push



cell_subdivide



face_fill

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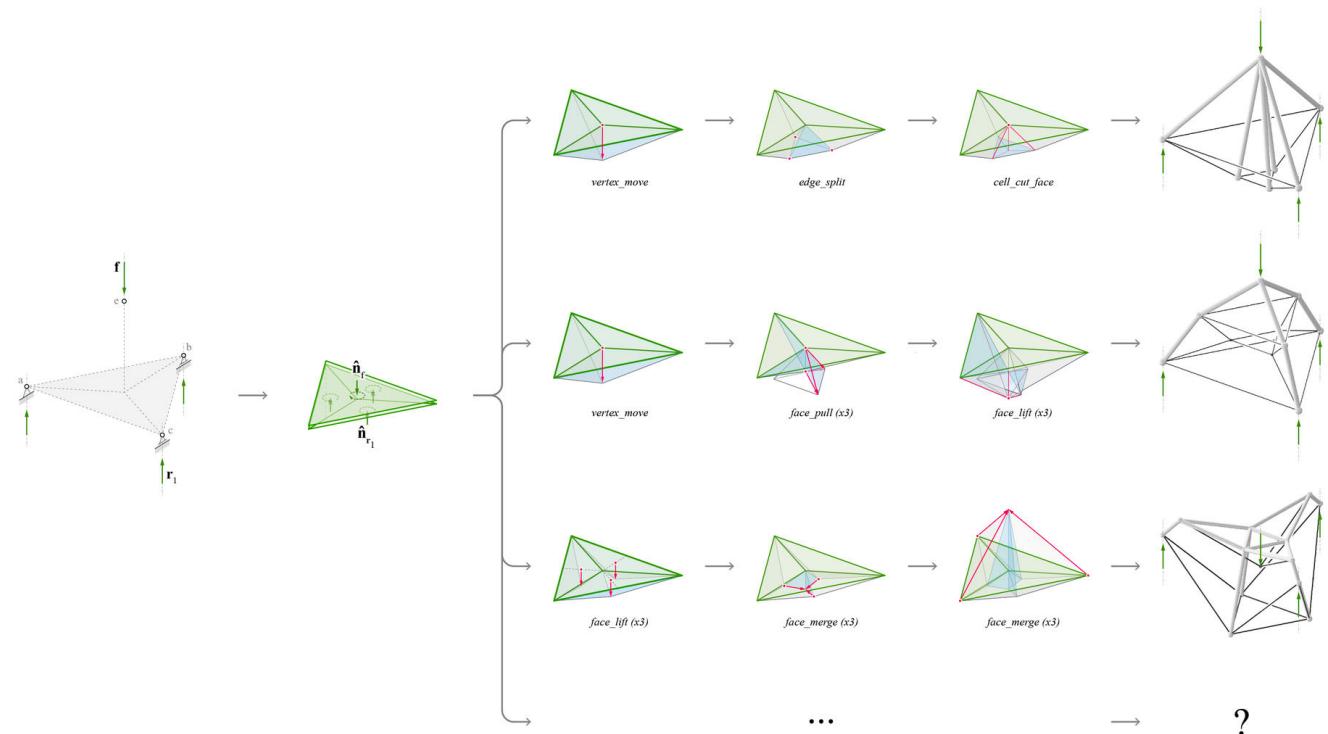
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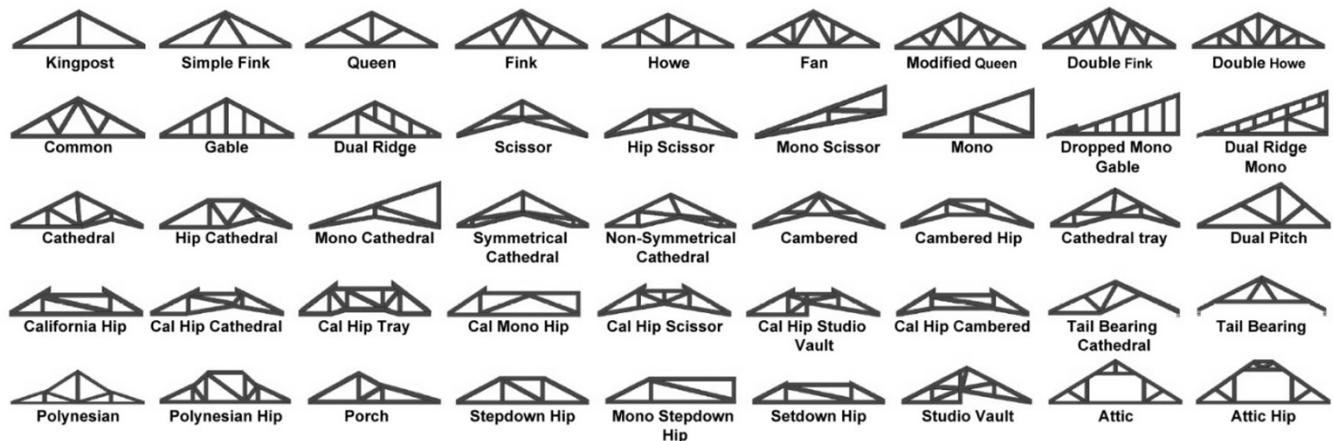
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*“In order to arrive at new forms and concepts,
we have to free ourselves from such pre-defined typologies.”*

Analysis

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Algebraic graph(ic) statics (AGS)

Bi-directional AGS

Vector-based Graphic Statics (VGS)

Form-finding

Interactive drawings

Constrained form-finding

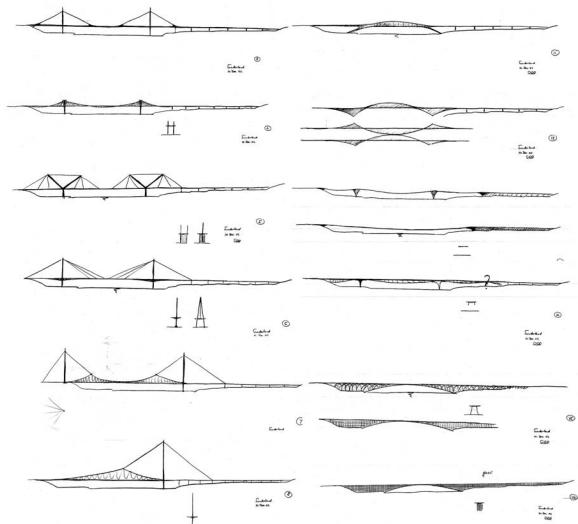
Thrust Network Analysis (TNA)

3D Graphic Statics (3GS)

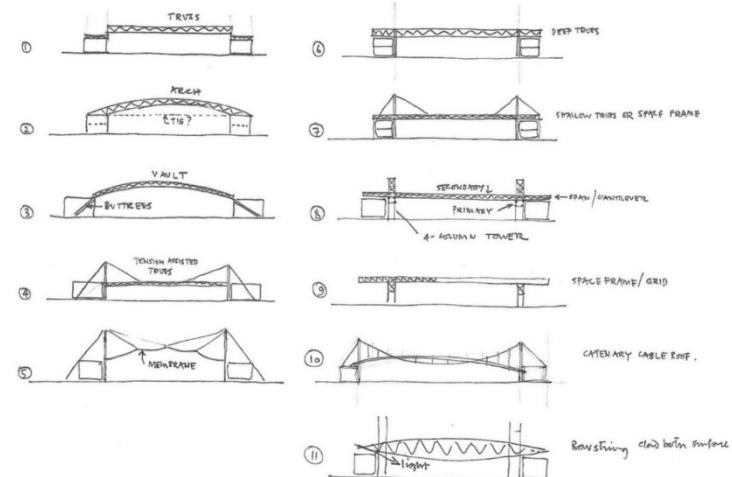
Subdivision

Shape grammars

Combinatorial Equilibrium Modelling (CEM)



Possible Structural Sections



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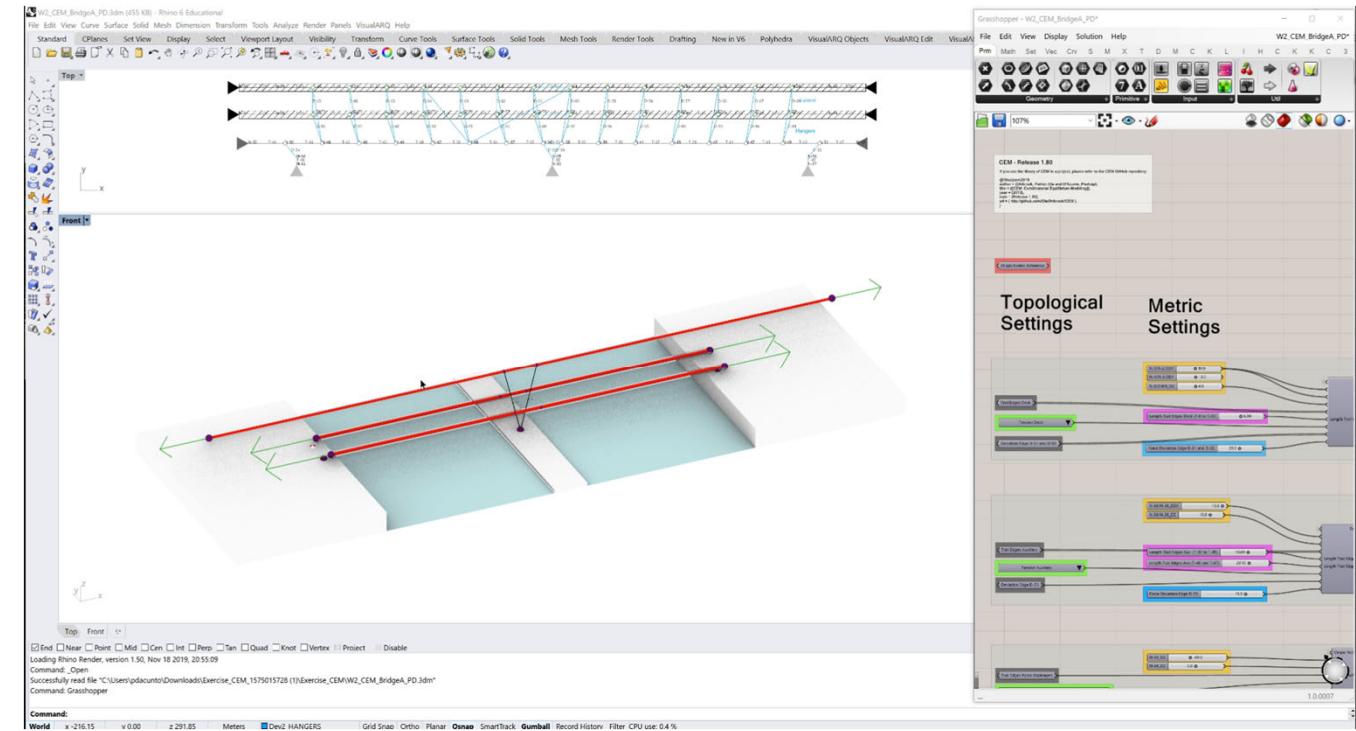
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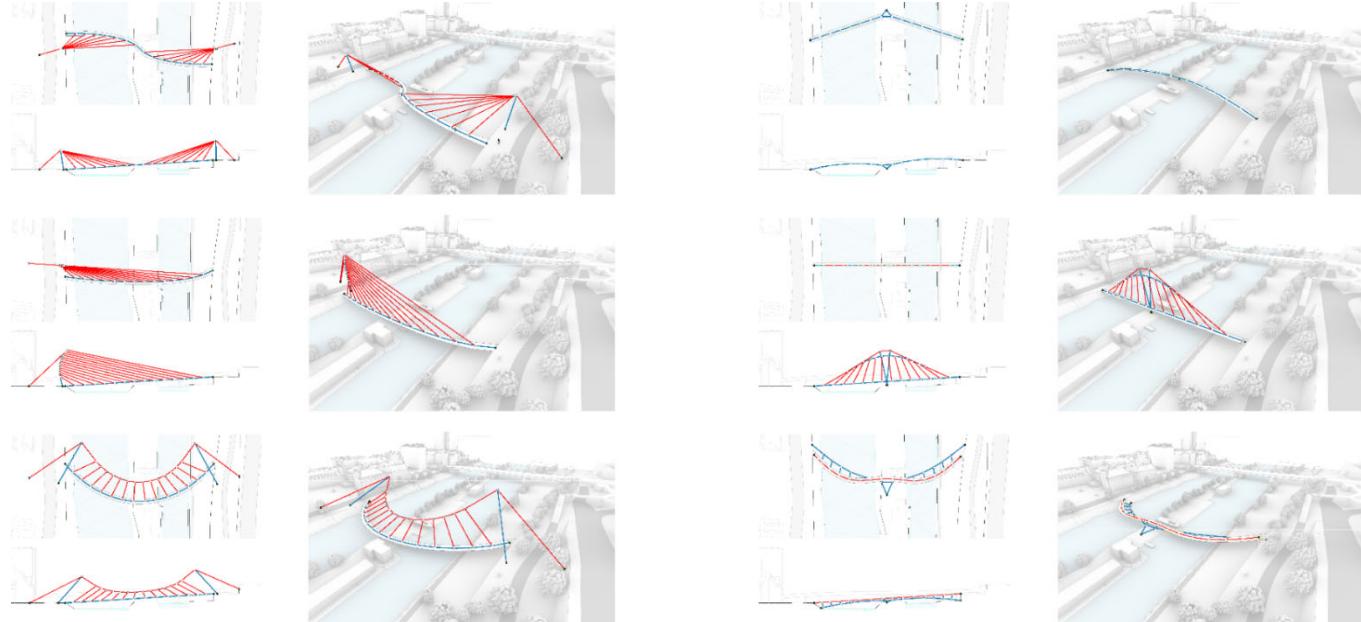
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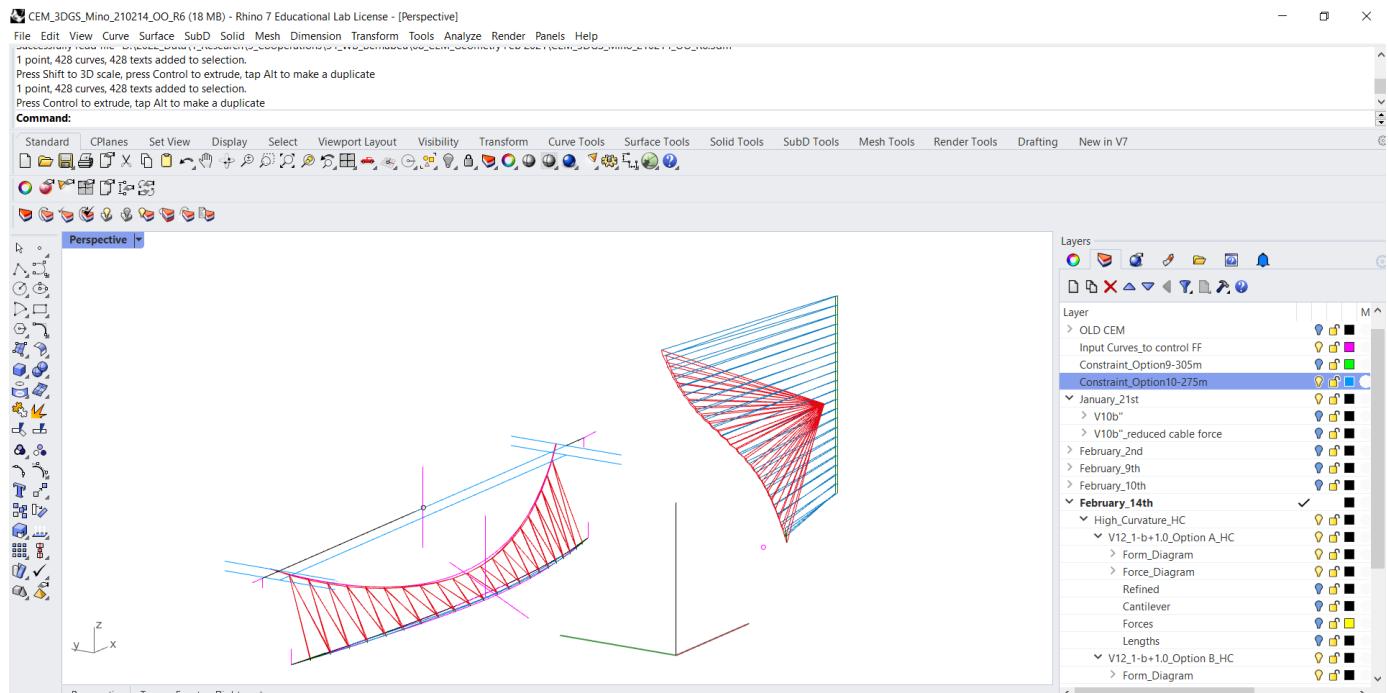
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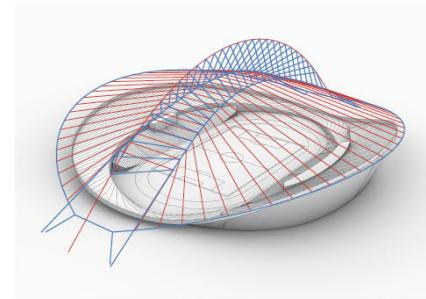
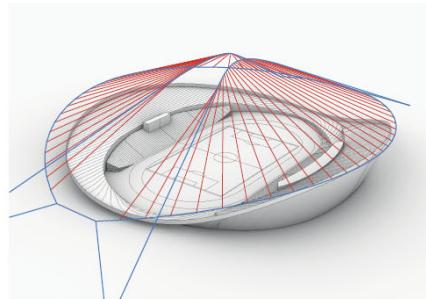
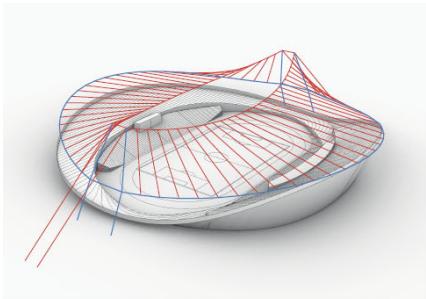
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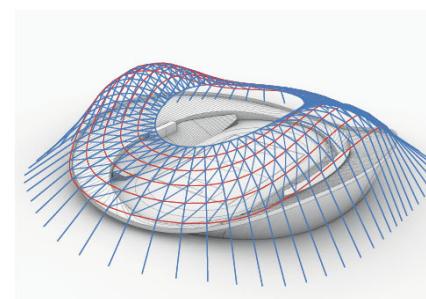
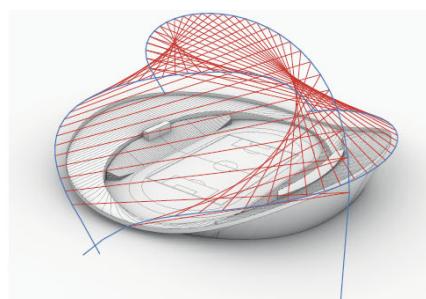
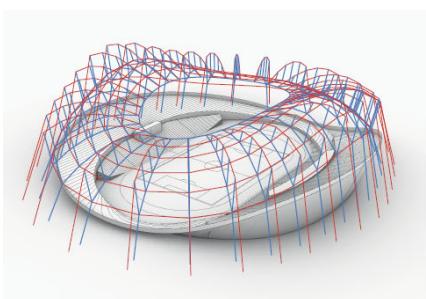
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Stadium roof design with CEM

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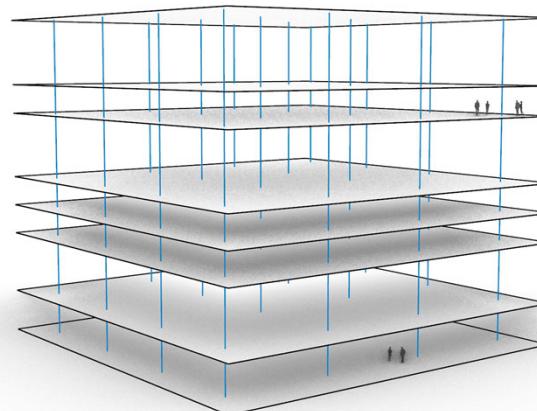
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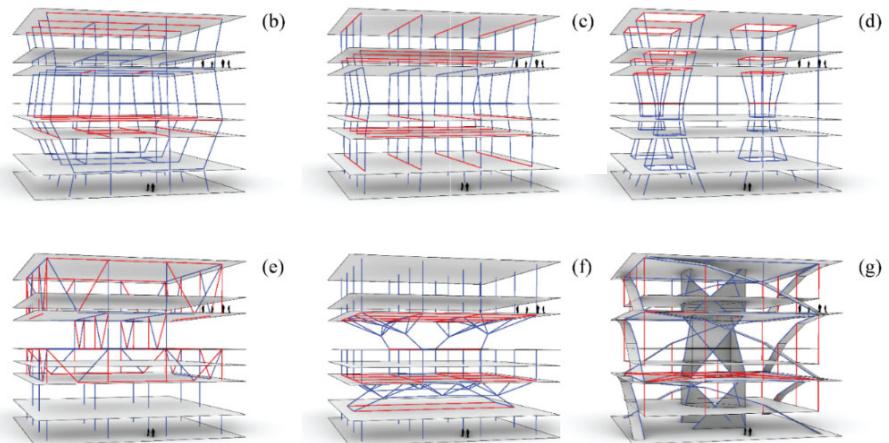
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[Combinatorial Equilibrium Modelling \(CEM\)](#)



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