Stock defined gridshells

P5 presentation – Nick Heijne

Content

Introduction

The current situation

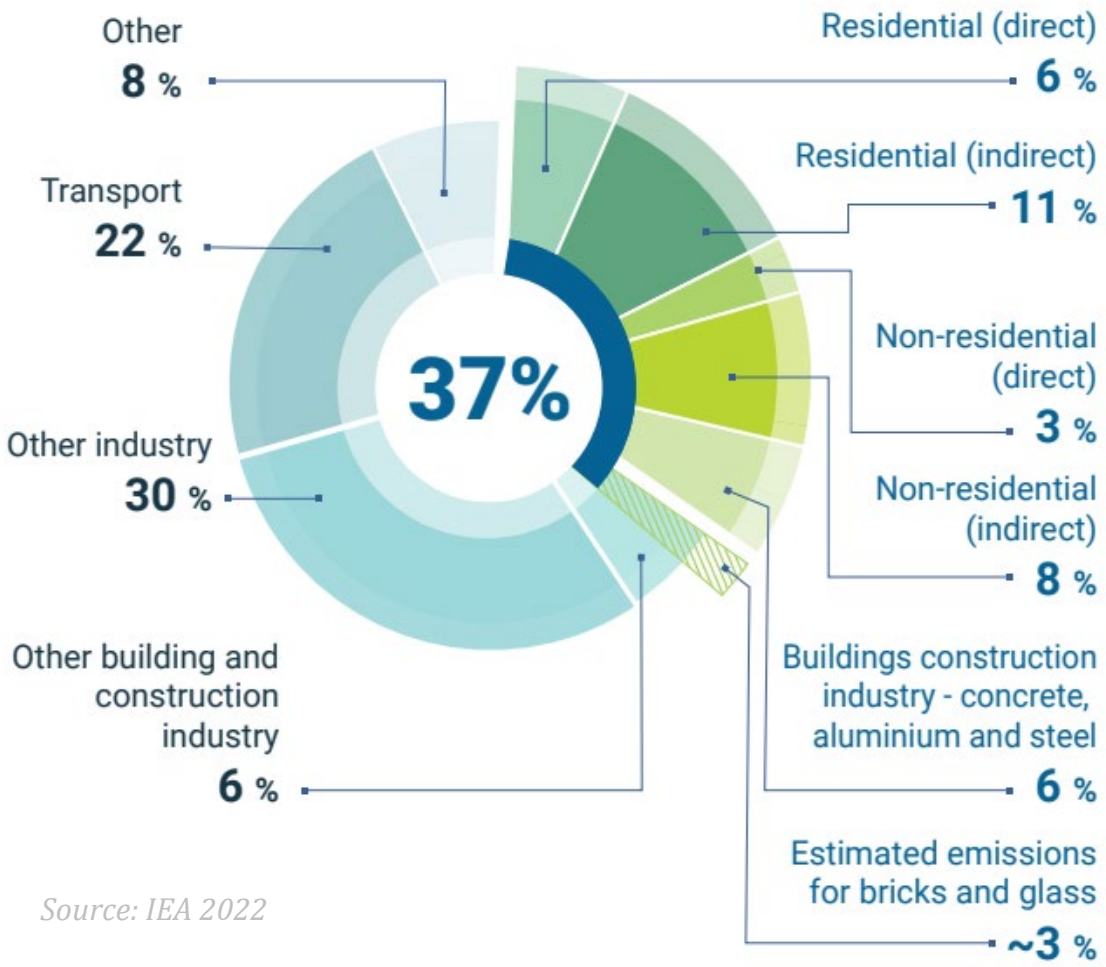
We've been given a warning by science and a wake-up call by nature; it is up to us now to heed them.

~ Bill McKibben

The current situation

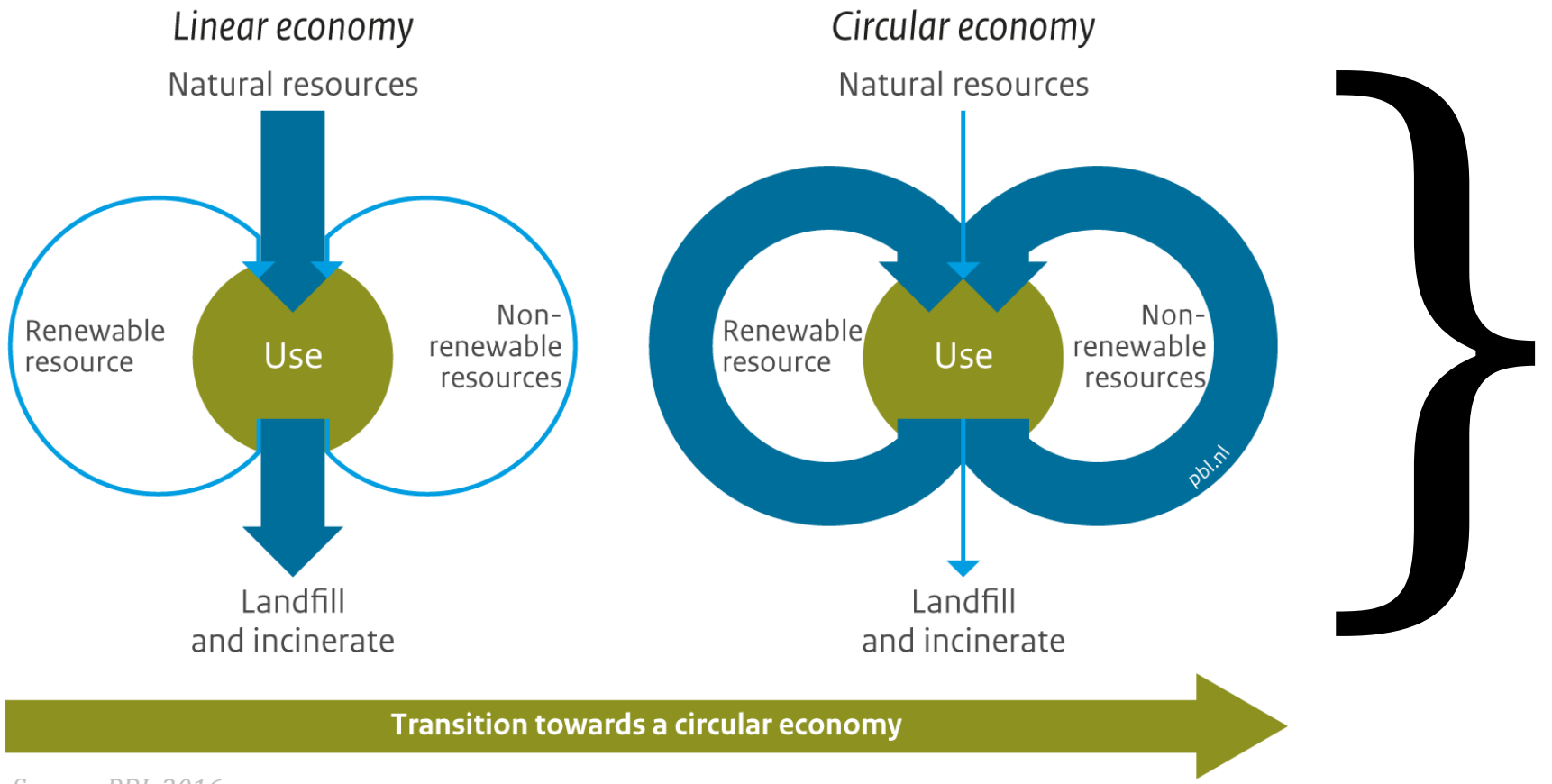
Problem formulation

Distribution emissions



Source: IEA 2022

Material efficiency



Efficient use of materials

Source: PBL 2016

Material efficiency

Efficient use of materials

- Reuse of materials
- Structural efficiency

Historical perspective

Historically reuse was more common

The industrial revolution “unlearned” us to reuse

Is there the need to reuse again?

Popular when material was more expensive then labour

Material efficient span because of the double curvature

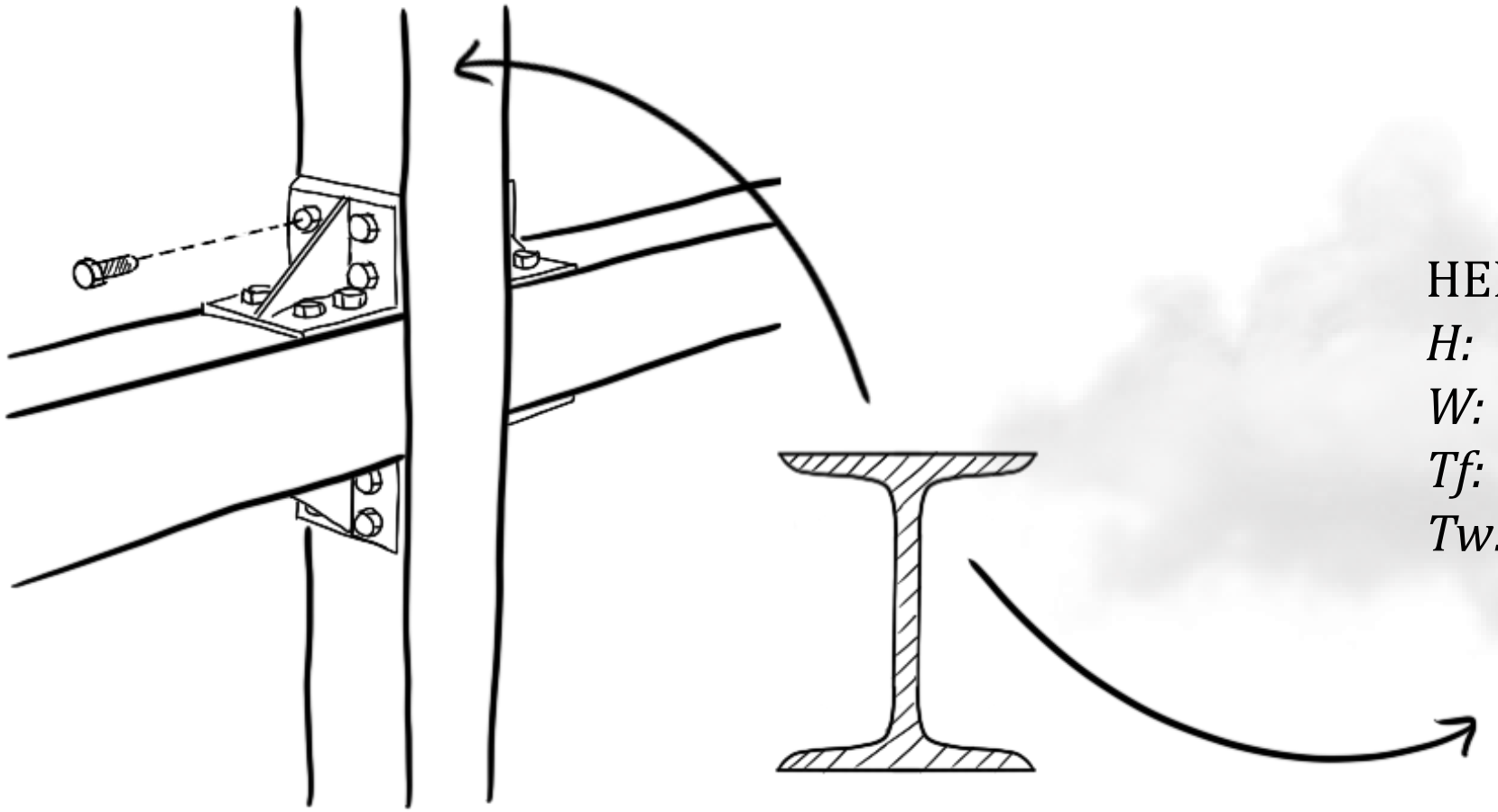
Is the shell topology relevant again?

Impact of steel

8831,2 $kgCO_{2eq}/m^3$

Source: CINARK 2022

Impact of steel



HEB 200 - S275

H: *200mm*

W: *200mm*

Tf: *15mm*

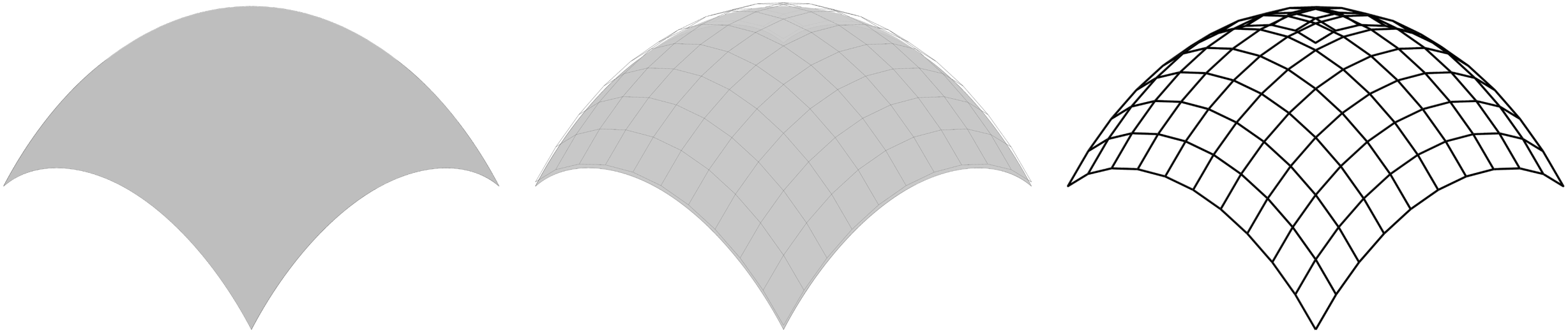
Tw: *9mm*

Material efficiency

Efficient use of materials

- Reuse of materials = reusing steel members
- Structural efficiency = gridshell as efficient topology

Gridshell



Shell → Gridshell

Gridshell

Digital manufacturing
Digital design

Virgin materials

Material databases

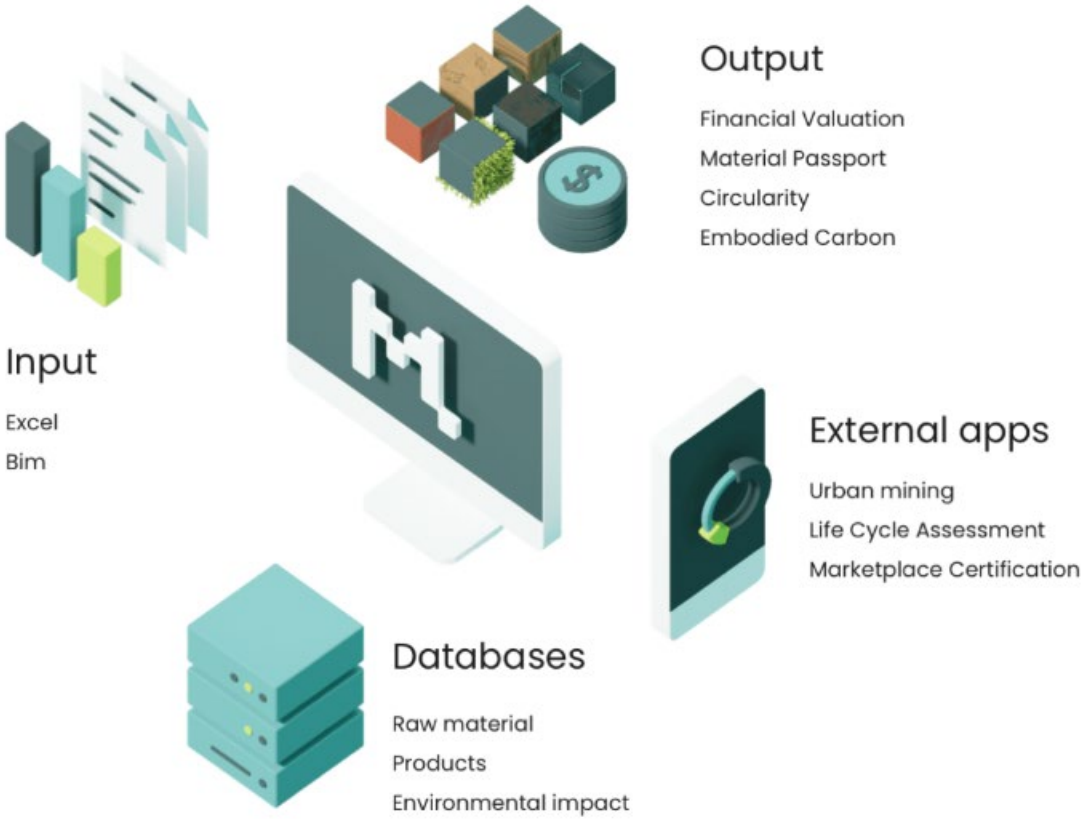
Madaster

Let the user create a material passport

BUT, information is not publicly available

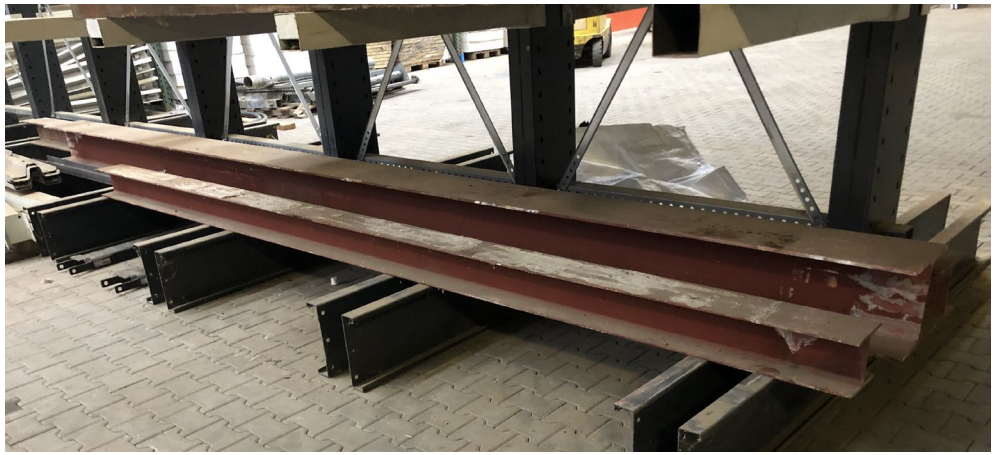
RESULT, still no knowledge about the current material supply within the built-environment

RESULT, sourcing from existing buildings time-dependent and unreliable



Material marketplaces

Current status of online second-hand material marketplaces

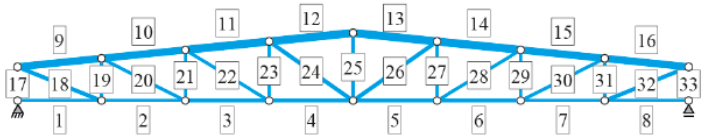


Sources: insert, oogstkaart, matching materials

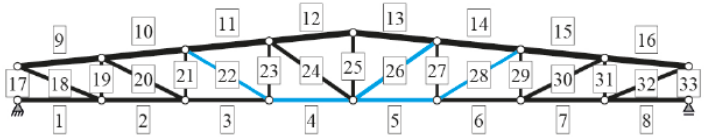
More complexity

To make it more complicated:
100% RR ≠ optimal EI

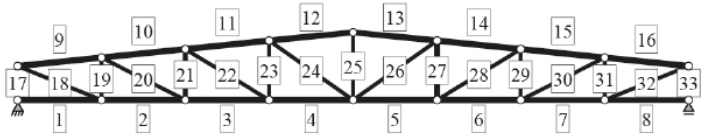
(a) Pratt New $RR = 0\%$ $EI = 64.8$

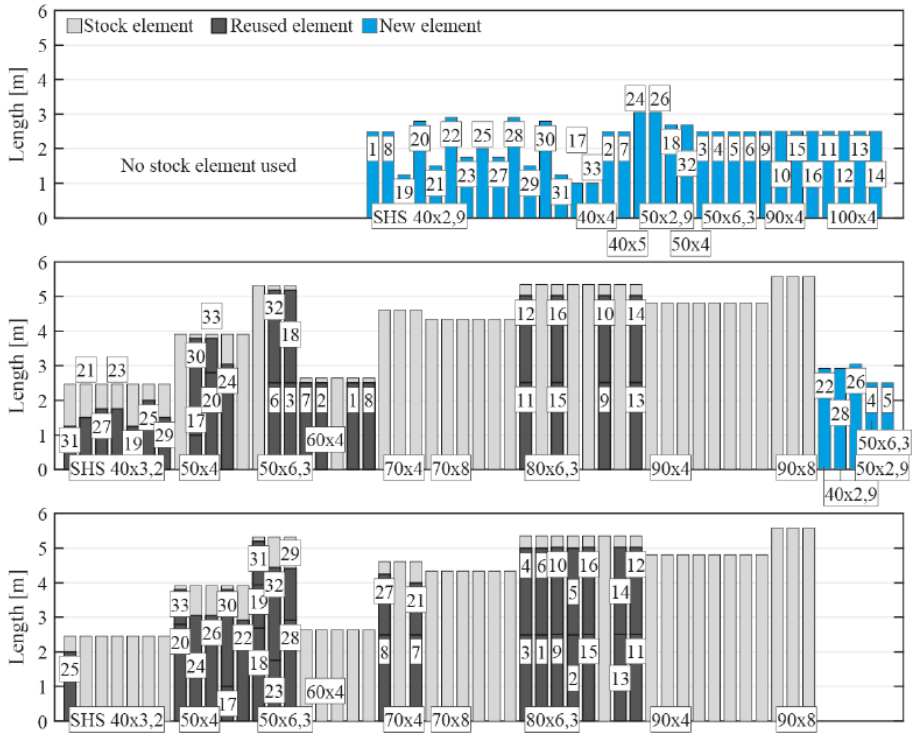


(b) Pratt Optimal $RR = 88\%$ $EI = 35.4$



(c) Pratt Reuse $RR = 100\%$ $EI = 36.6$

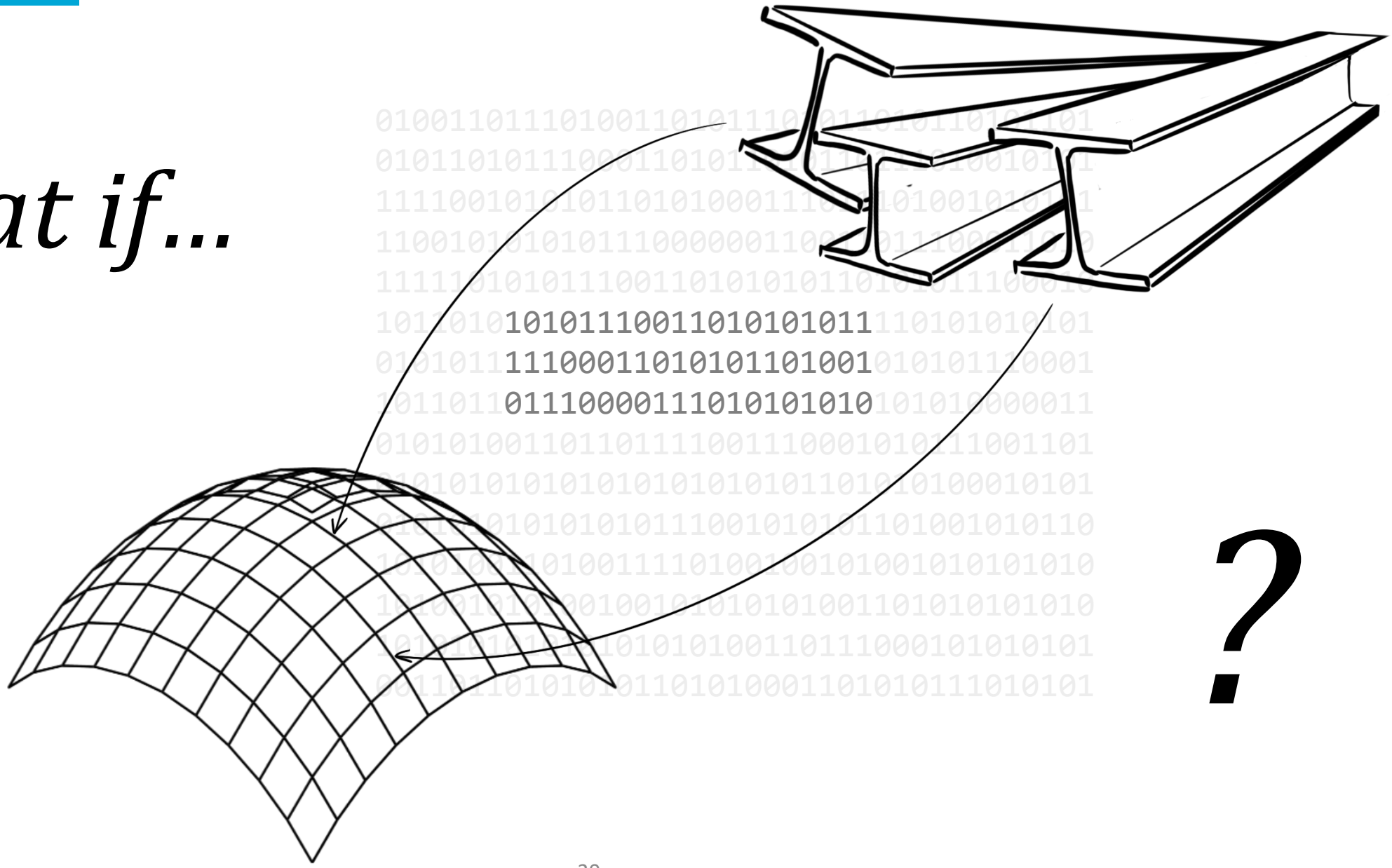




Source: Brütting, 2020

Research question

What if...



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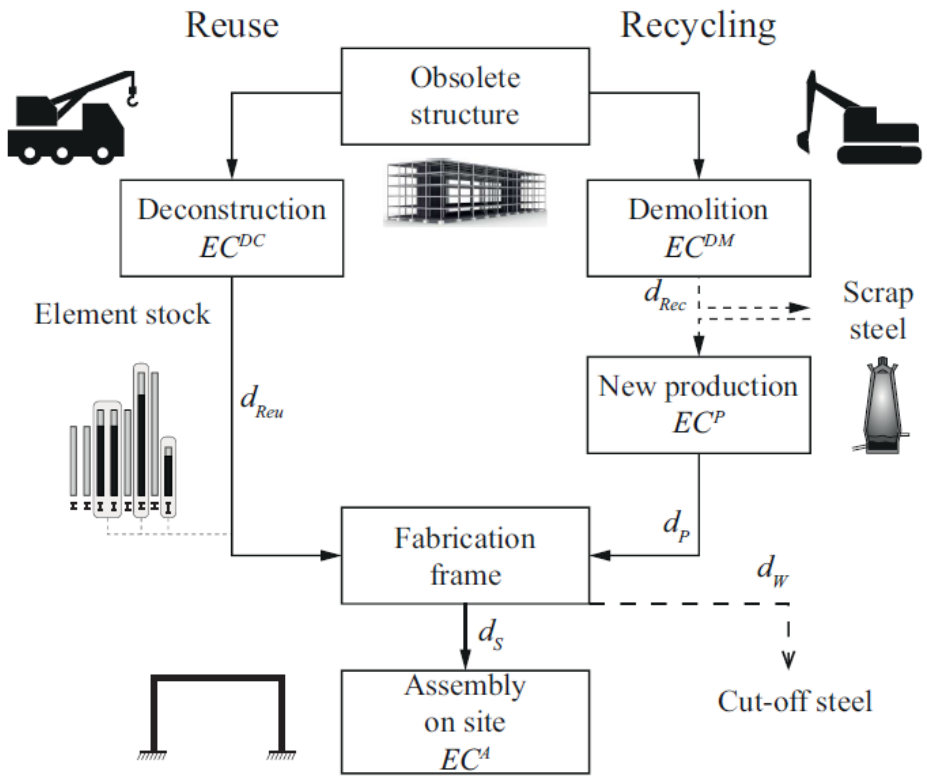
Current knowledge

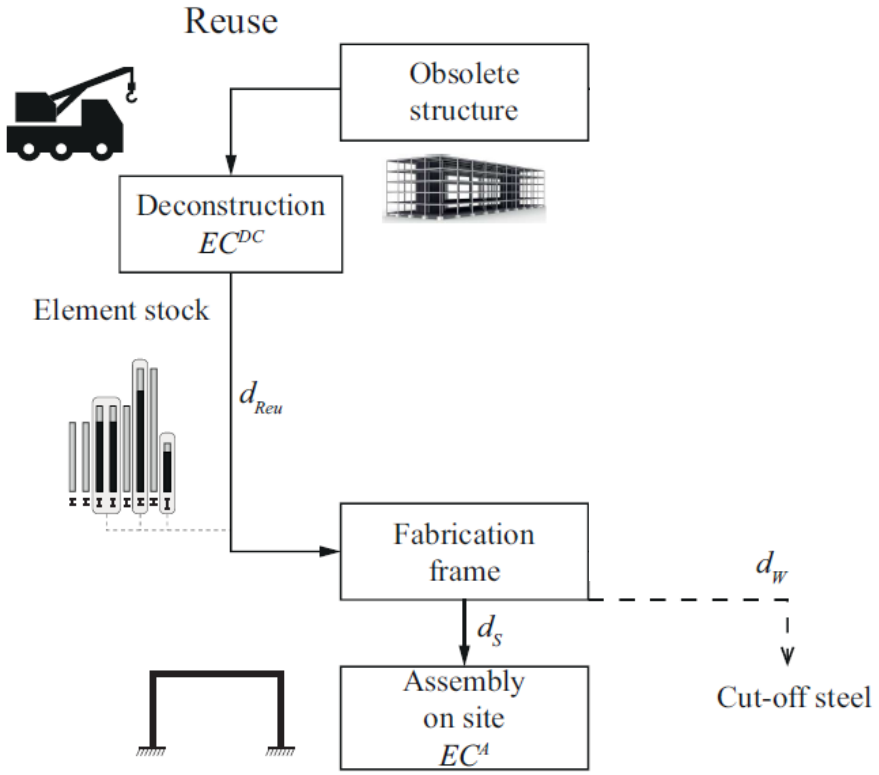
Identified scenarios

Different scenarios



Source: Brütting, 2020

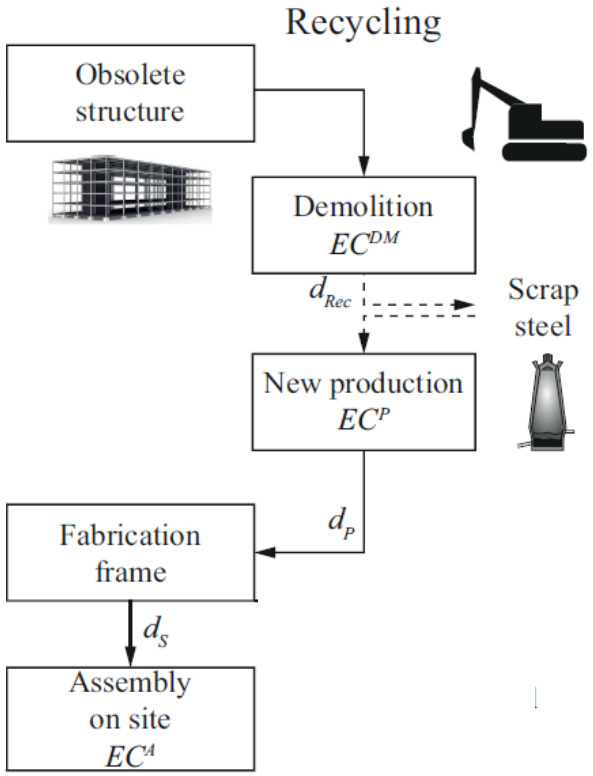
Different scenarios



Source: Brütting, 2020

"Deconstruction scenario"

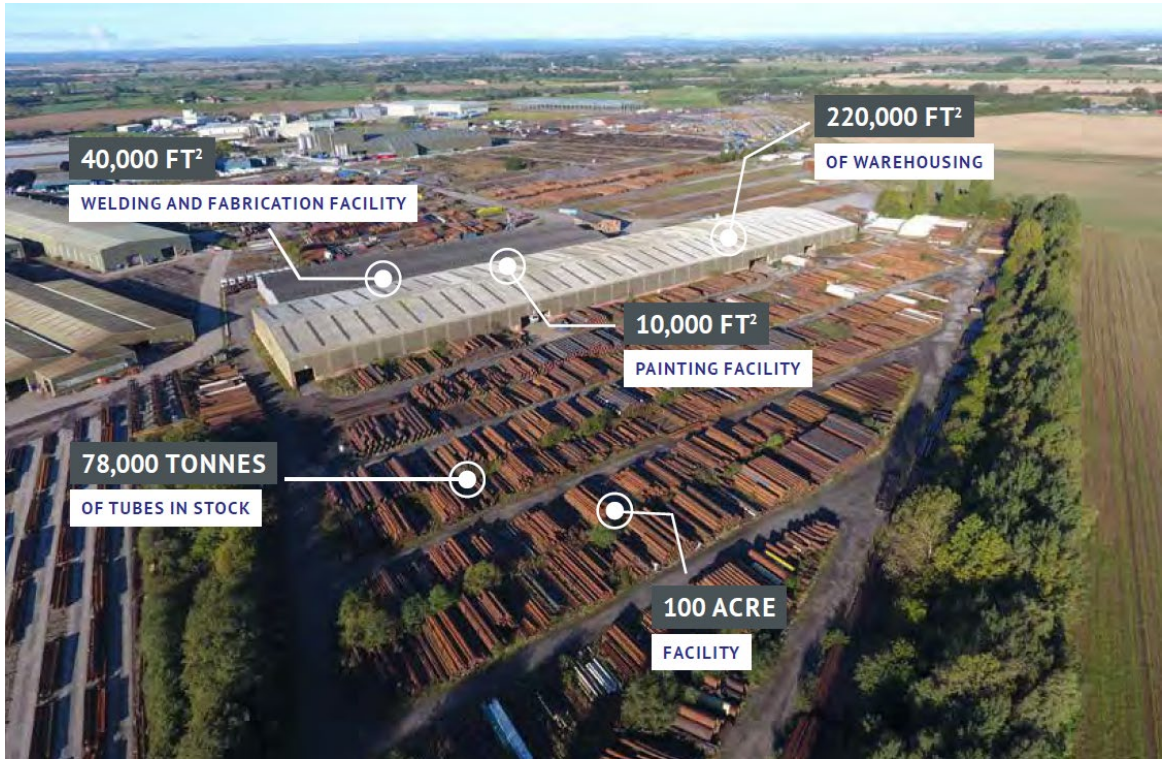
Different scenarios

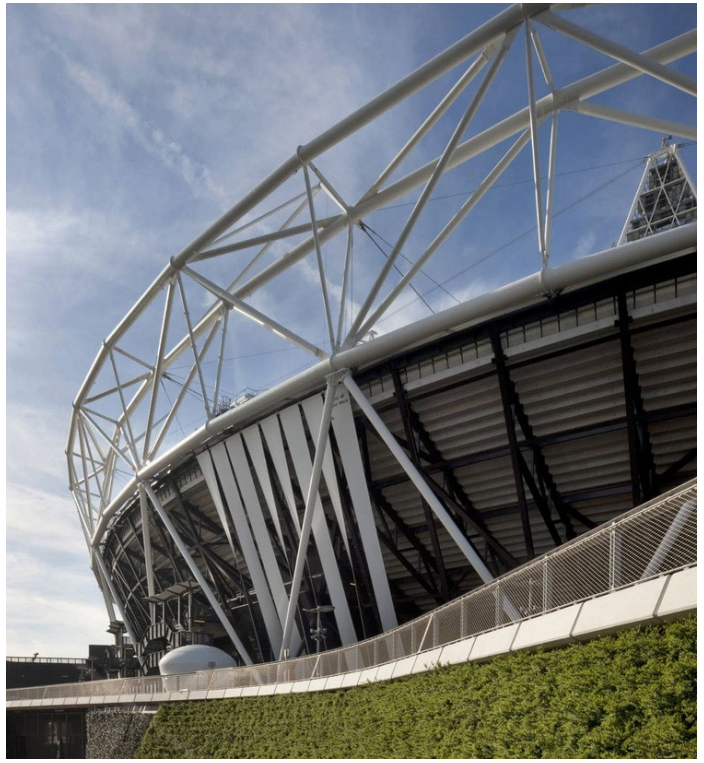


Source: Brütting, 2020

"New production scenario"

Different scenarios



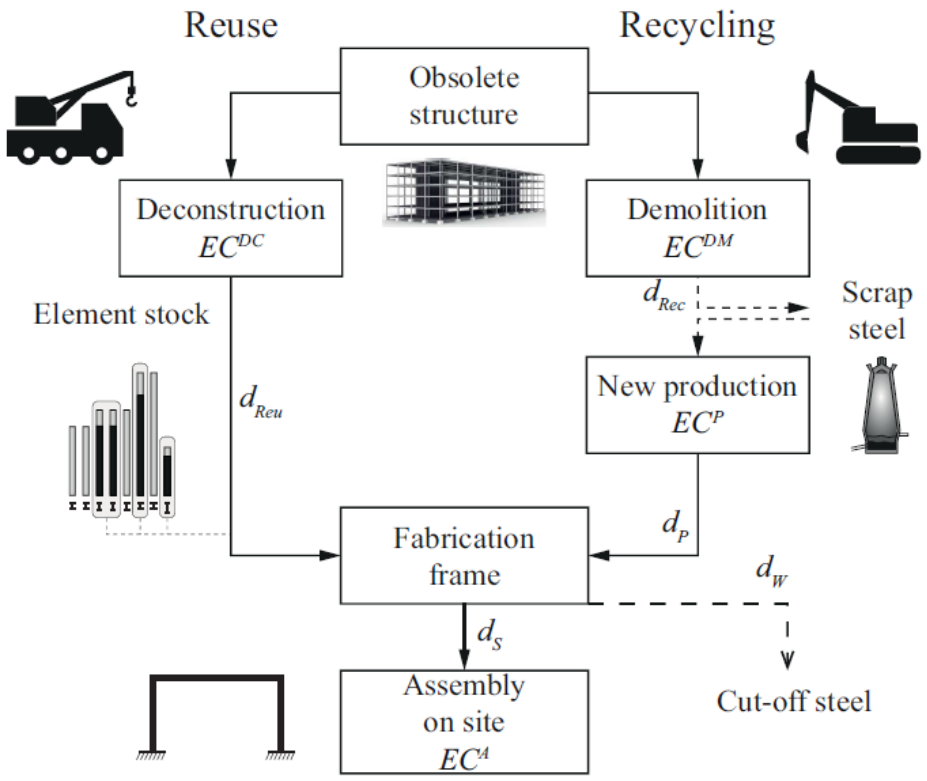


A third-party harvesting stock to be reused

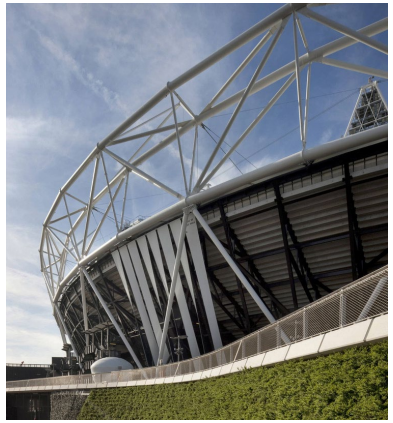
Different scenarios

Available stock through online second-hand material databases

Different scenarios



Source: Brütting, 2020



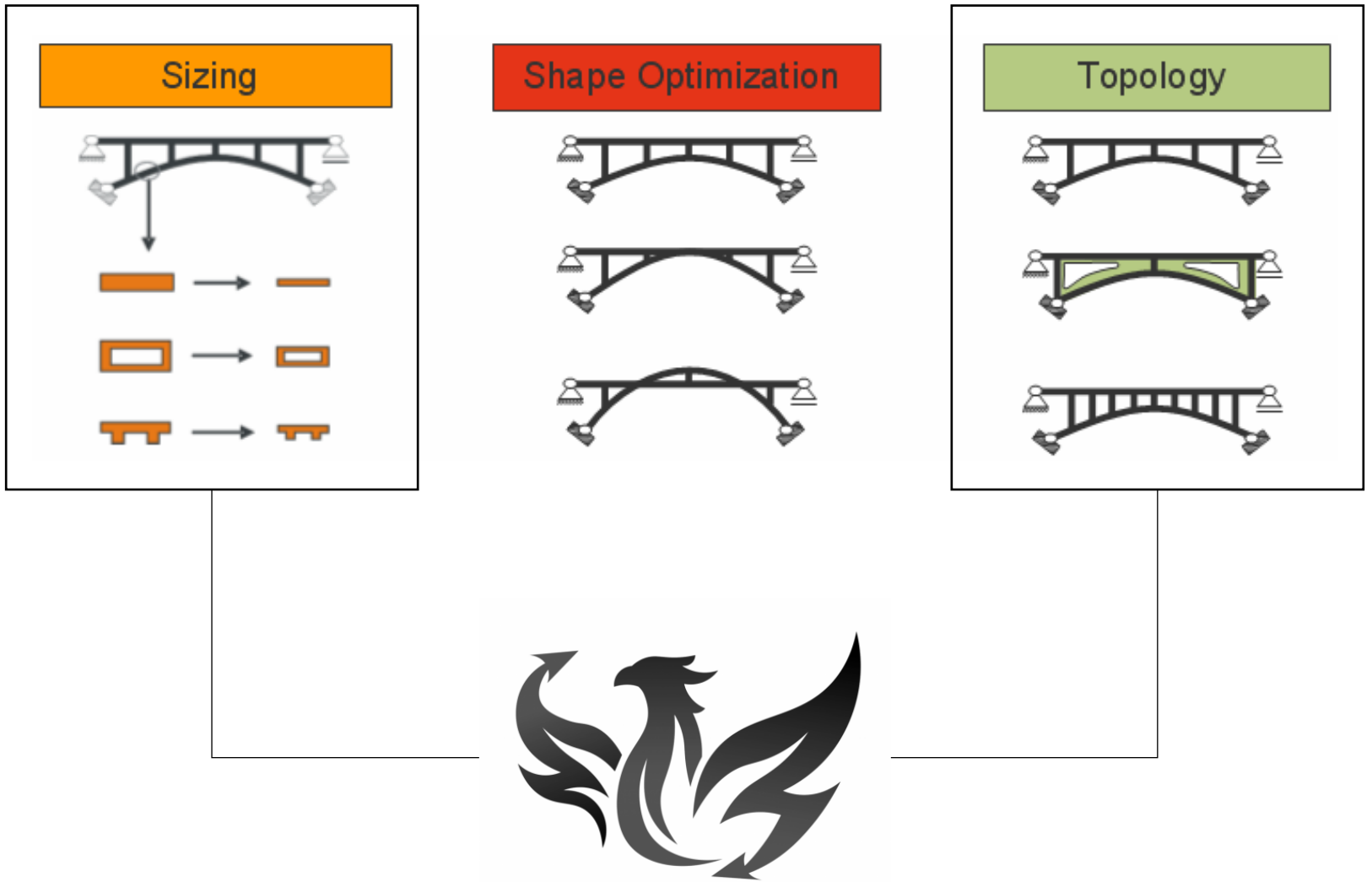
+

?

= “stockpile scenario”

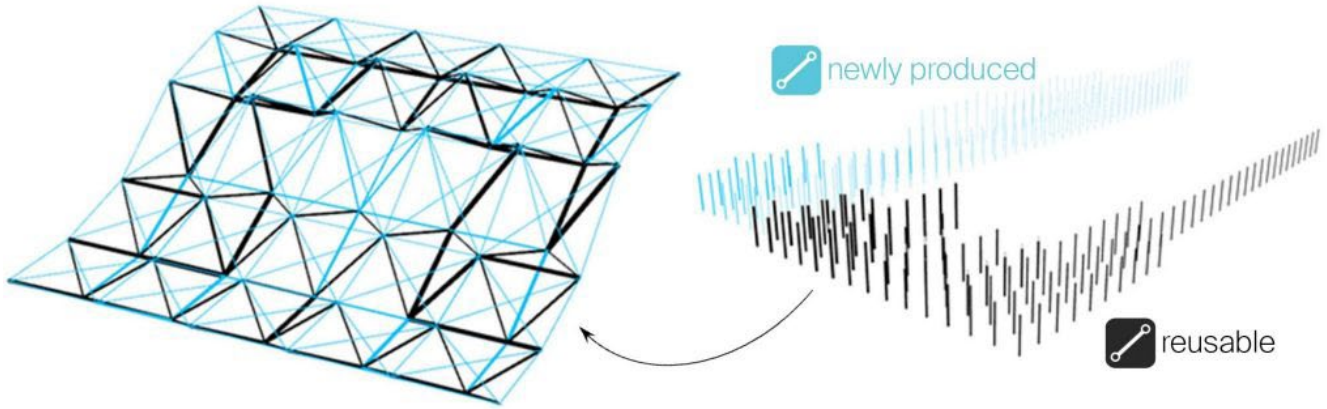
(Structural) optimization

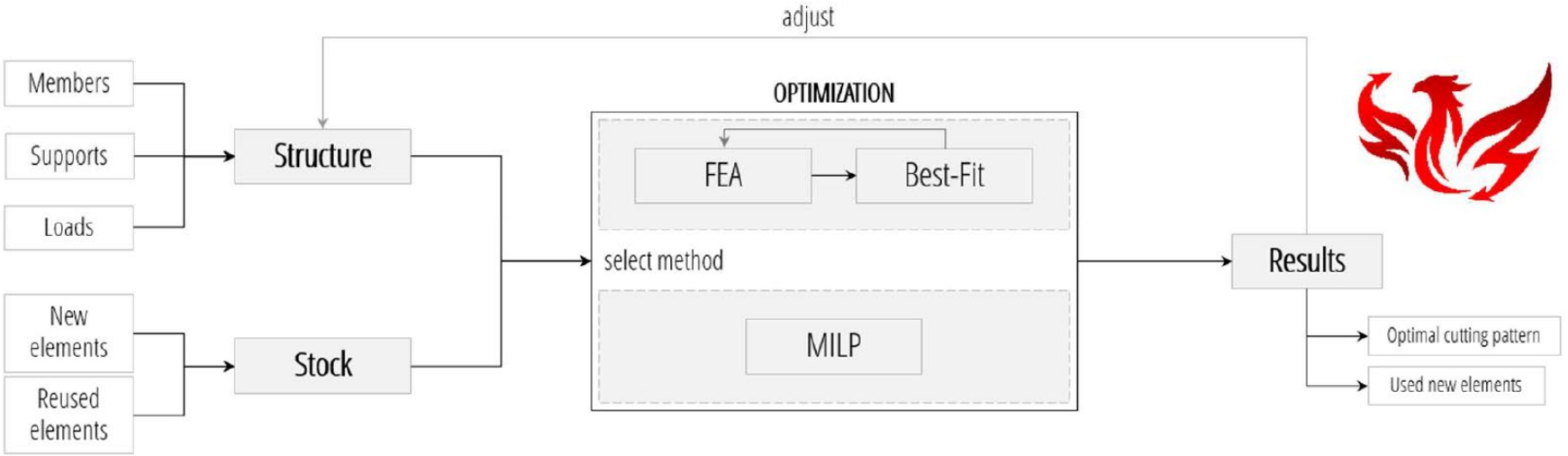
(Structural) optimization



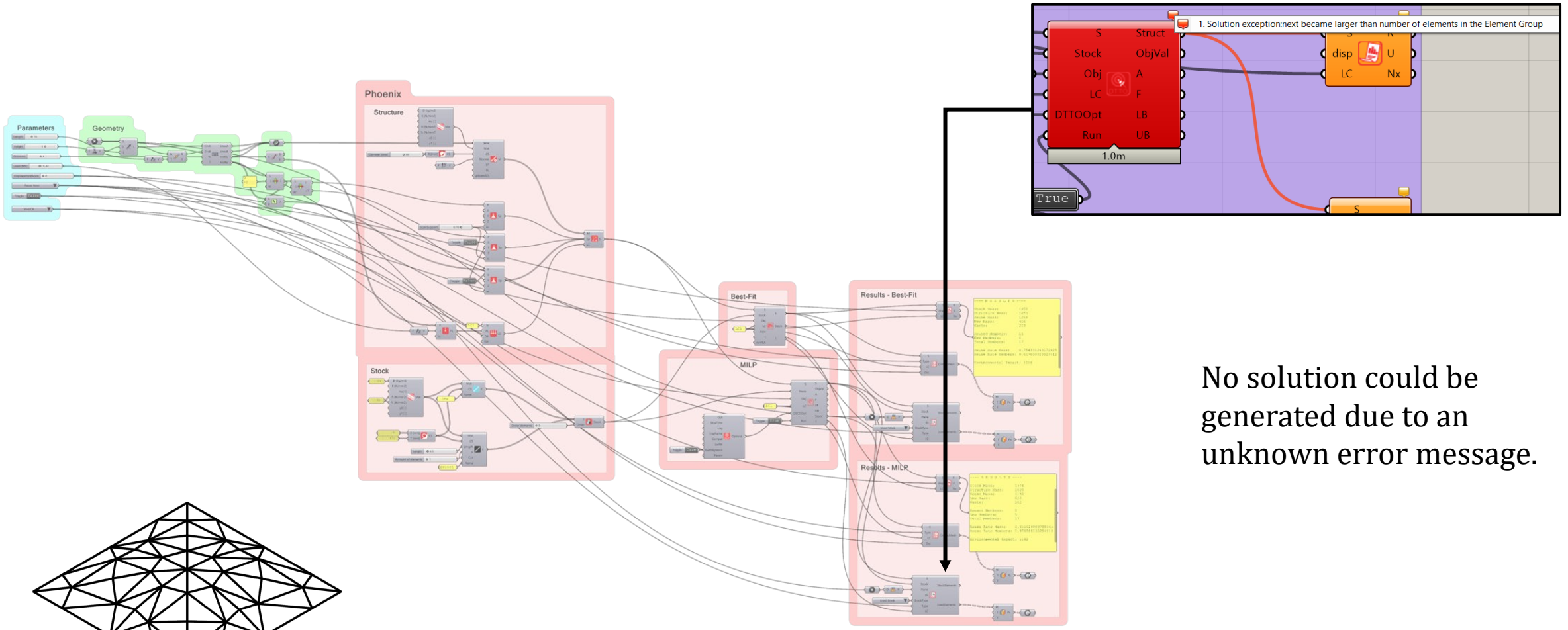
Phoenix3D

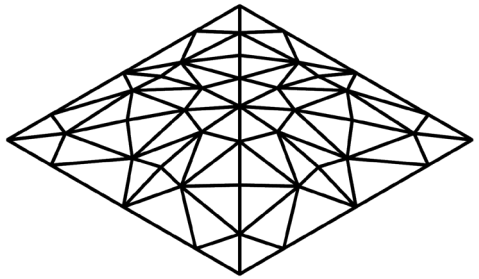
Phoenix3D,
integrated in Grasshopper





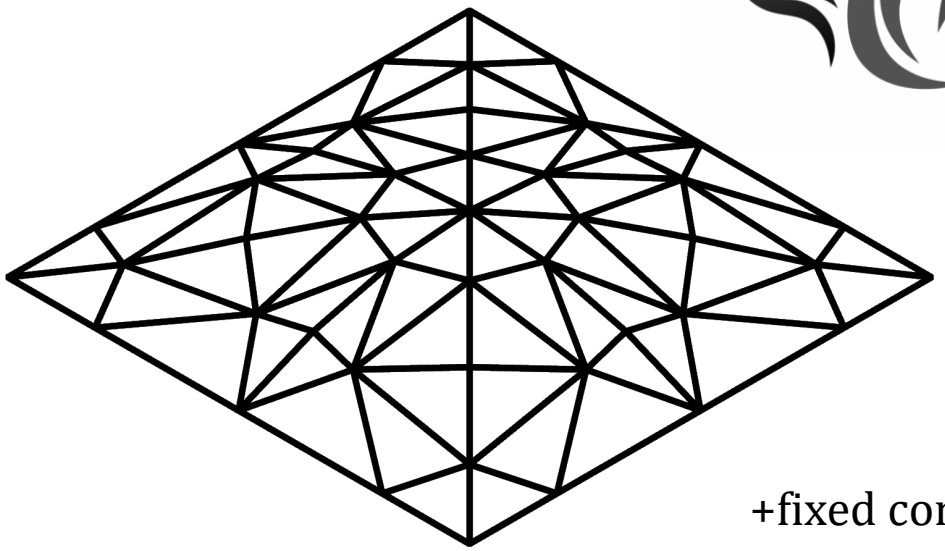
Phoenix3D

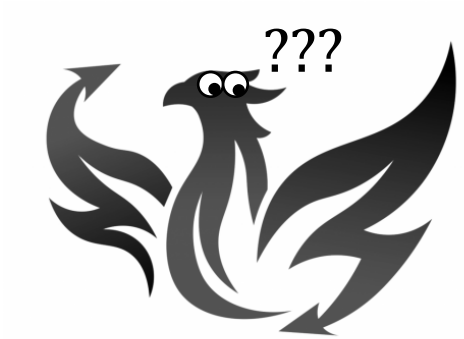




No solution could be generated due to an unknown error message.

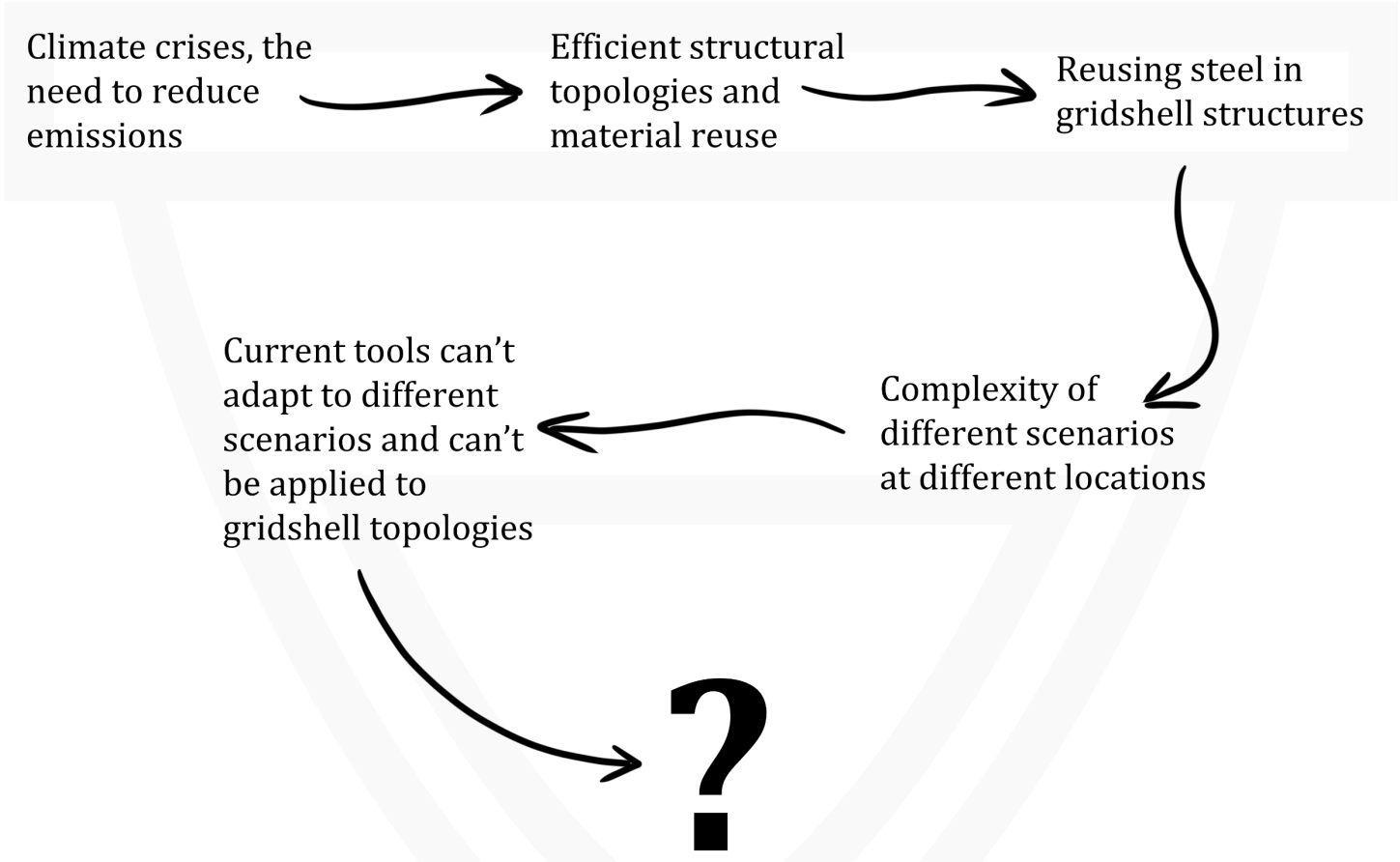
Phoenix3D





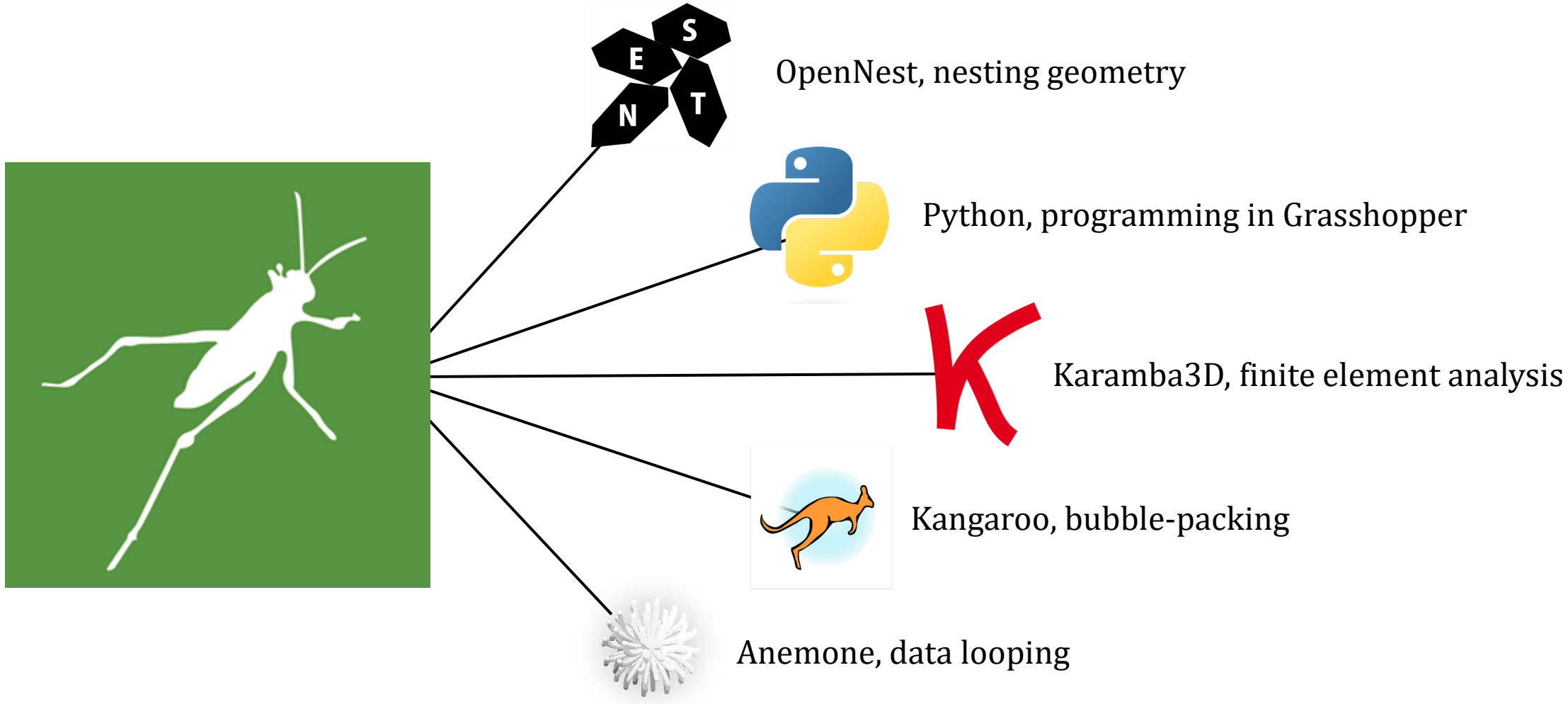
+fixed context

Summary

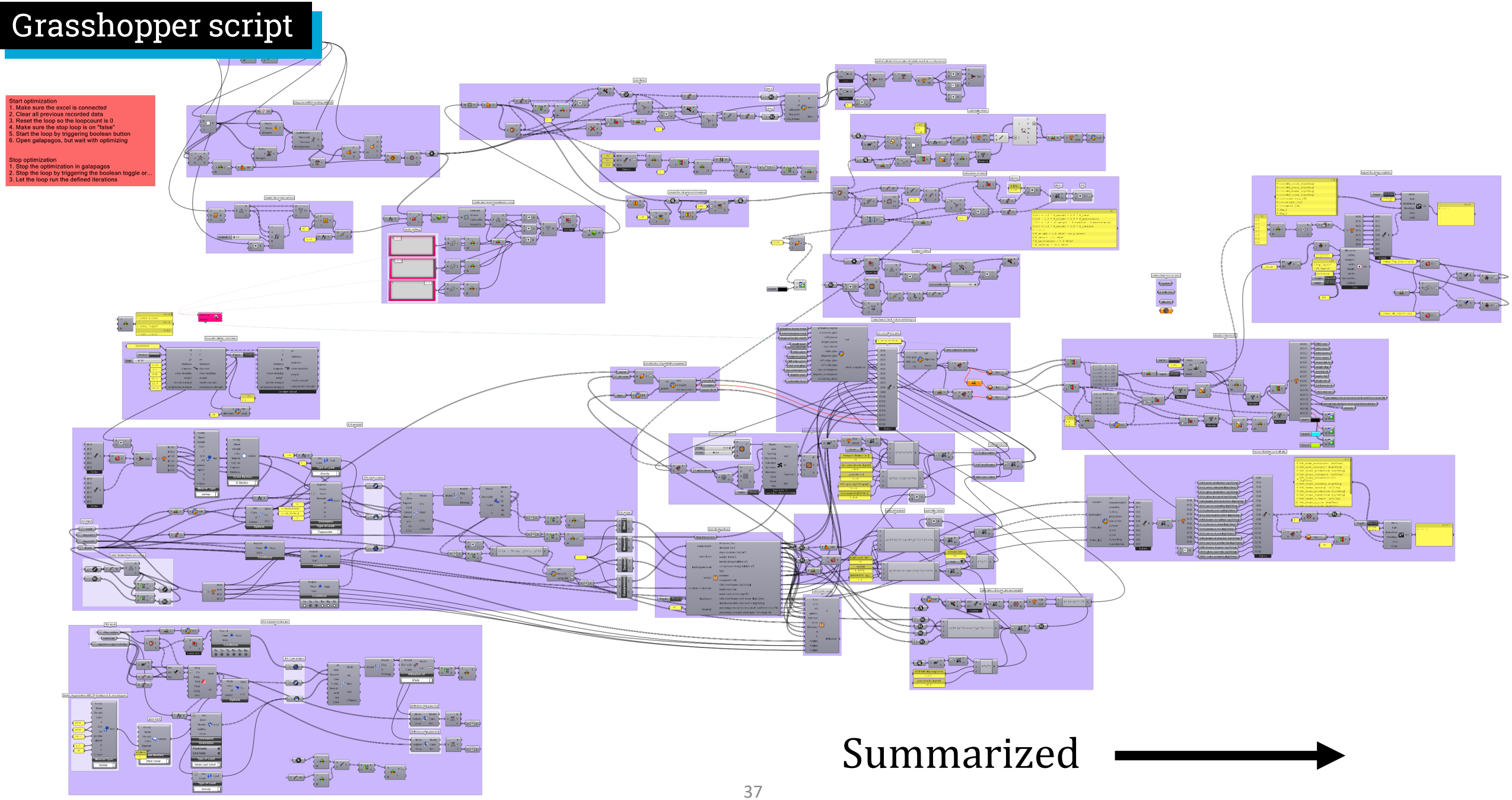

Climate crises, the need to reduce emissions
Efficient structural topologies and material reuse
Reusing steel in gridshell structures
Complexity of different scenarios at different locations
Current tools can't adapt to different scenarios and can't be applied to gridshell topologies
?

Computational tool

Used software/plugins

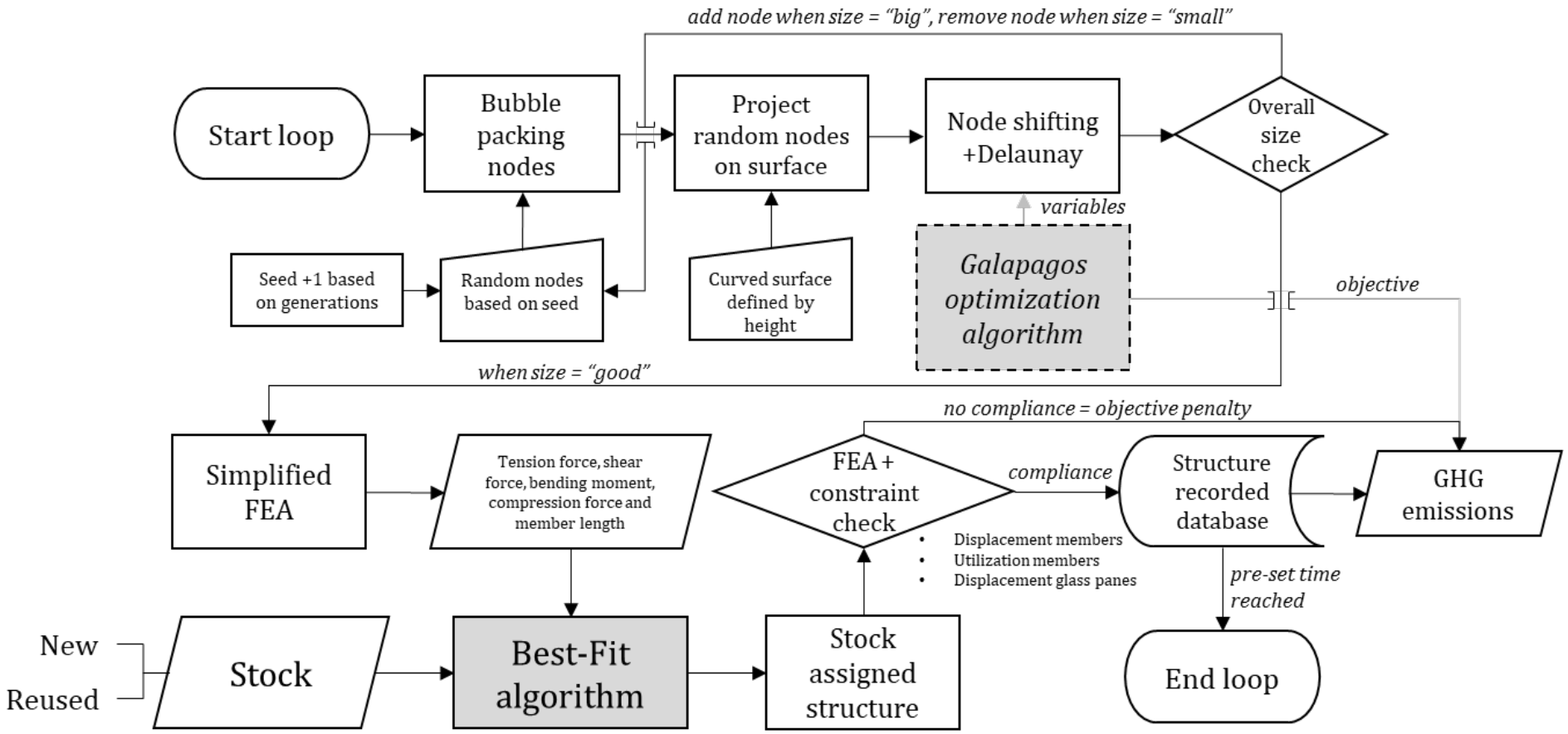


Grasshopper script



Summarized

Tool overview



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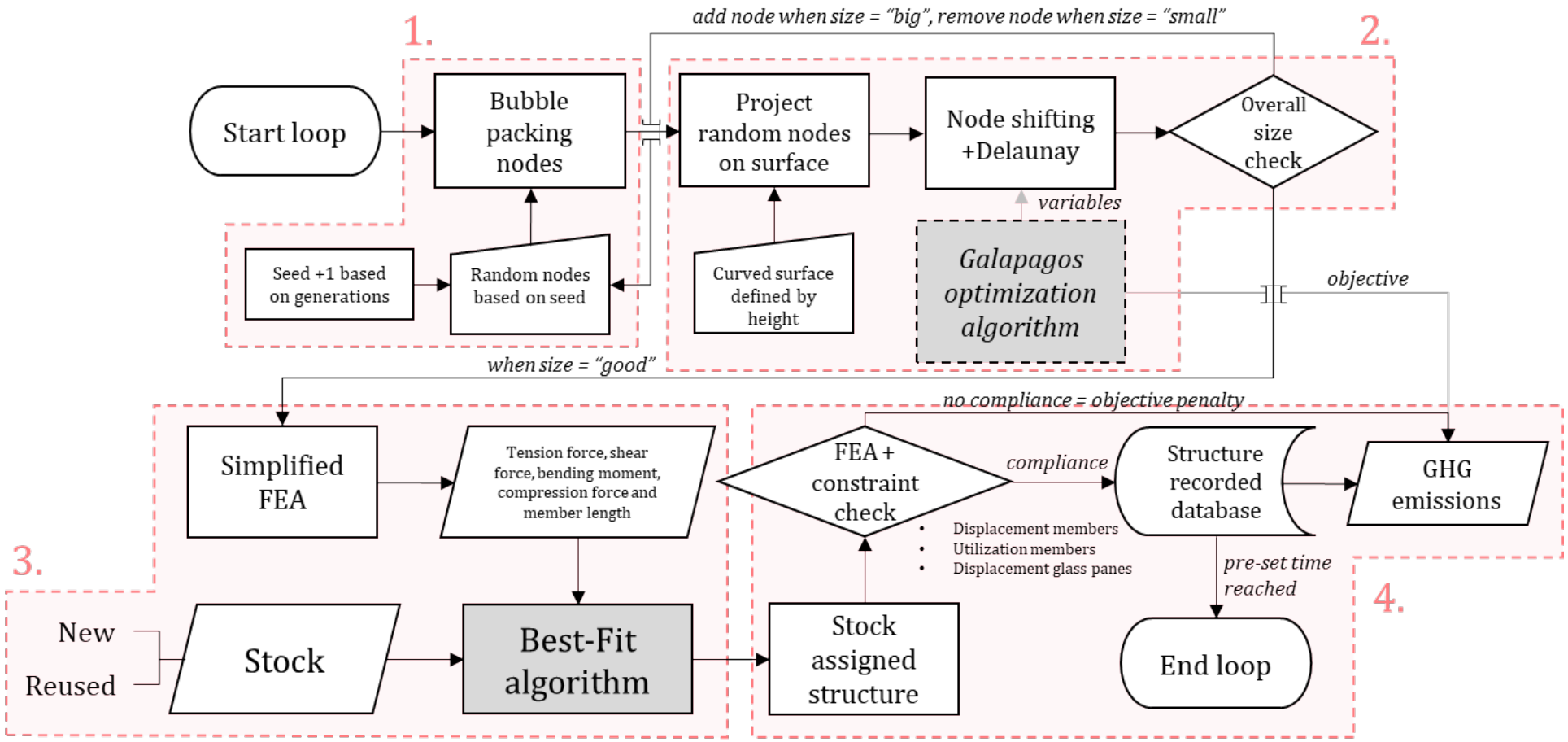

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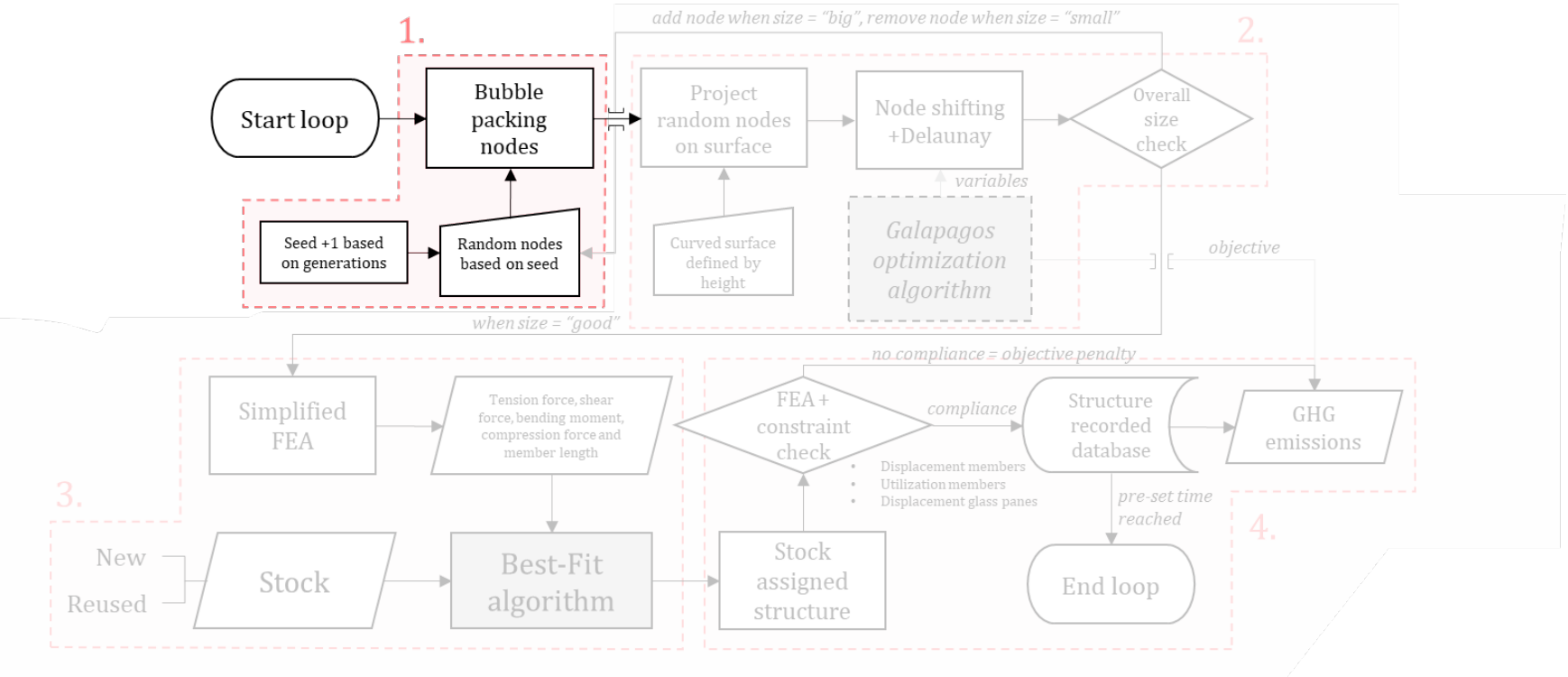

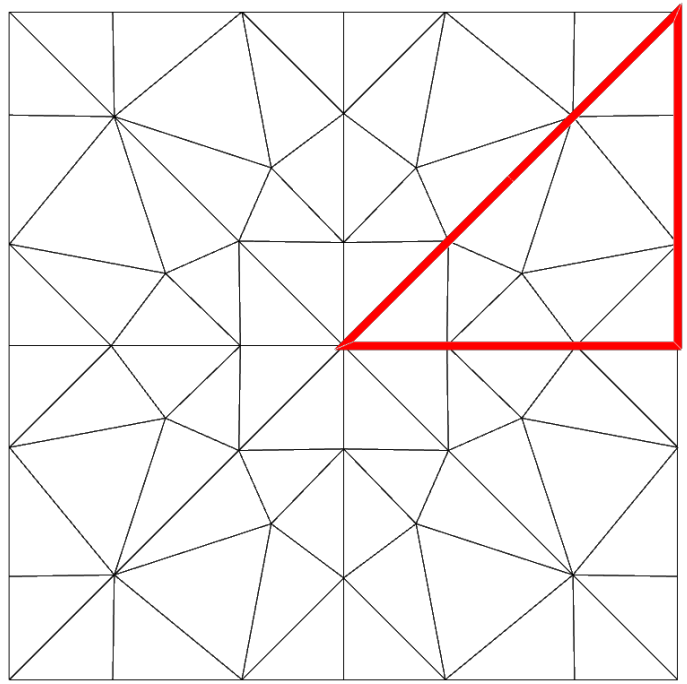

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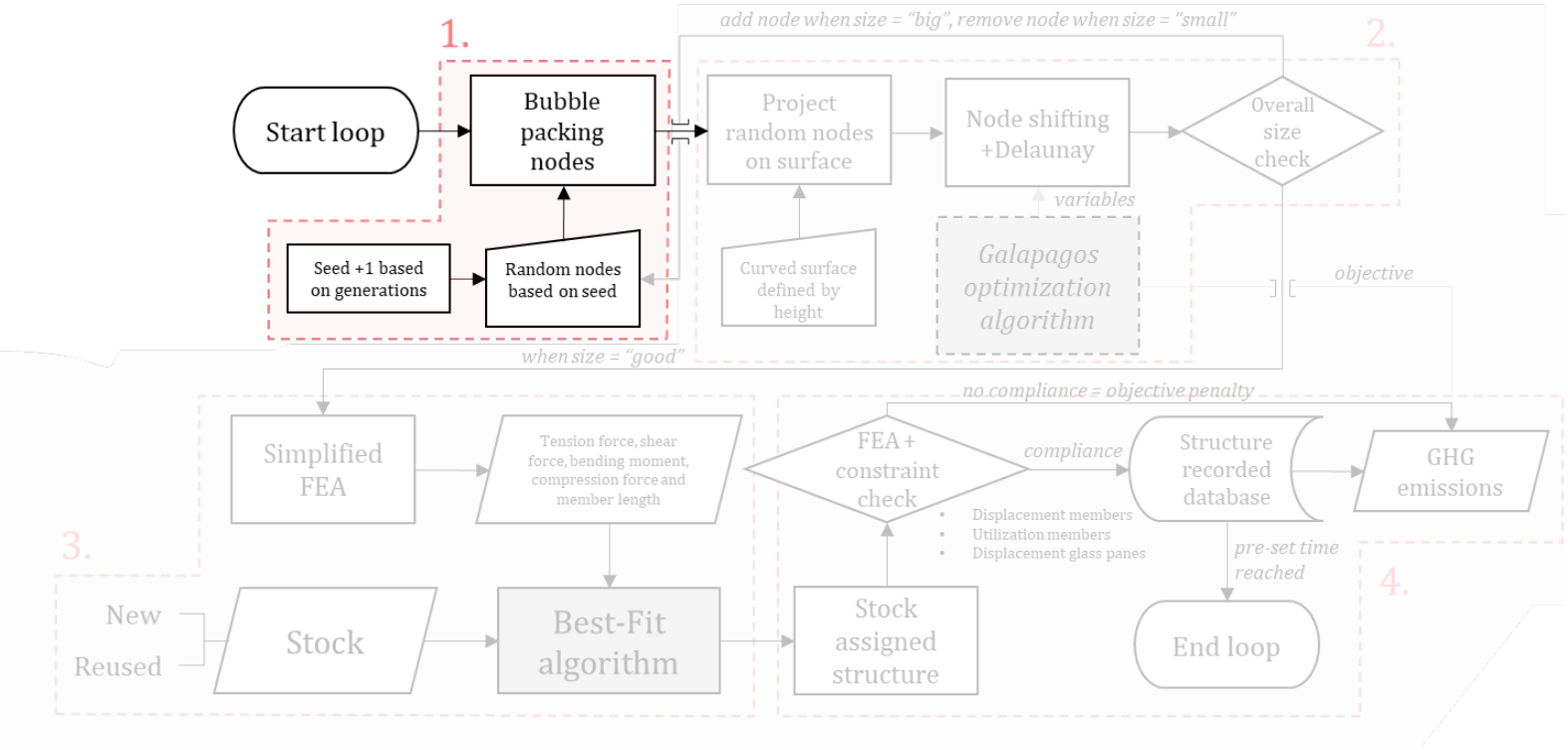
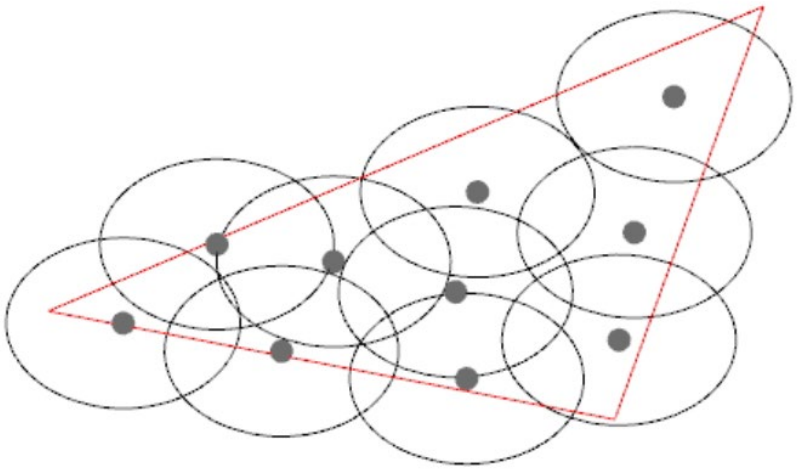
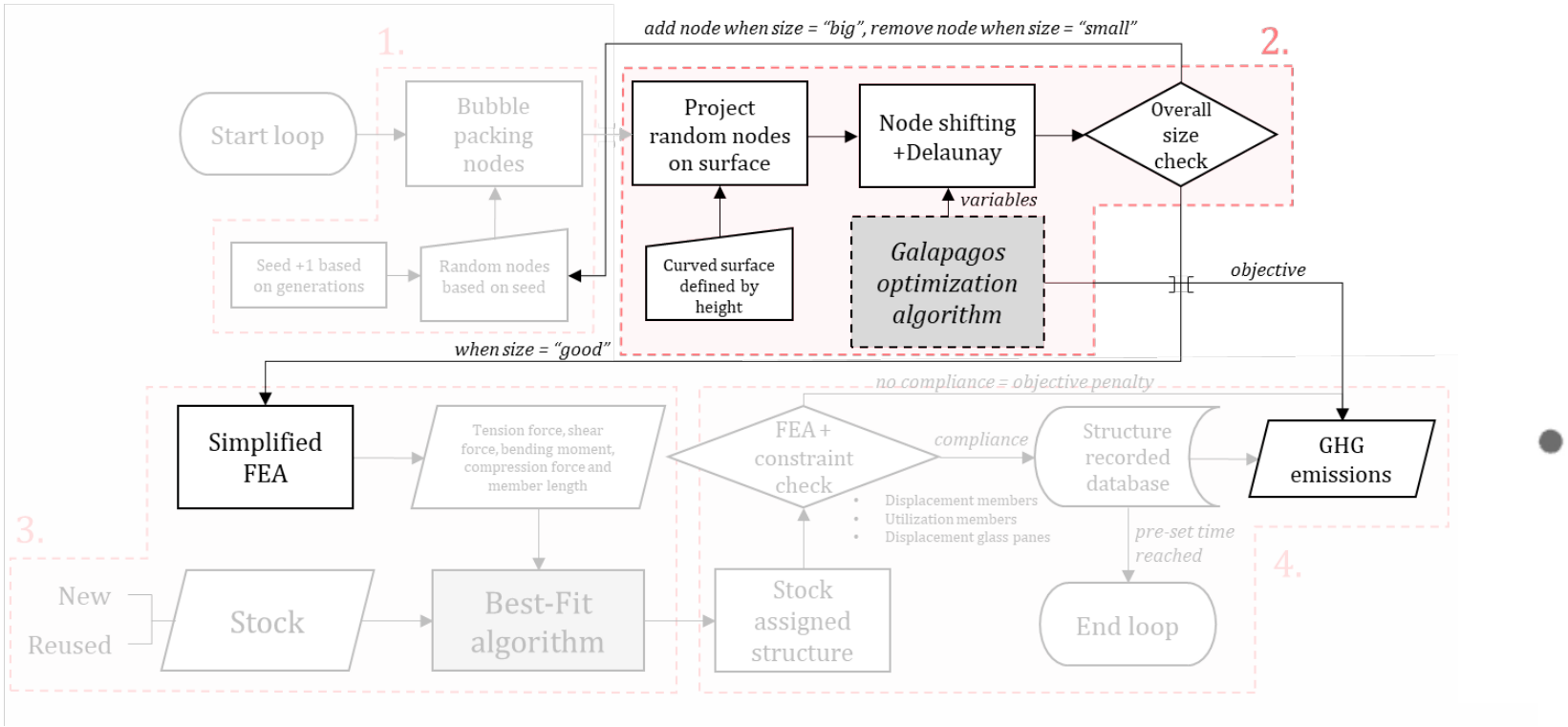




Tool overview



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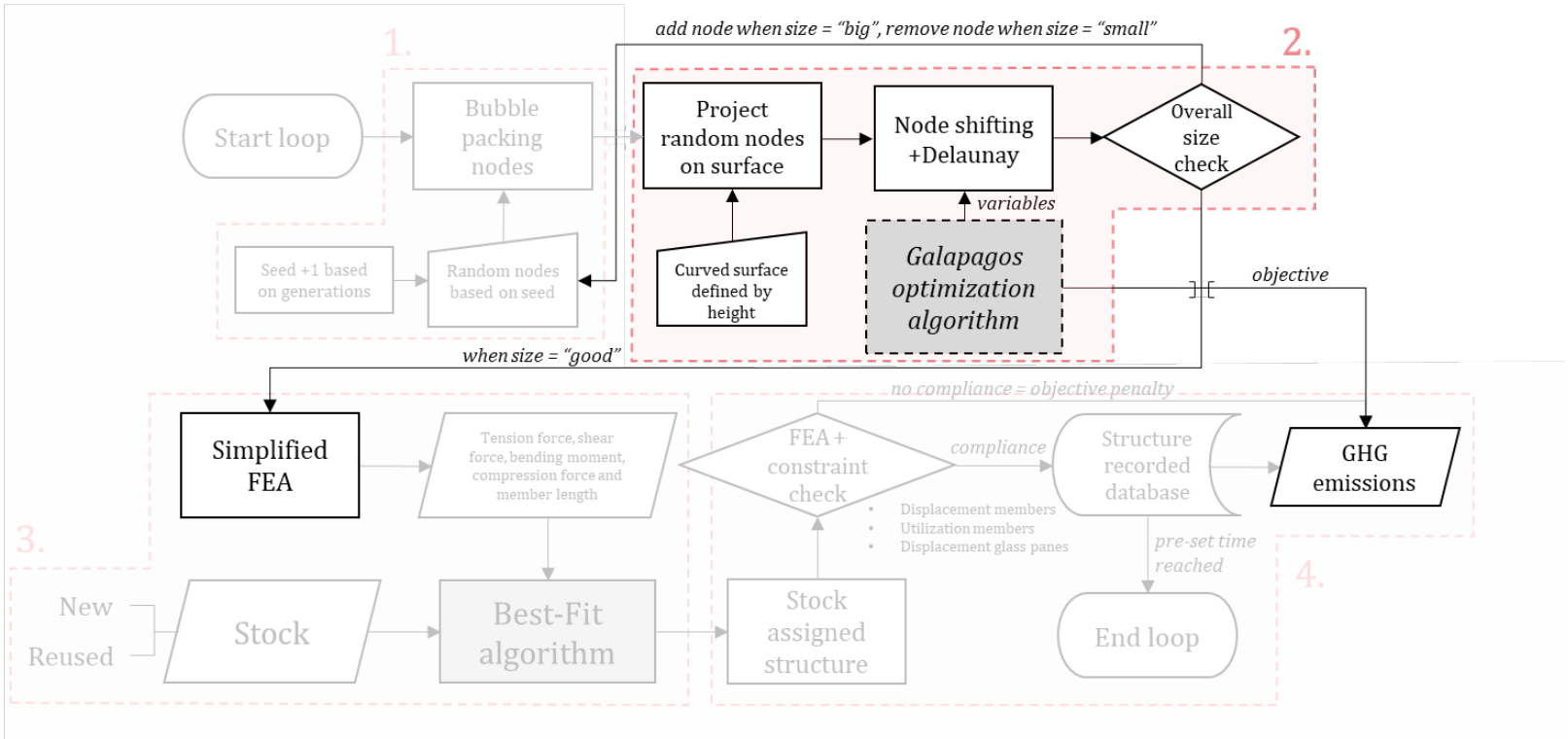

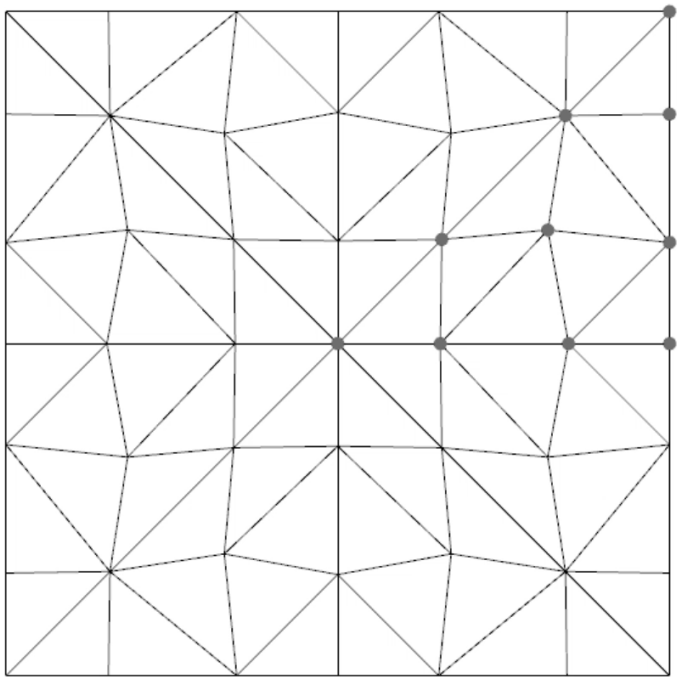

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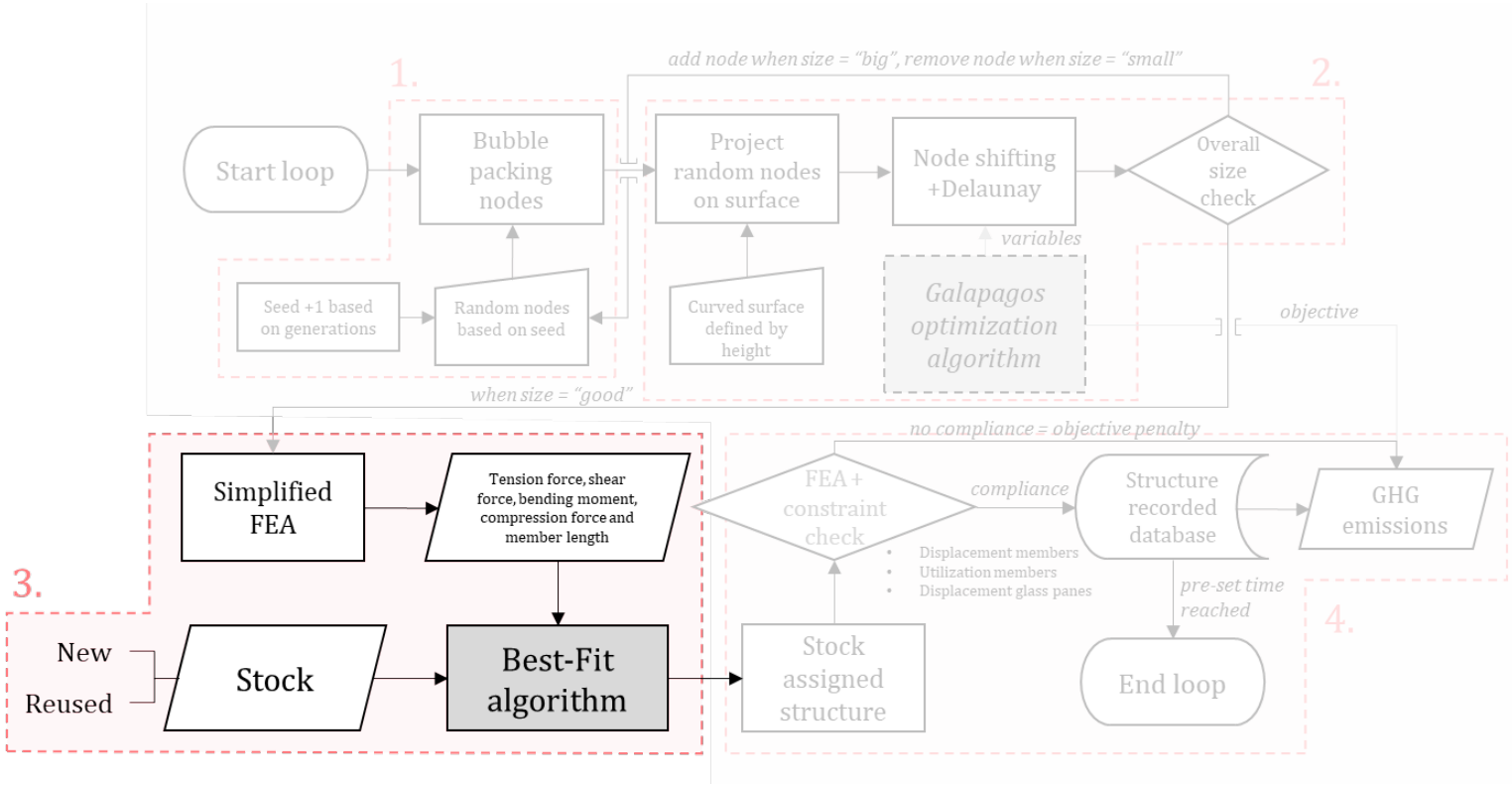

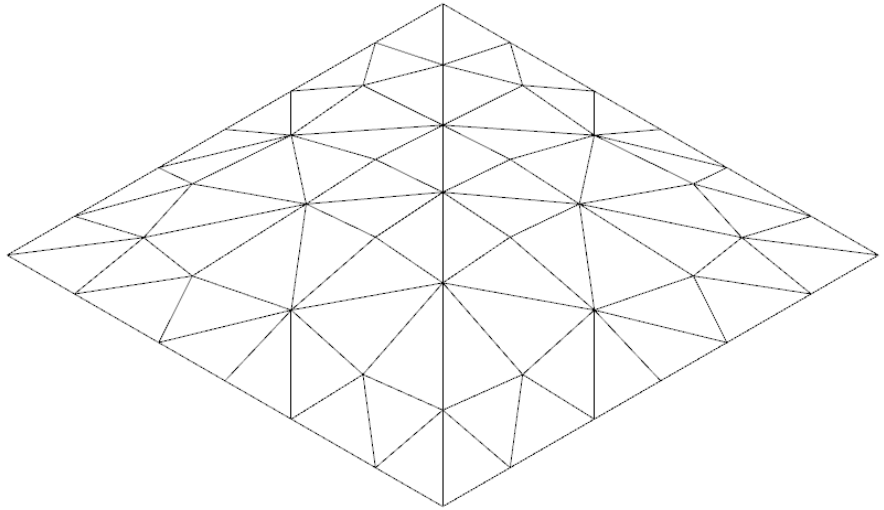

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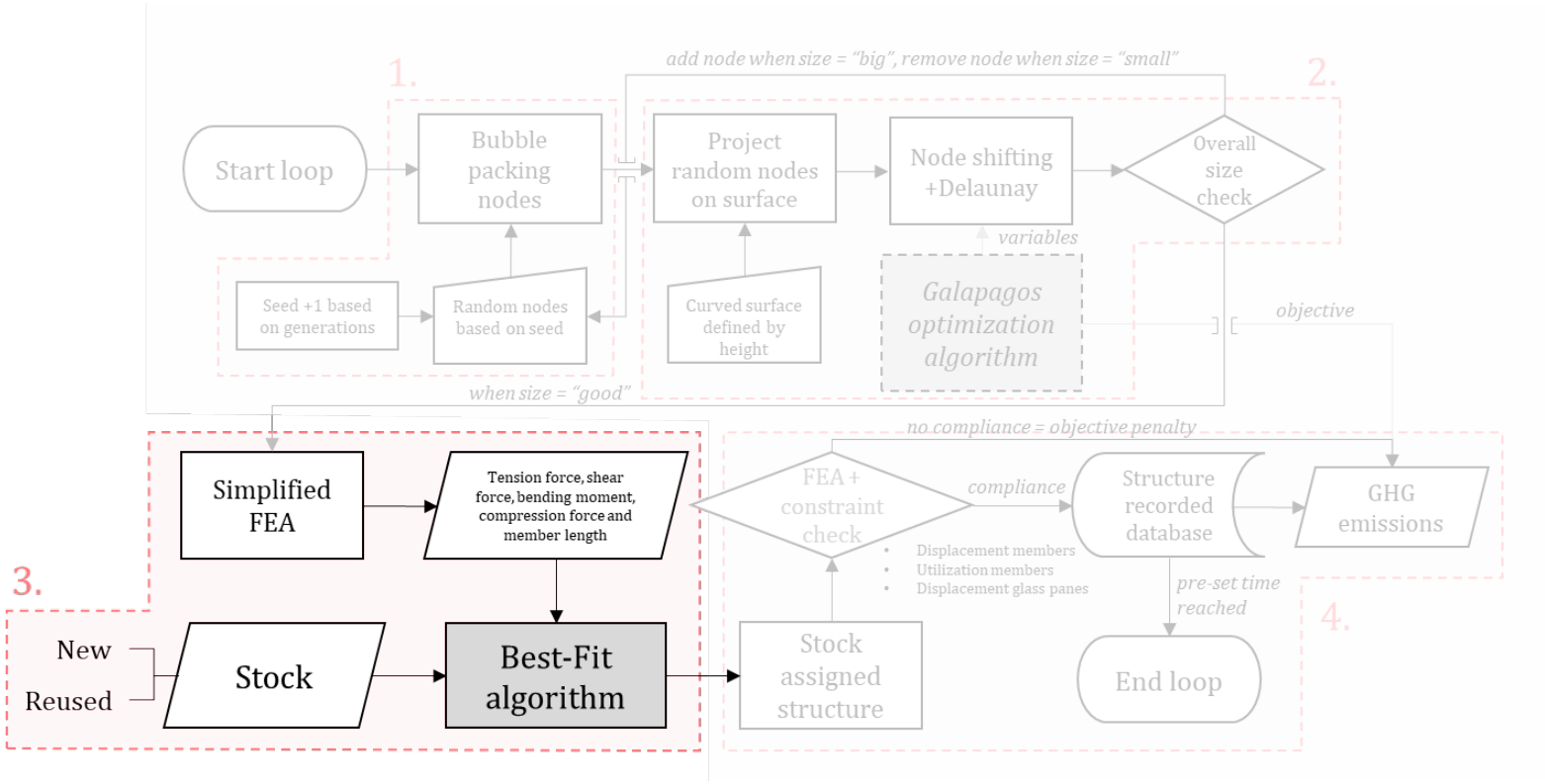

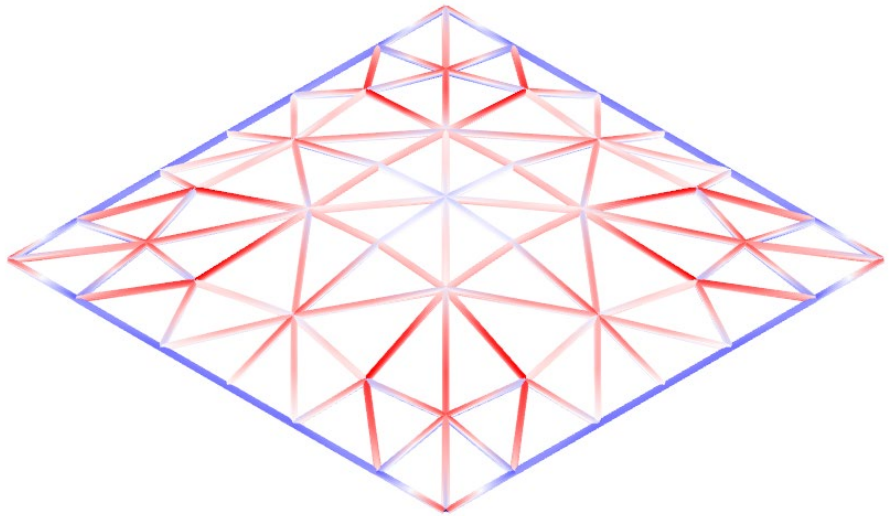

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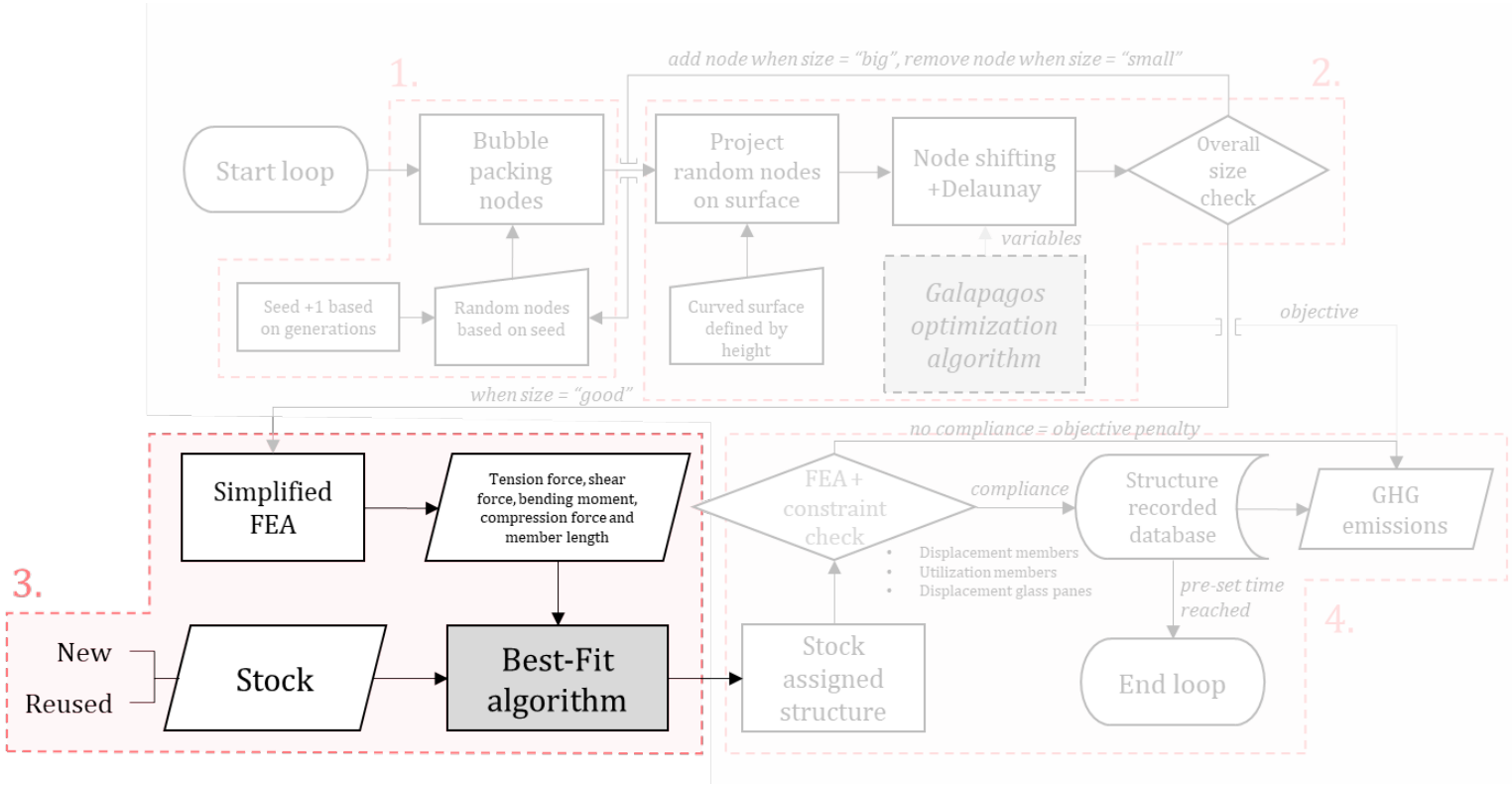

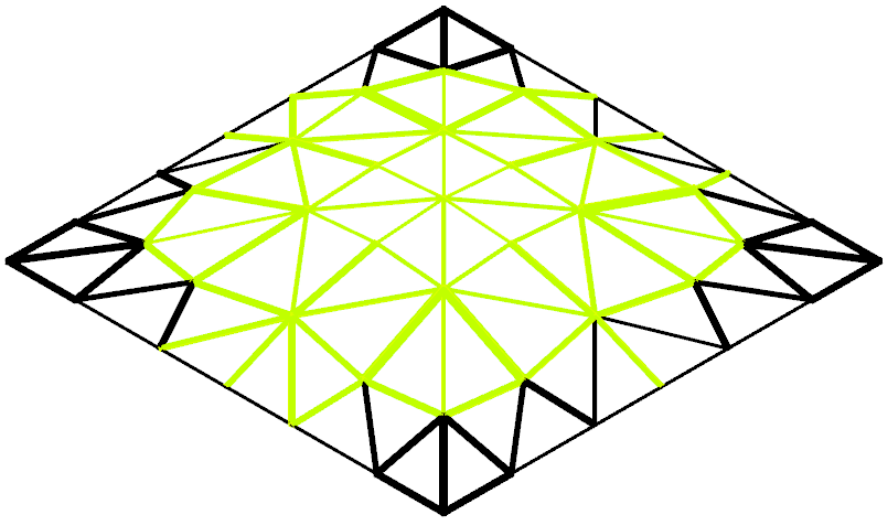

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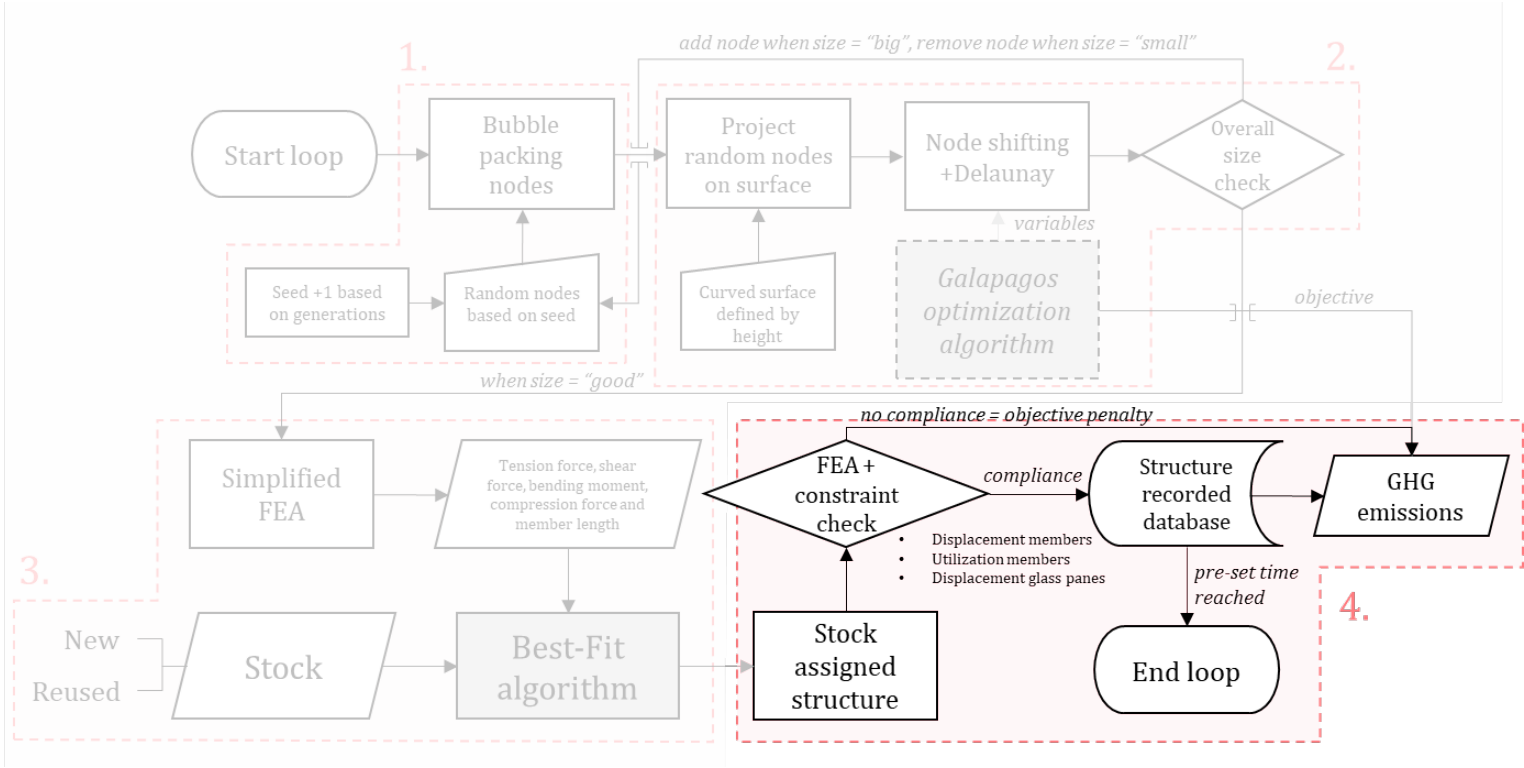

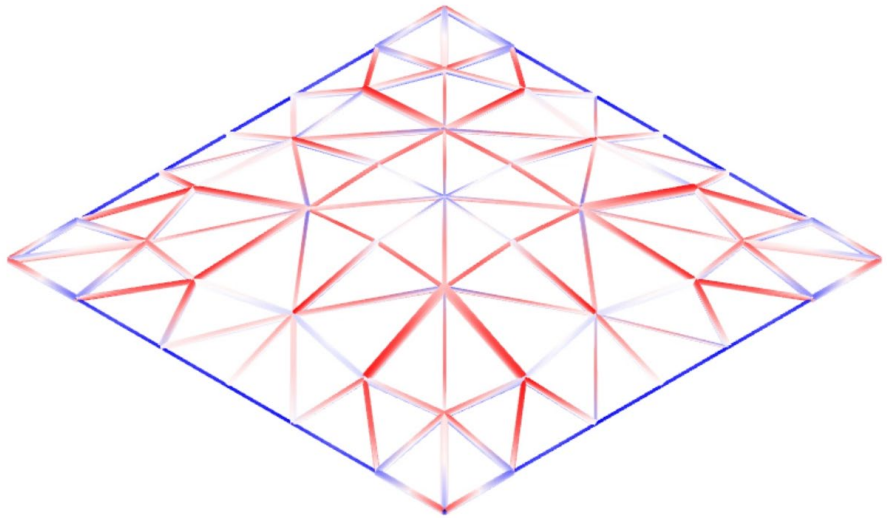

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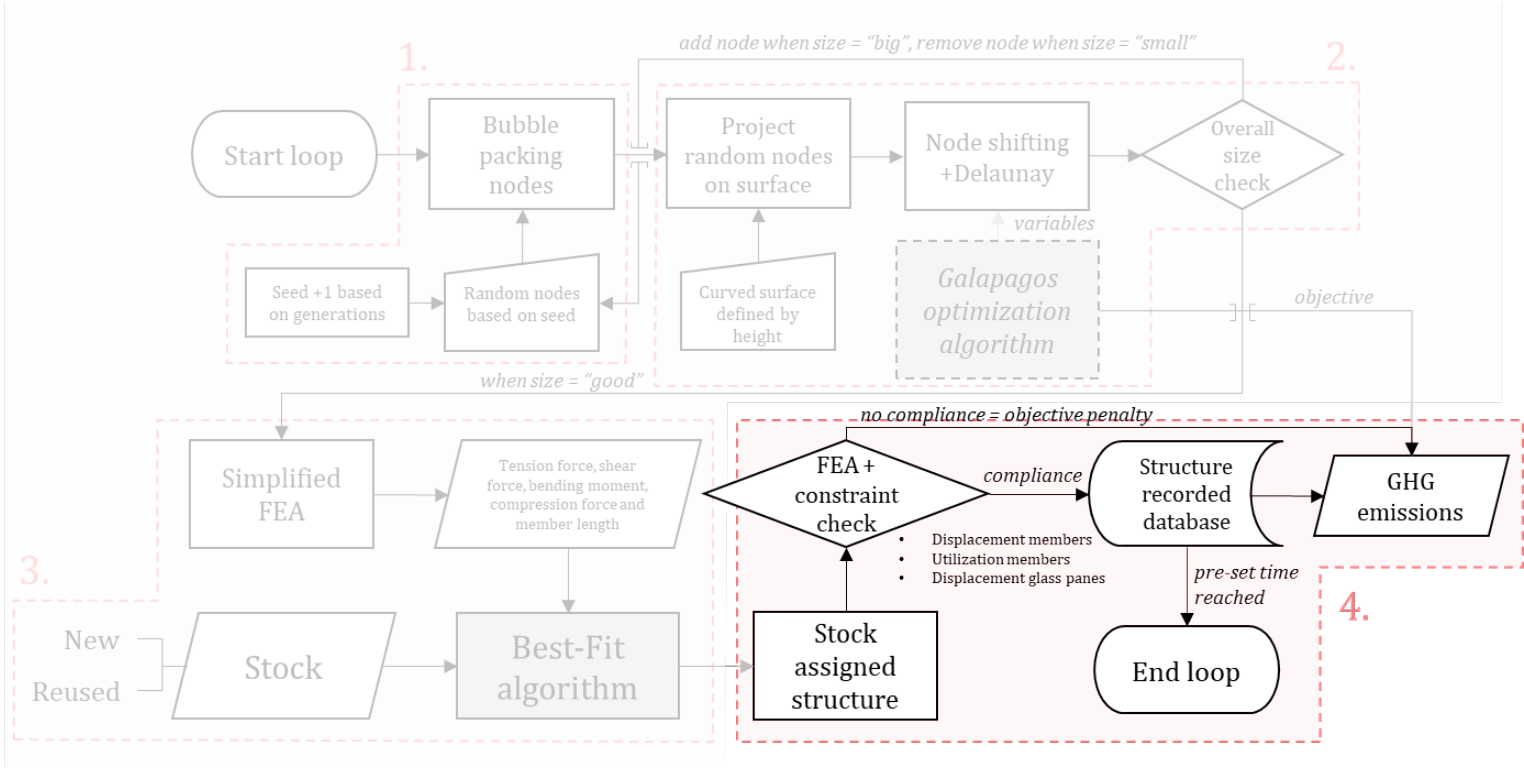

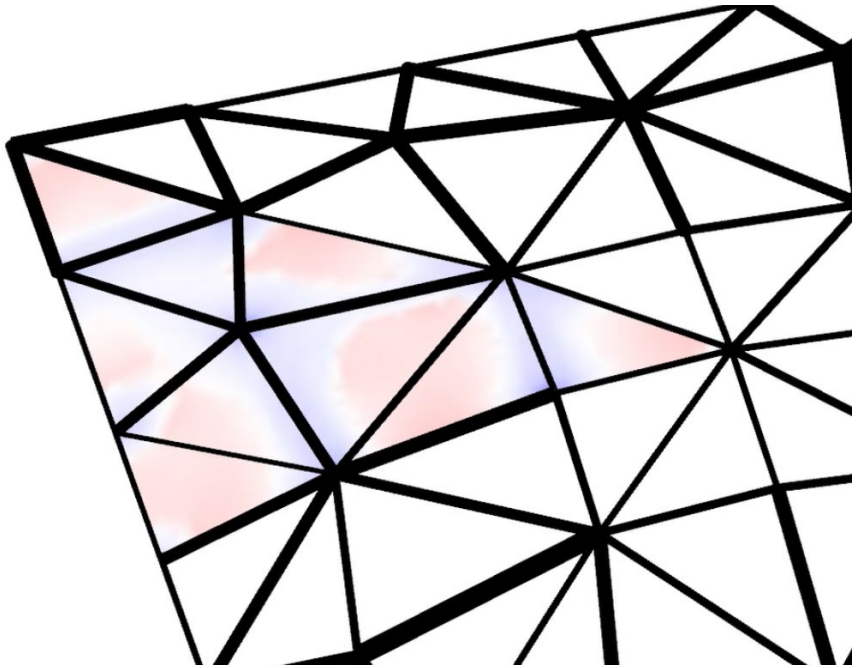

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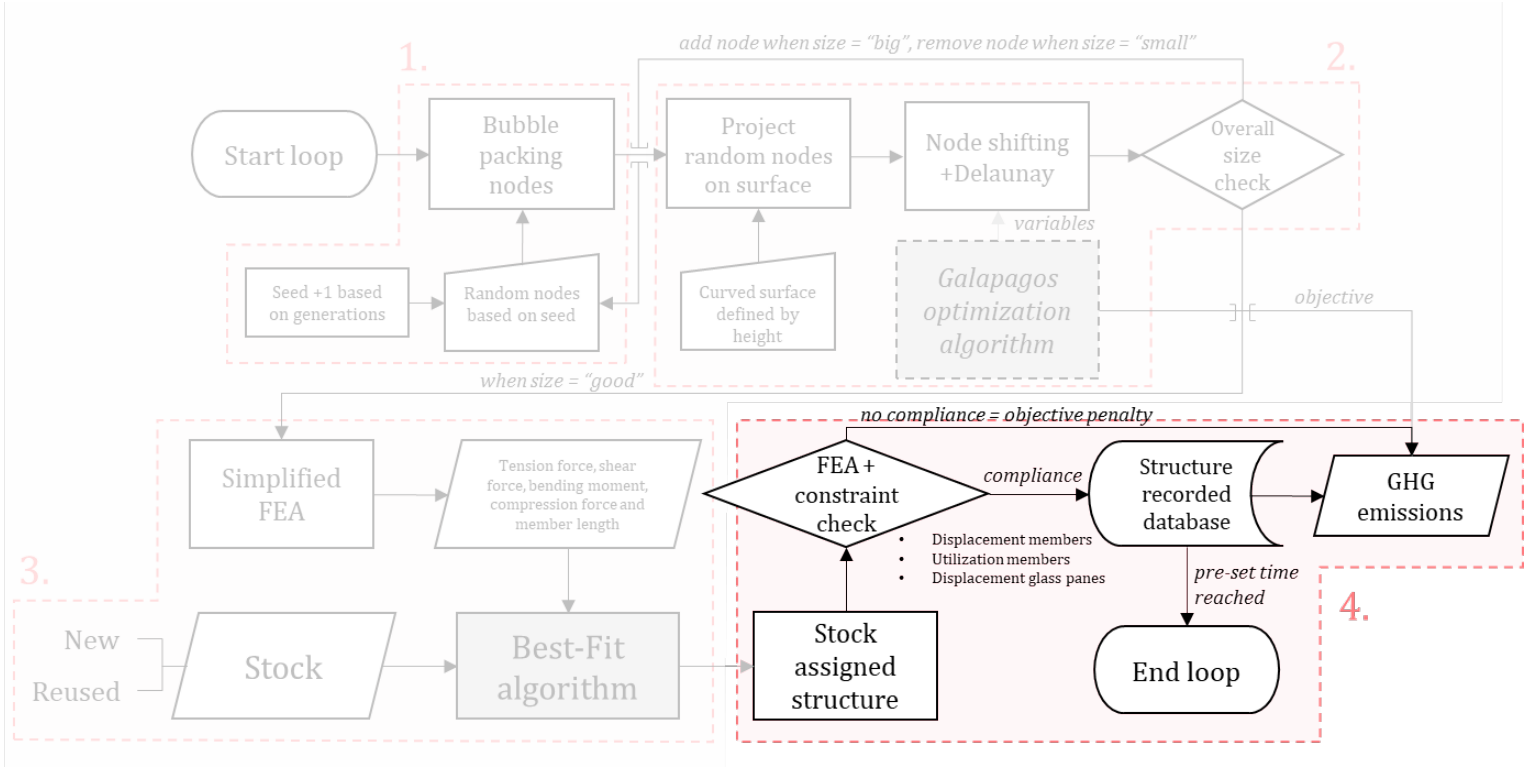
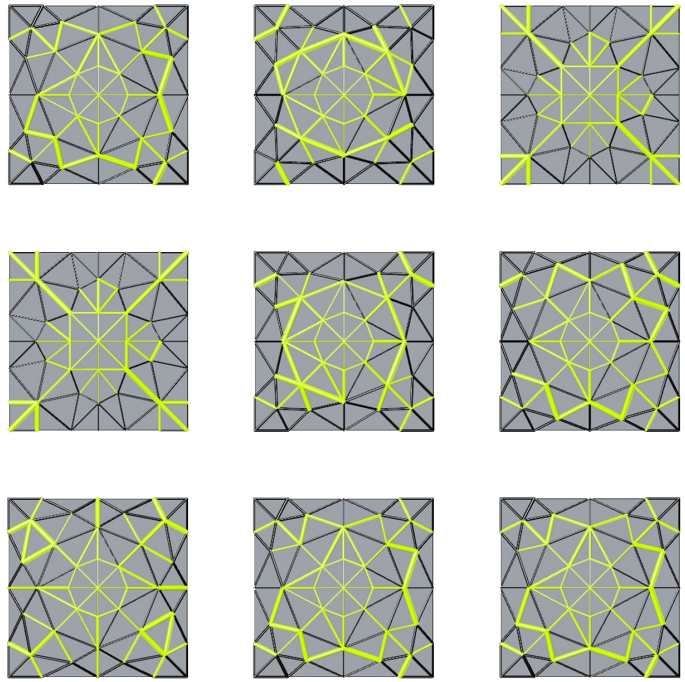
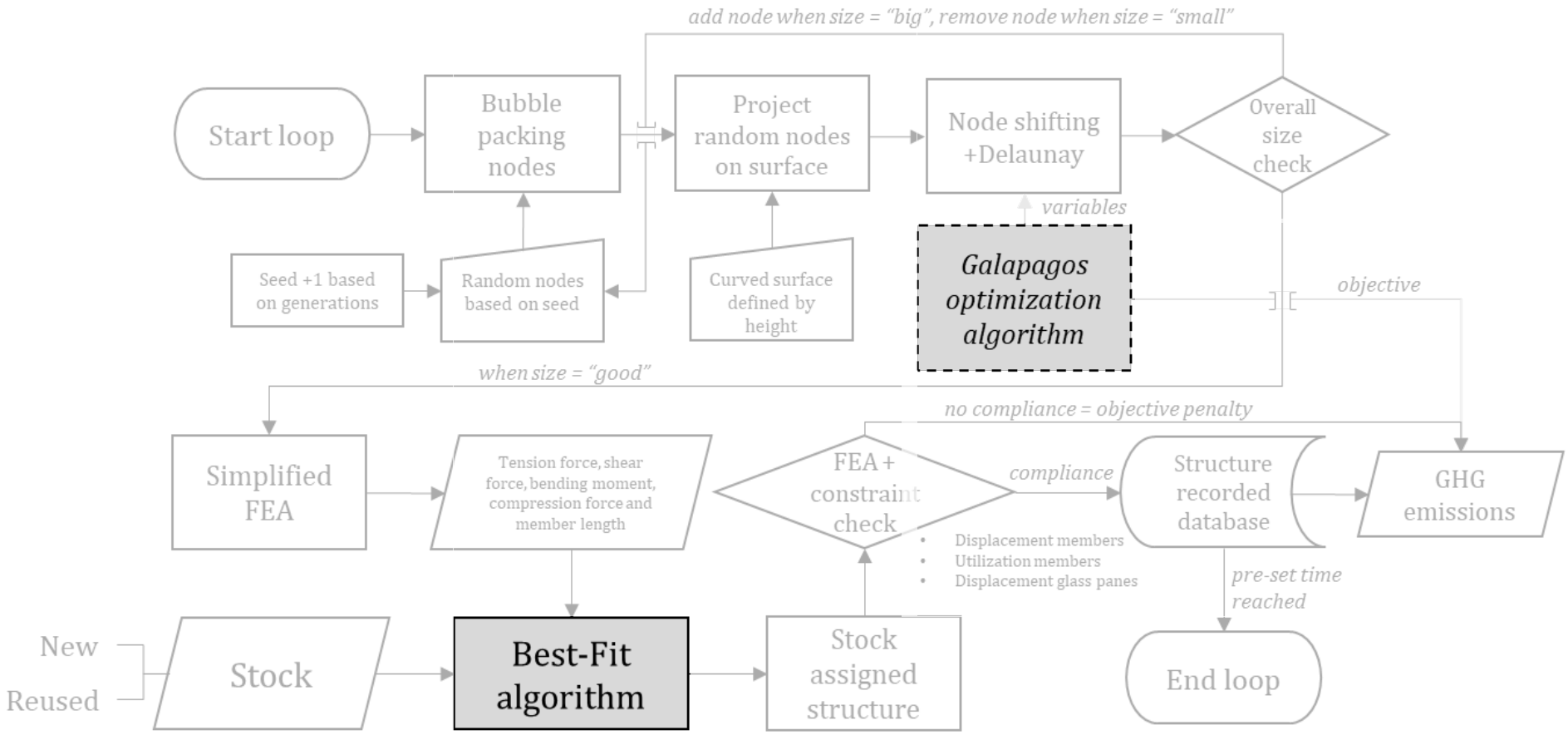




Used algorithms



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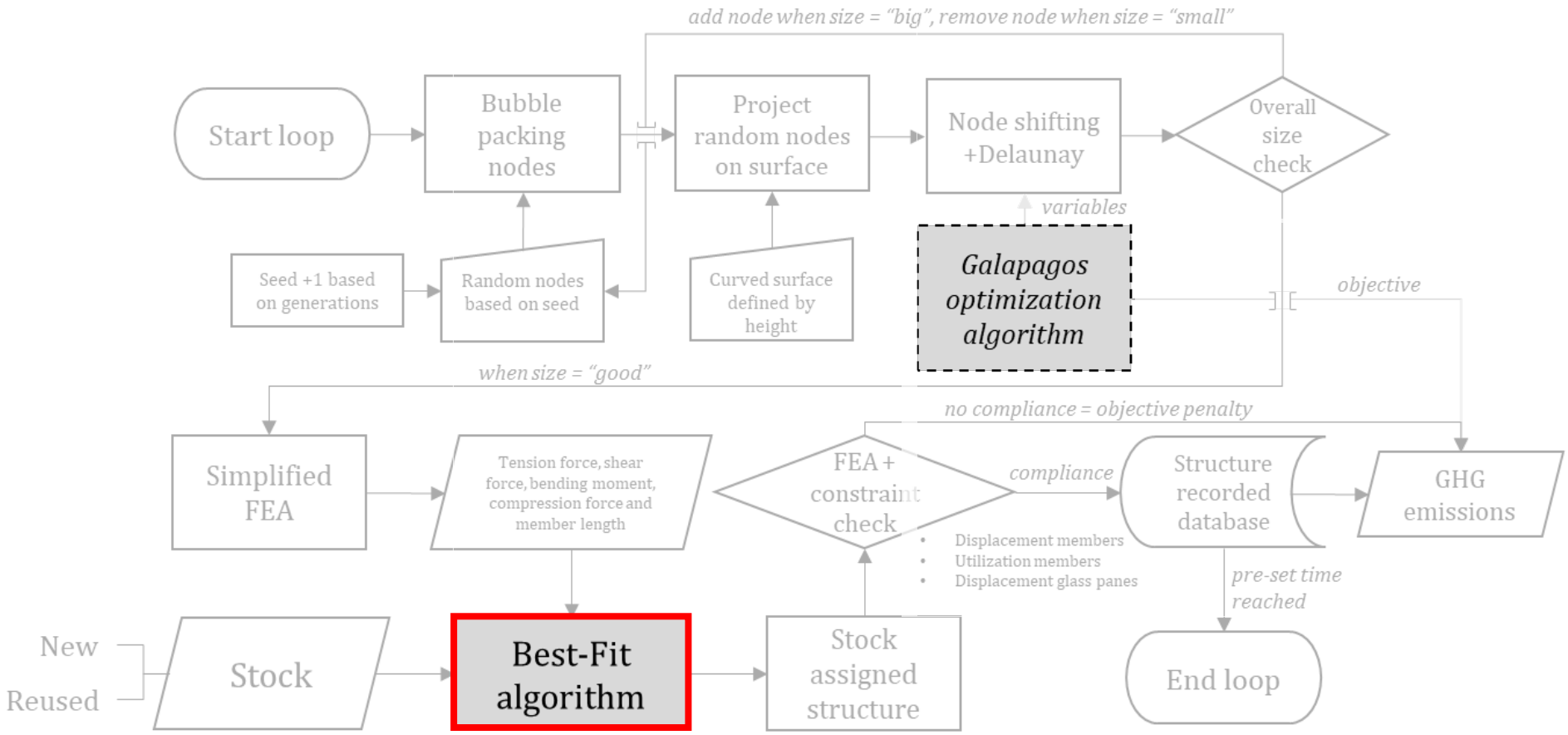
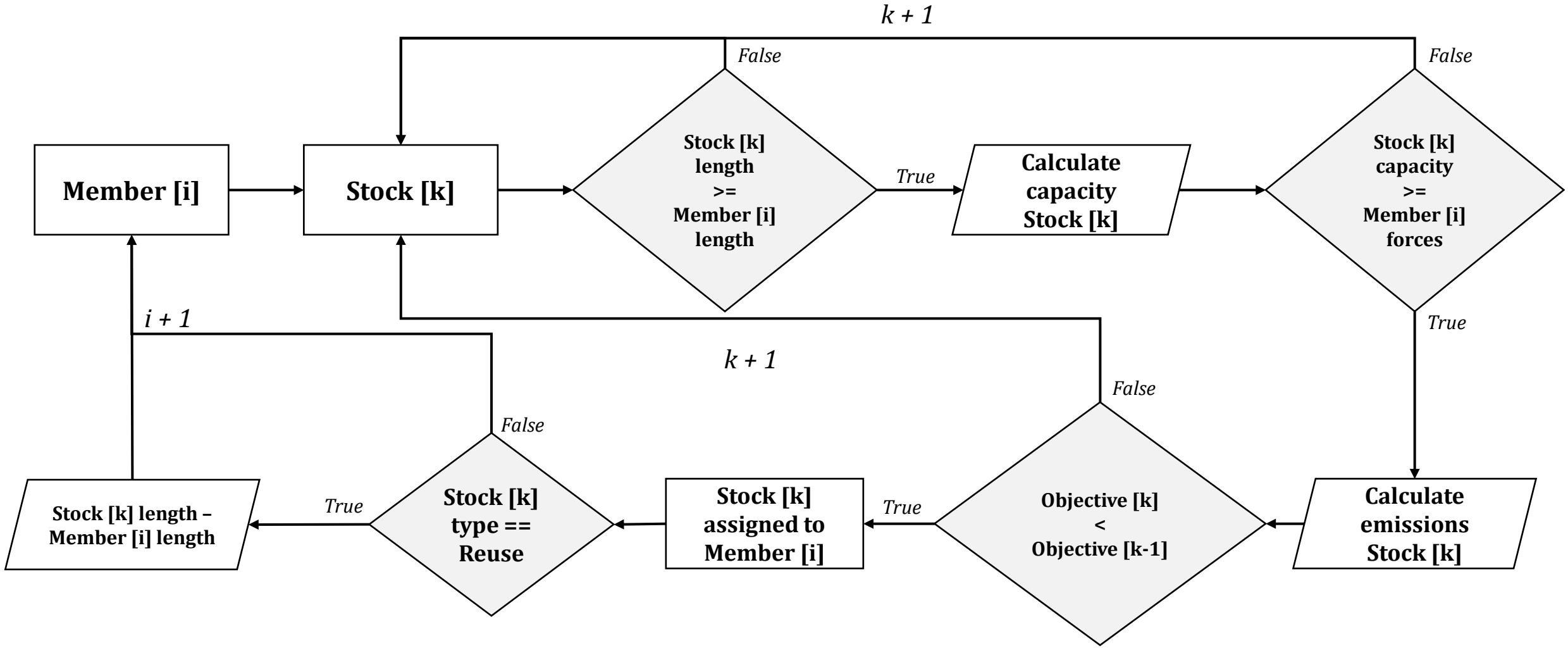


Self-developed Best-Fit

Coded in Python integrated in Grasshopper



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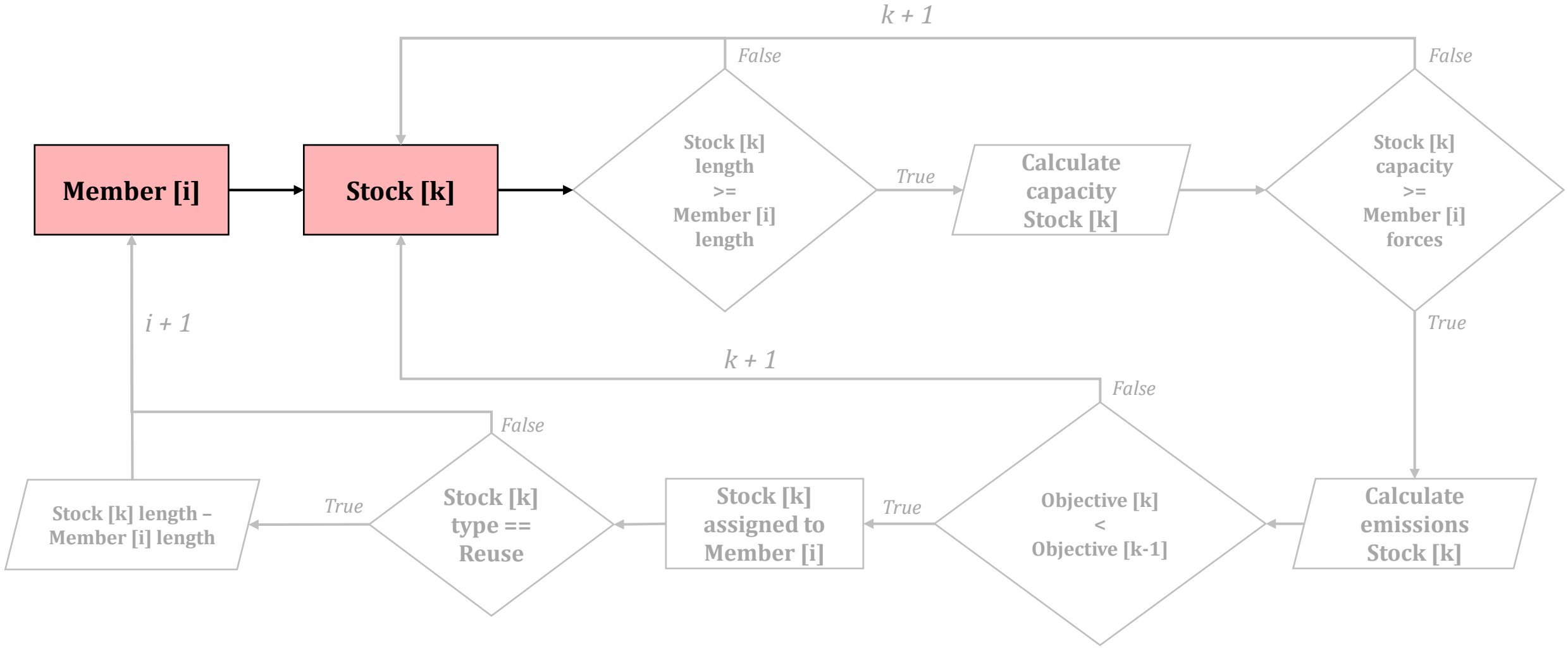

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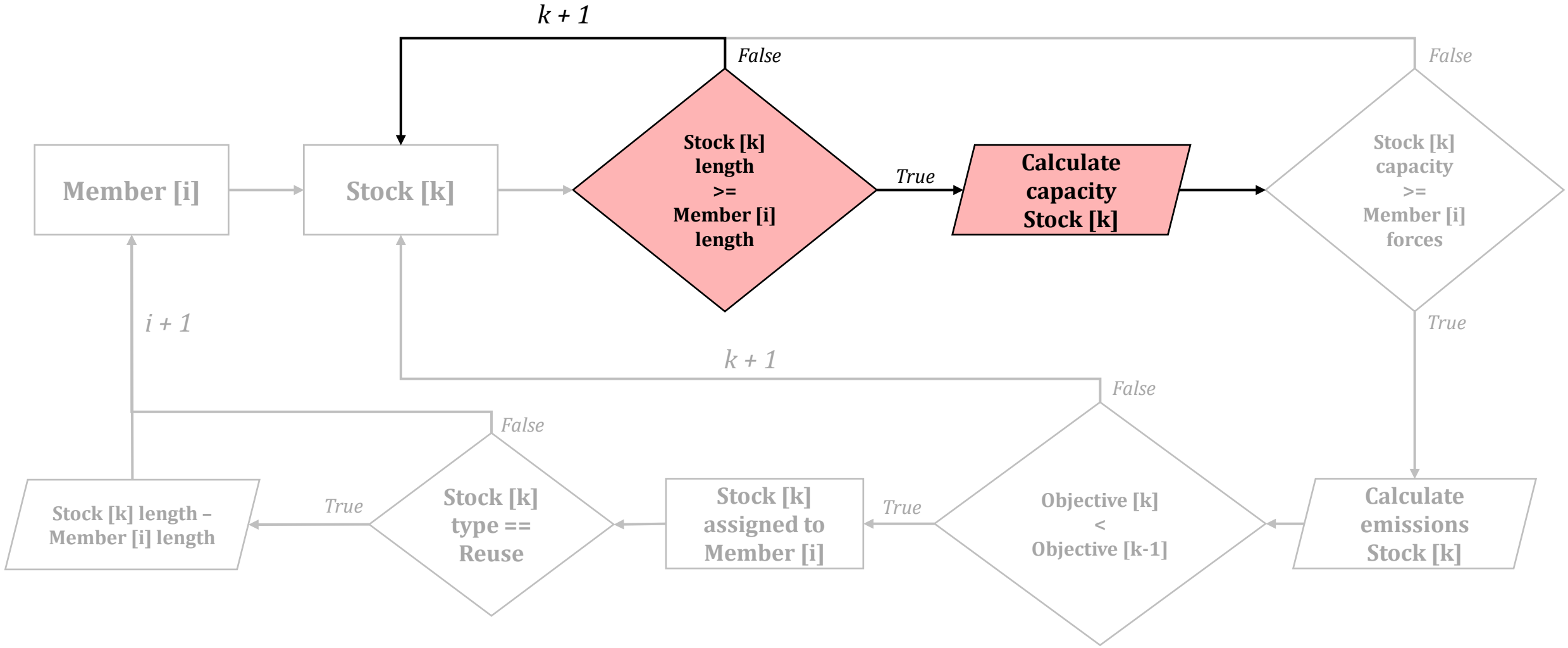

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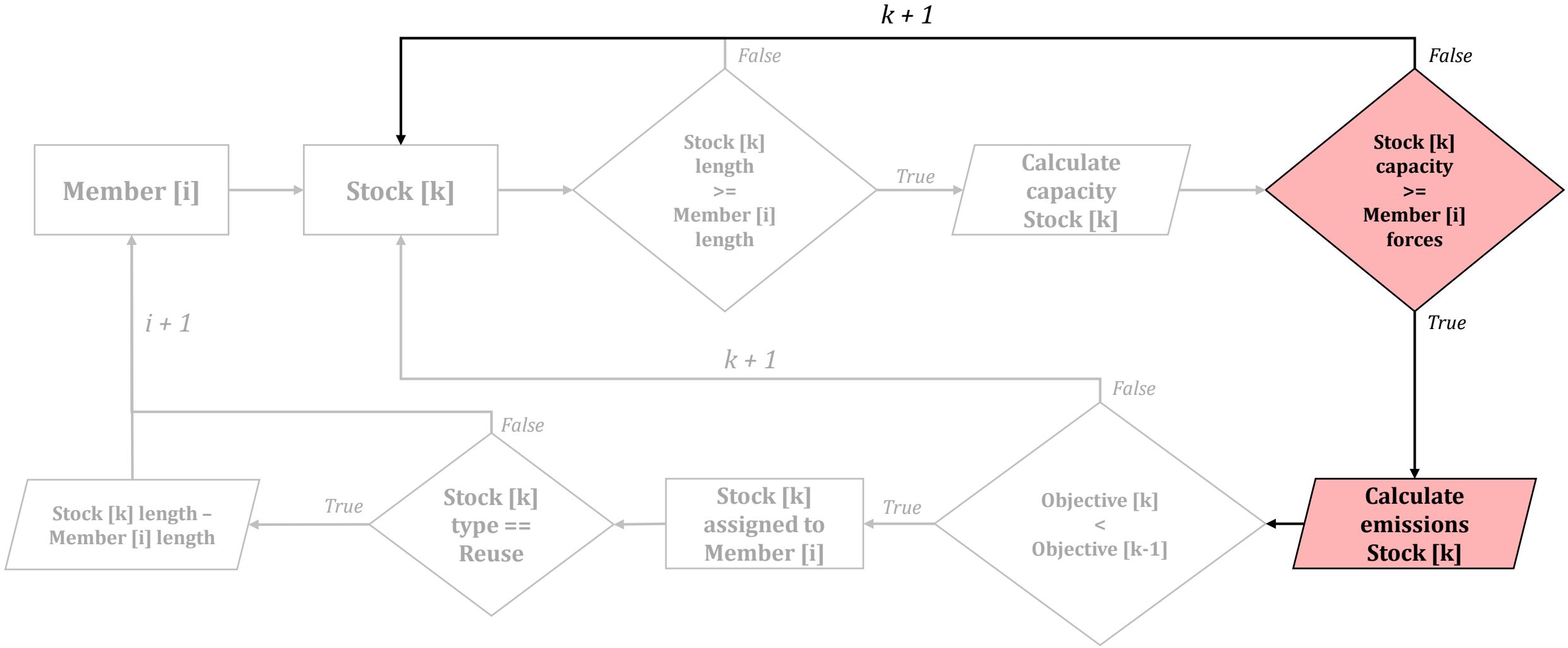

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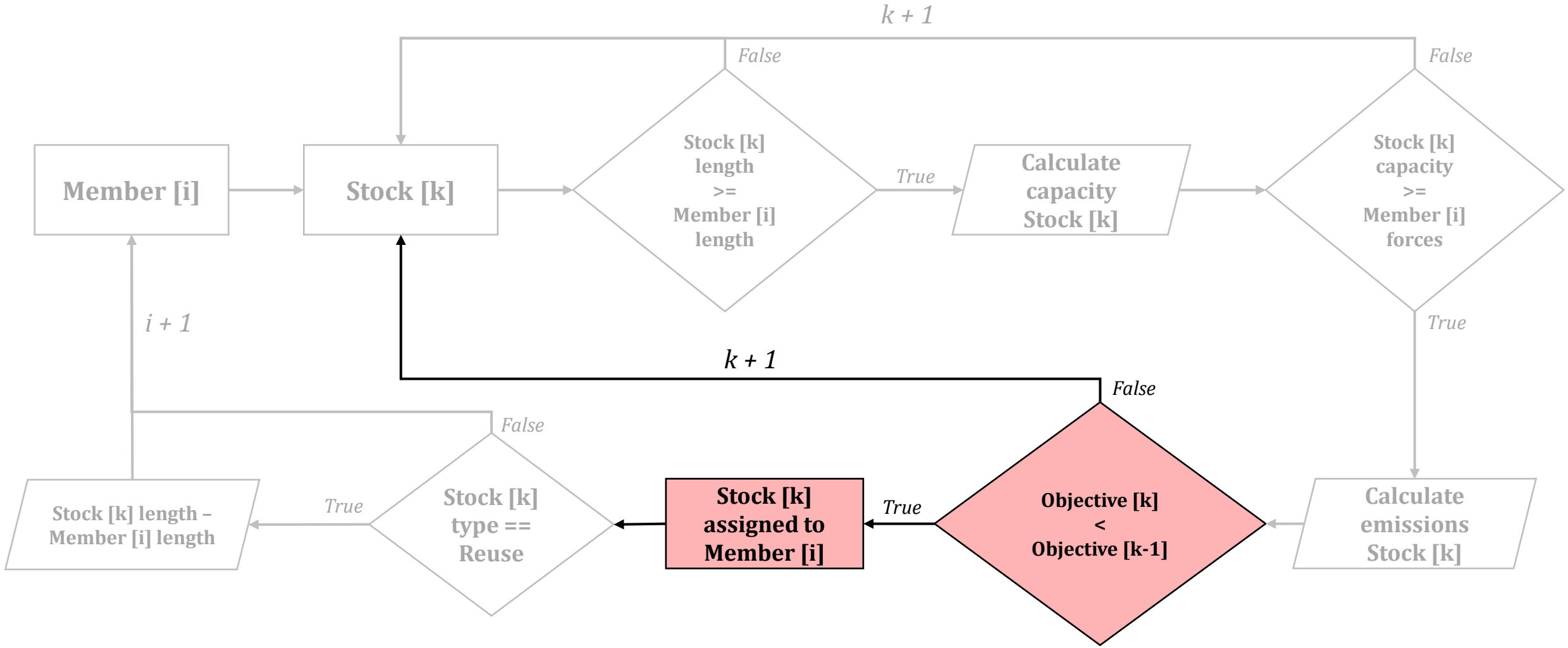

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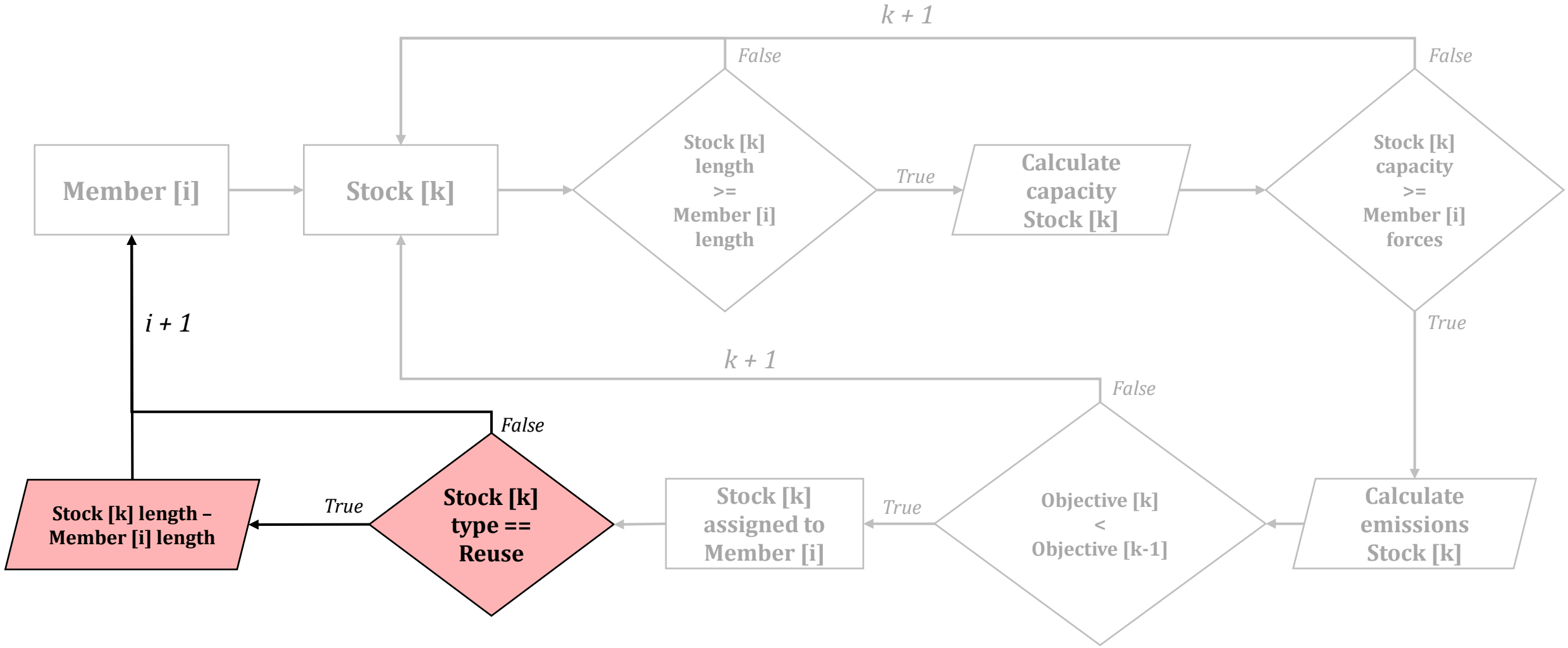
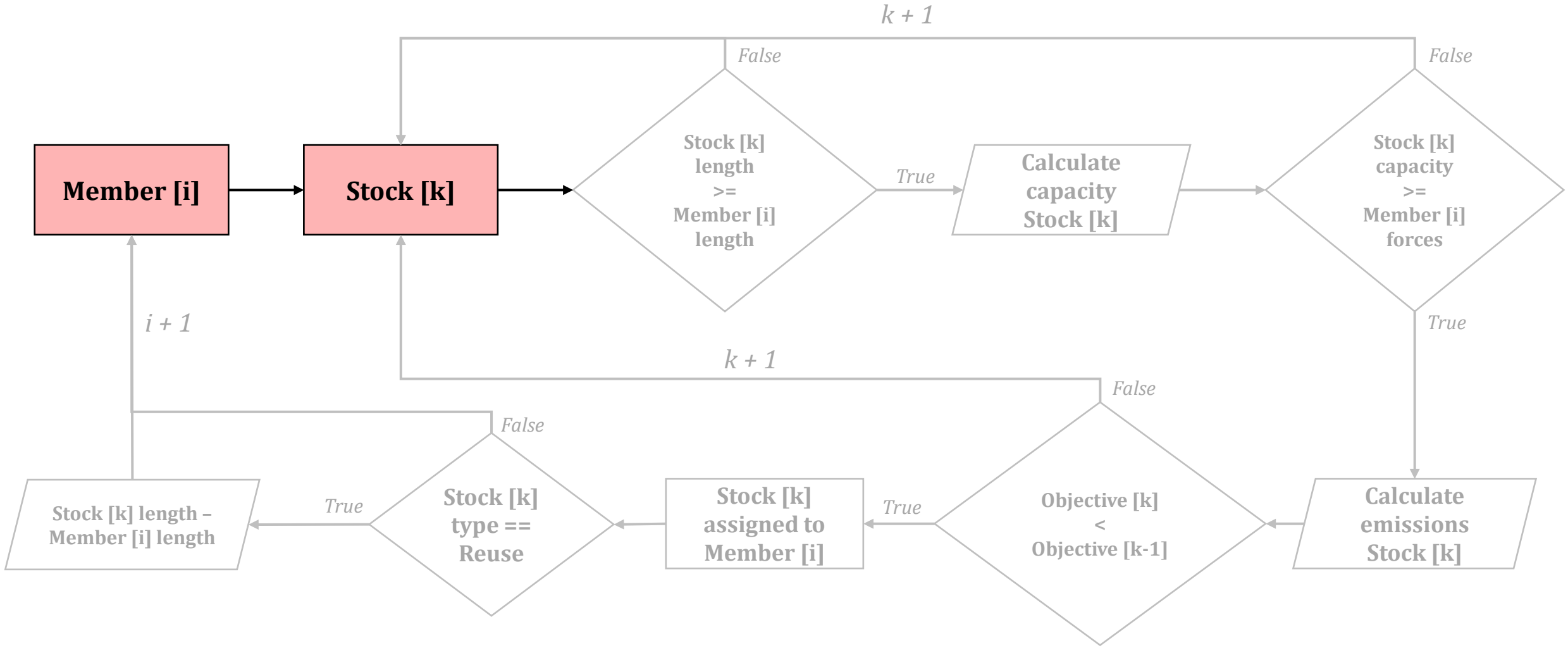
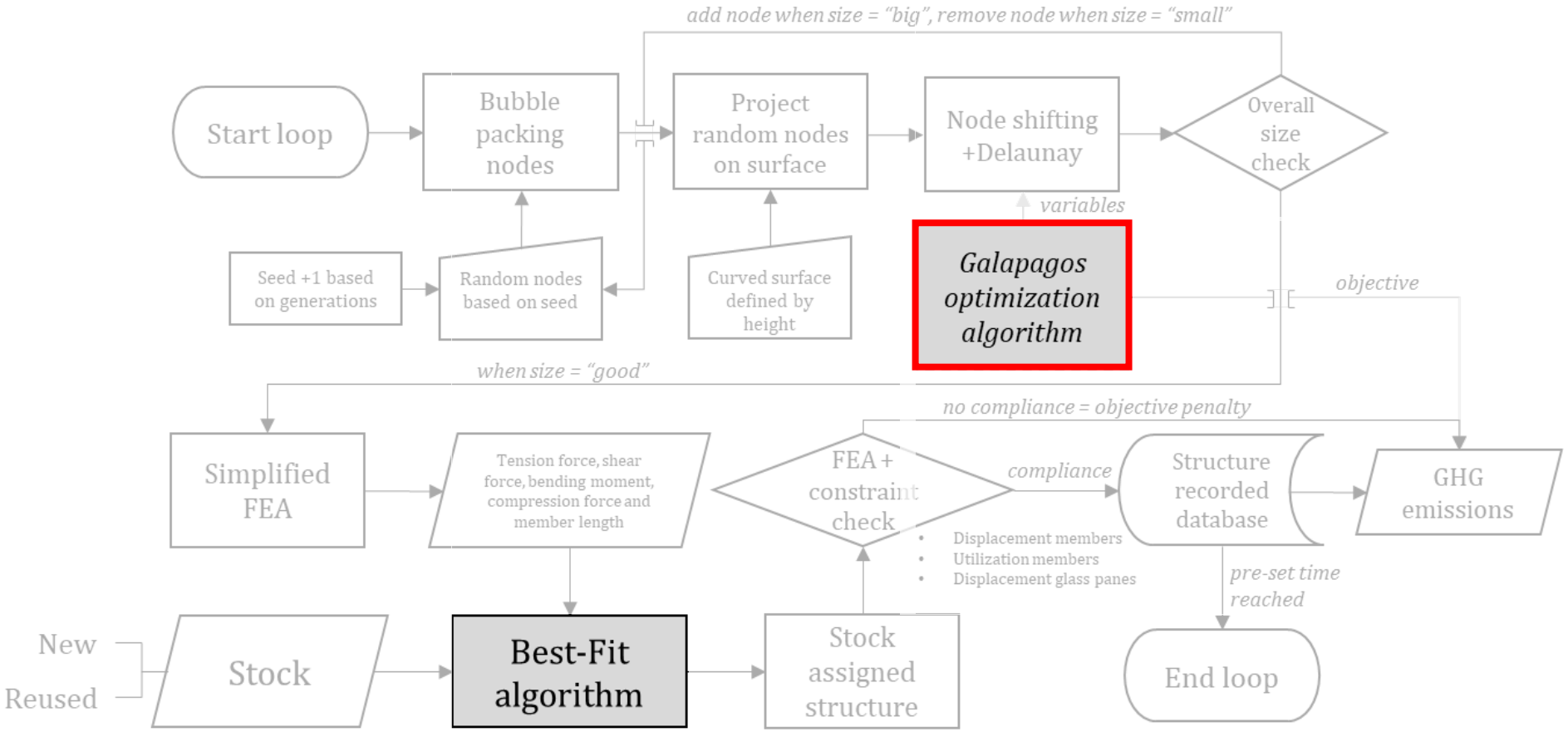


Self-developed Best-Fit

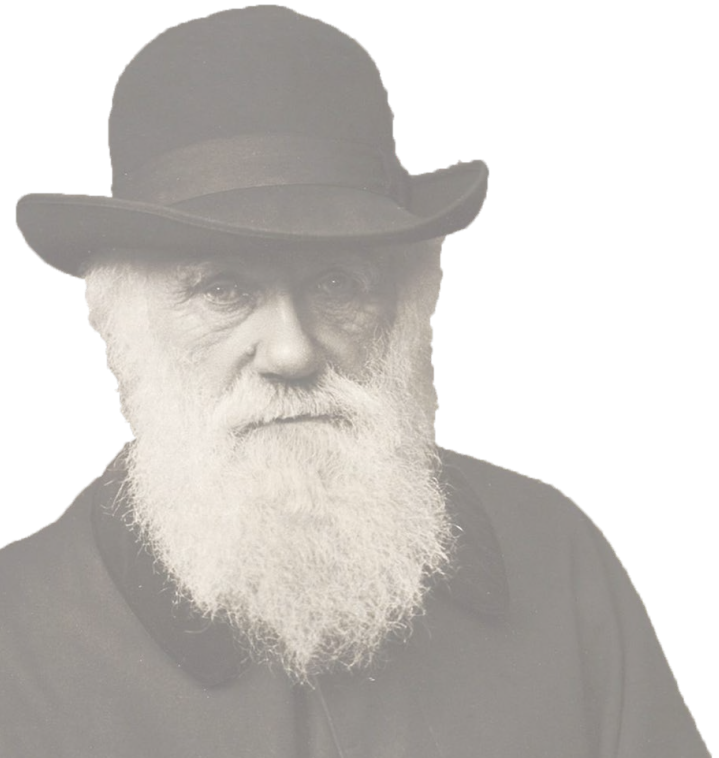
Coded in Python integrated in Grasshopper

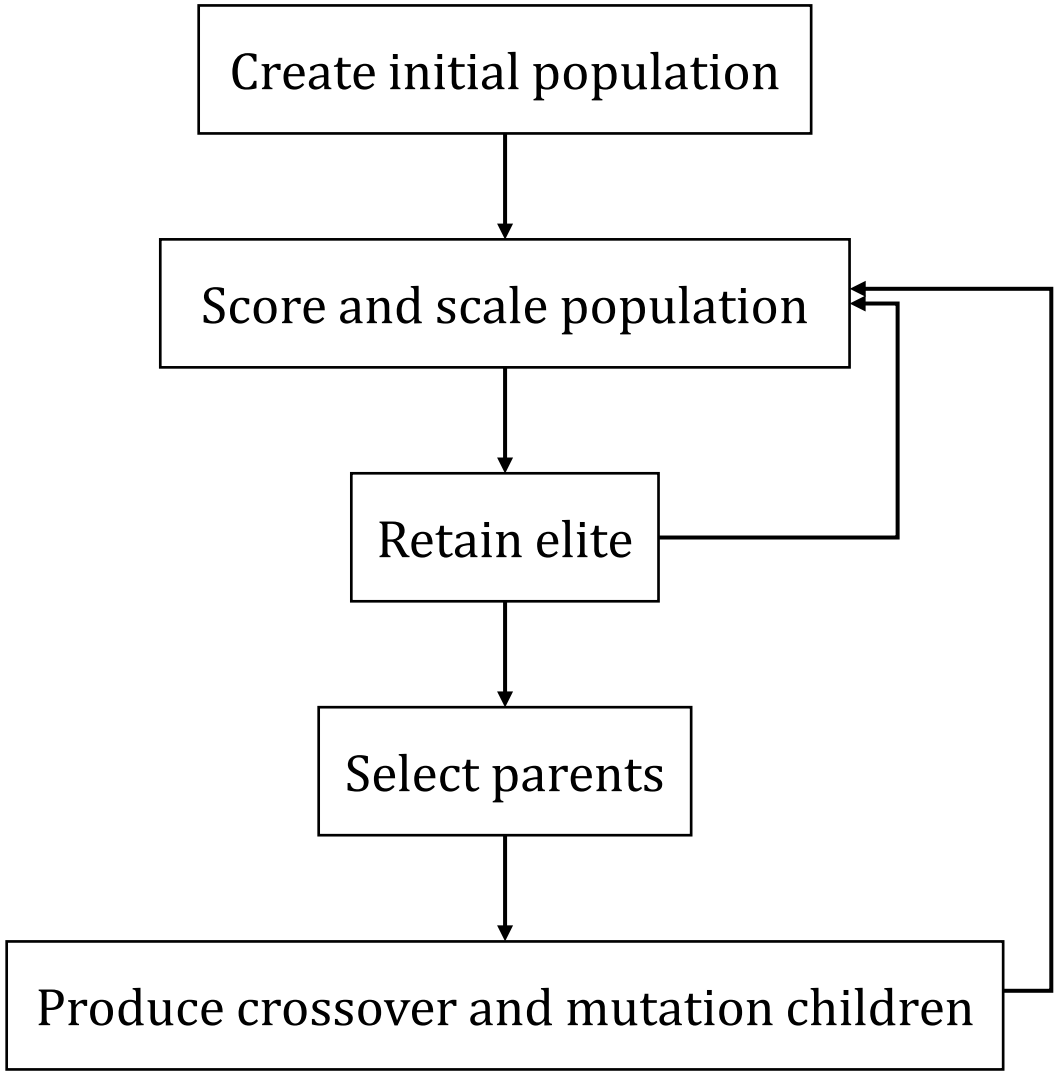


Used algorithms

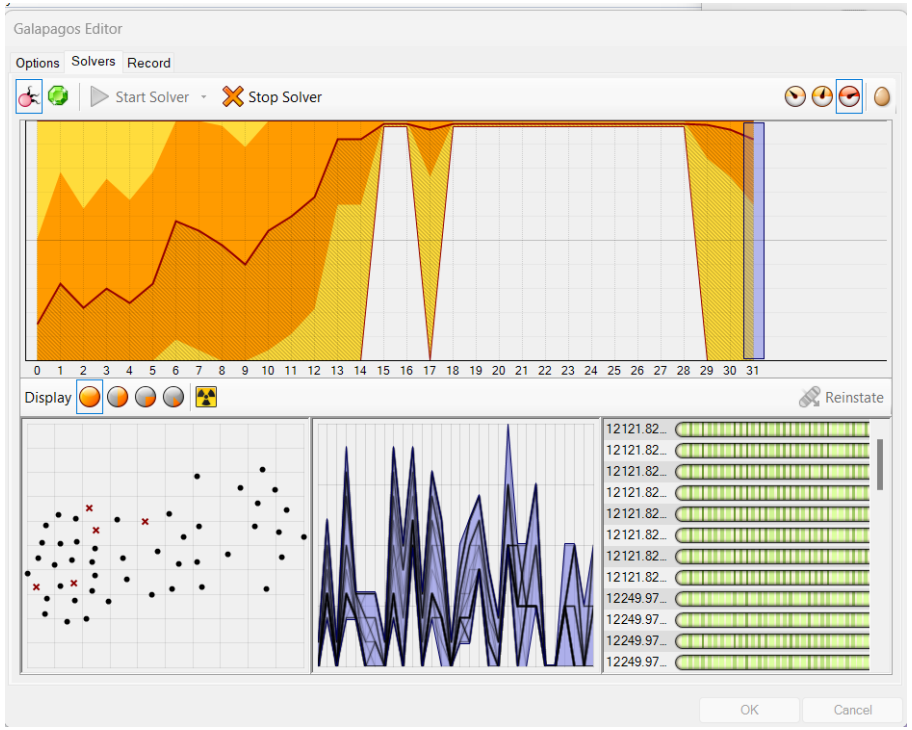


Galapagos




Create initial population
Score and scale population
Retain elite
Select parents
Produce crossover and mutation children

Galapagos


Galapagos Editor
Options
Solvers
Record
Start Solver
Stop Solver
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Display
Reinstate
12121.82...
12121.82...
12121.82...
12121.82...
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12249.97...
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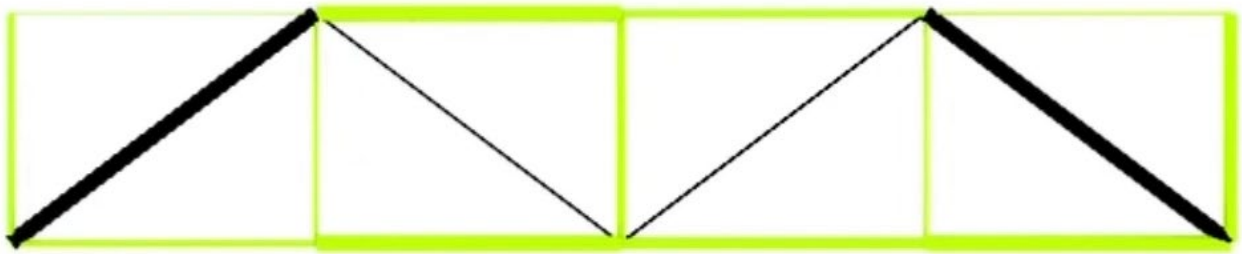
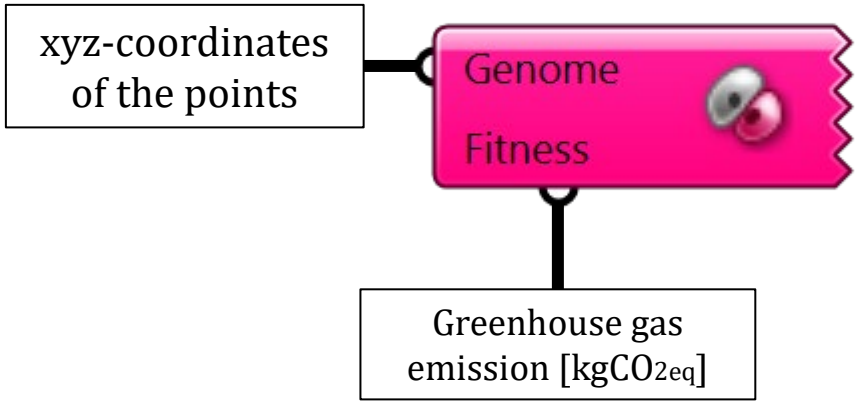
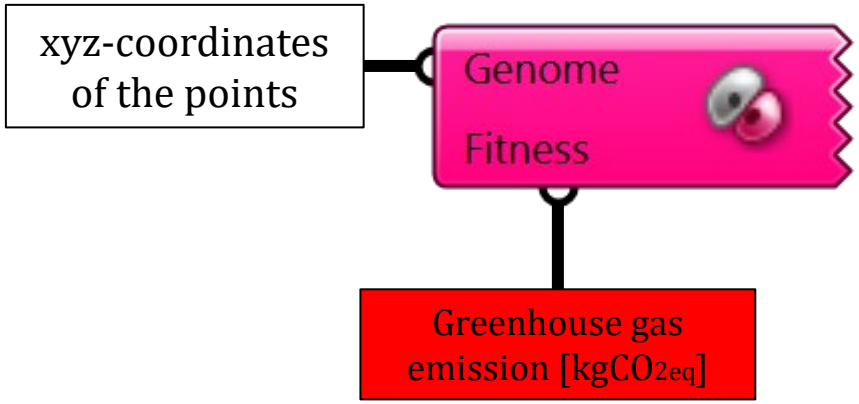
OK
Cancel



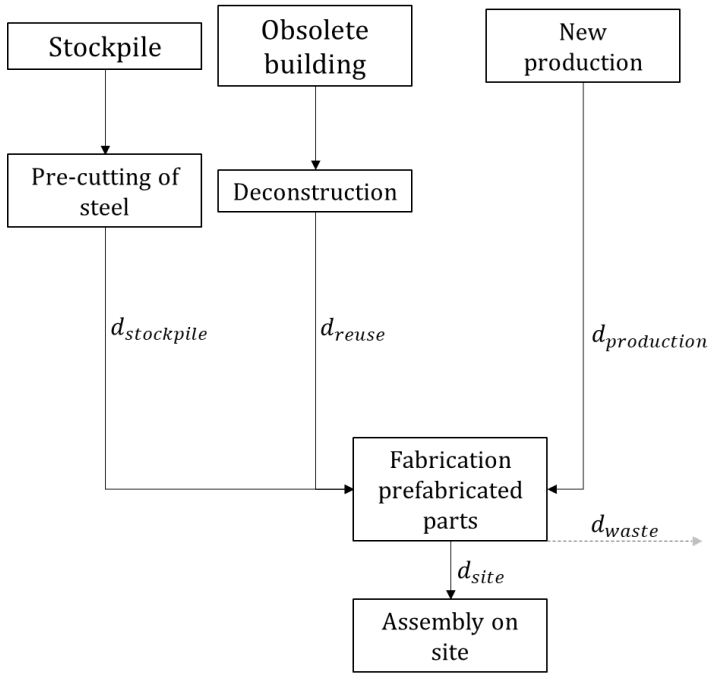
Galapagos


xyz-coordinates of the points
Genome
Fitness
Greenhouse gas emission [kgCO2eq]

Galapagos


xyz-coordinates of the points
Genome
Fitness
Greenhouse gas emission [kgCO2eq]

Emissions beam members



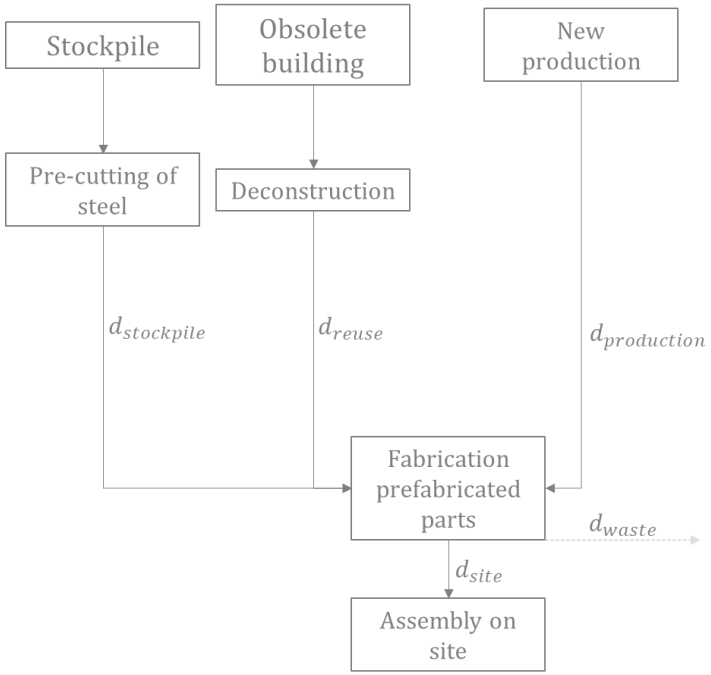
$$GHG_{new} = Mass * (EC_P + EC_A + EC_T)\ [\text{kgCO2eq}]$$

$$GHG_{deconstruction} = Mass * (EC_{DC} + EC_A + EC_C + EC_T) + Mass_{waste} * EC_T\ [\text{kgCO2eq}]$$

$$GHG_{stockpile} = Mass * (EC_A + EC_C + EC_T)\ [\text{kgCO2eq}]$$

$EC_T = EC_{transporttype} * d_{phase}$ [kgCO2eq/kg]
d_{phase} = distance [km] related to the current phase

Emissions beam members



$$GHG_{new} = \boldsymbol{Mass} * (EC_P + EC_A + EC_T)\ [\text{kgCO2eq}]$$

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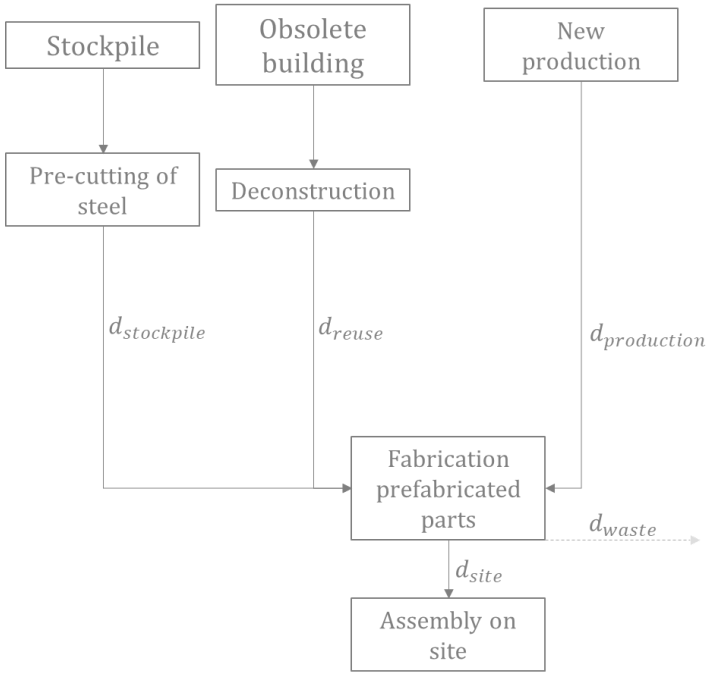
Emissions beam members



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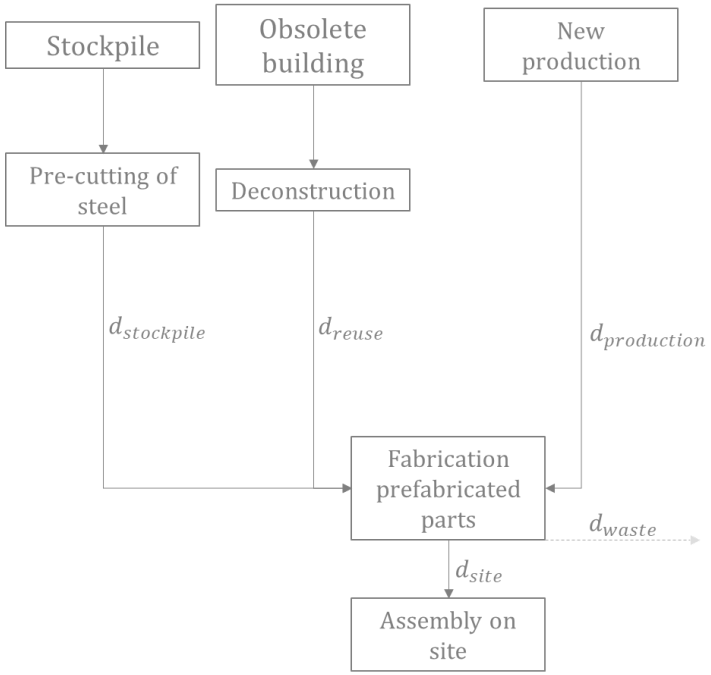
d_{phase} = distance [km] related to the current phase

Emissions beam members



0,337 kgCO2eq/kg

2,030 kgCO2eq/kg

$$GHG_{new} = Mass * (\boldsymbol{EC_P} + EC_A + EC_T)\ [\text{kgCO2eq}]$$

$$GHG_{deconstruction} = Mass * (\boldsymbol{EC_{DC}} + EC_A + EC_C + EC_T) + Mass_{waste} * EC_T\ [\text{kgCO2eq}]$$

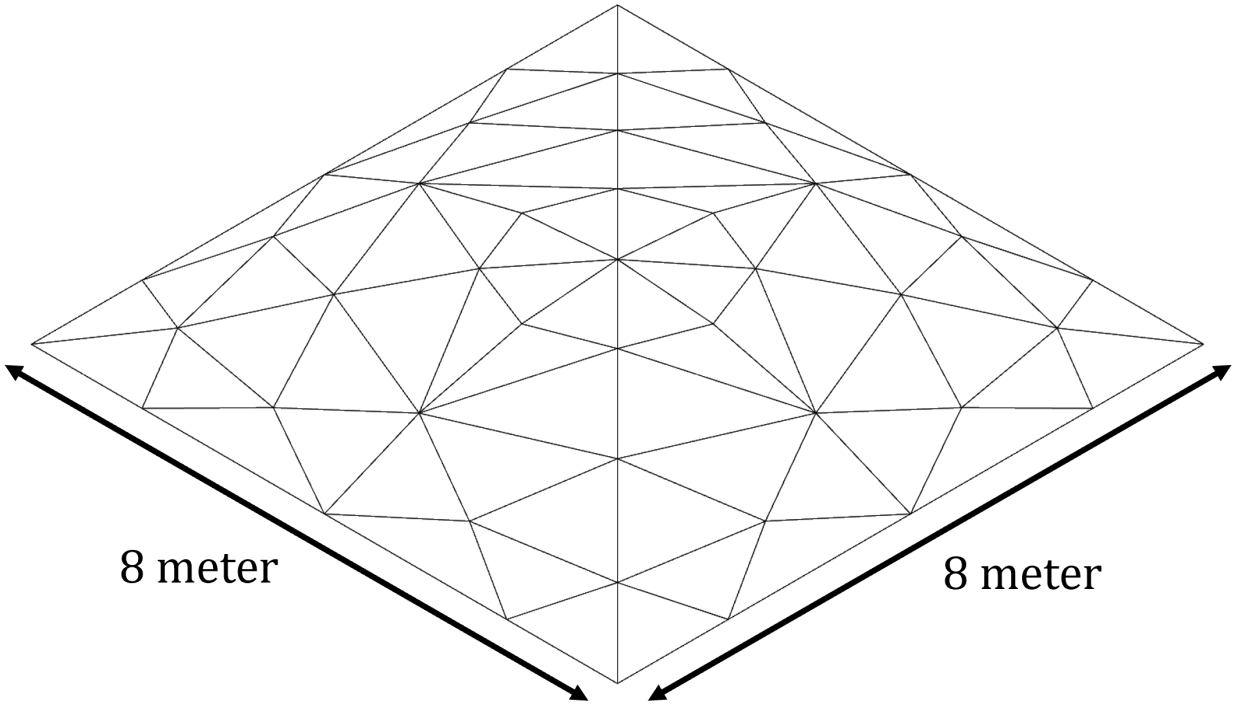
$$GHG_{stockpile} = Mass * (EC_A + EC_C + EC_T)\ [\text{kgCO2eq}]$$

$EC_T = EC_{transporttype} * d_{phase}$ [kgCO2eq/kg]
d_{phase} = distance [km] related to the current phase

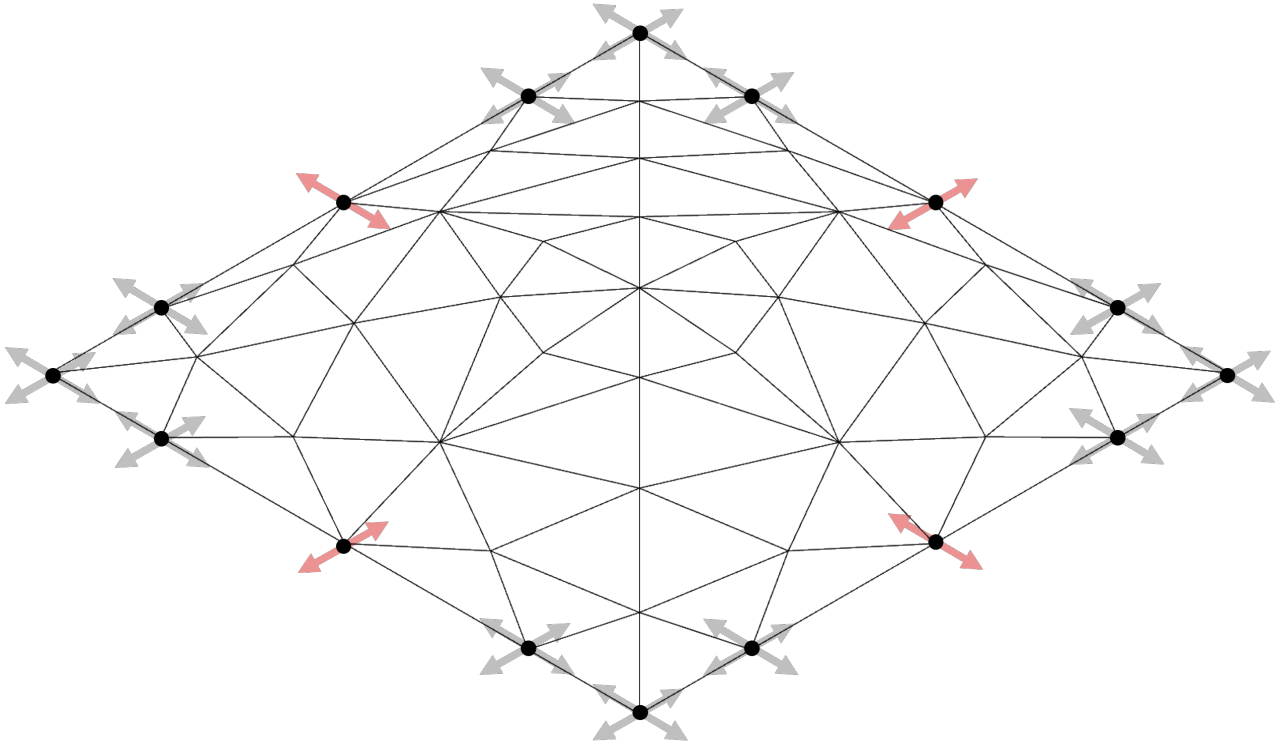
Results

General conditions

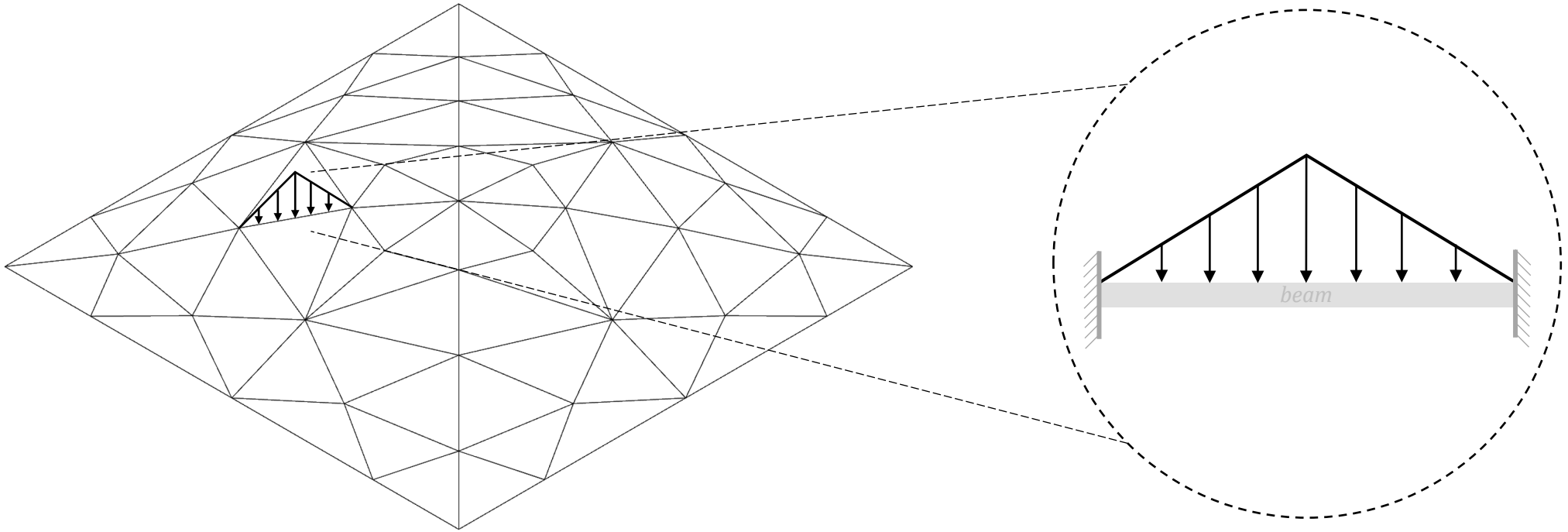
General conditions



General conditions

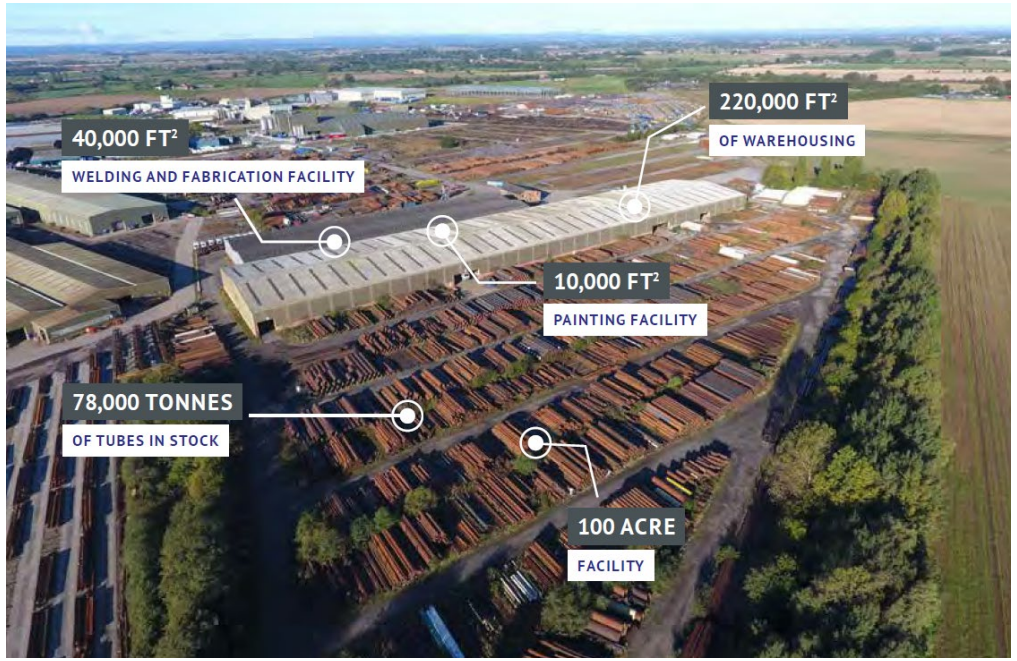


General conditions

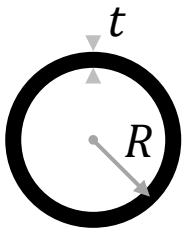


Testing scenarios

Testing scenarios

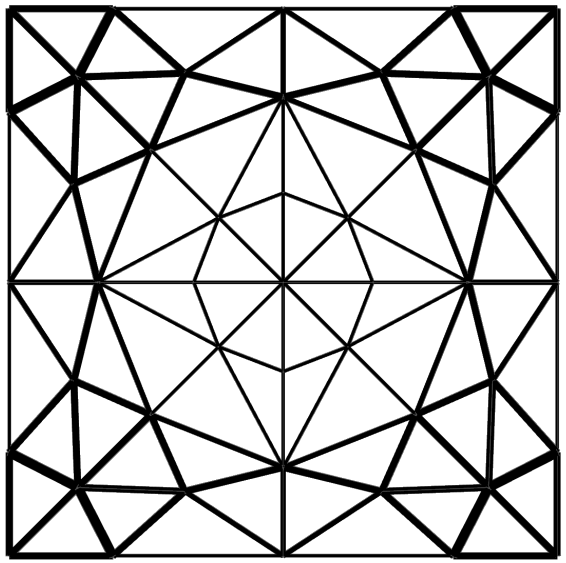


Steelgrade: S235, S275 and S355
Tickness (t): 2,5 up to 22,2 [mm]
Radius (R): 17 up to 109,5 [mm]

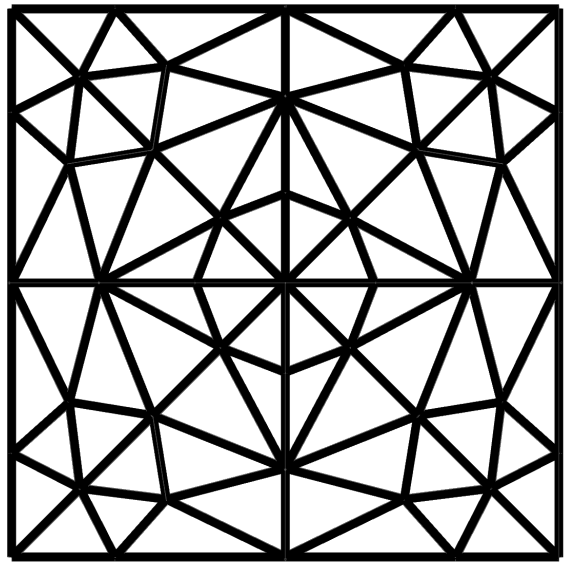


$d_{production}, d_{reuse}, d_{stockpile}$ = 70-km;
d_{site} = 15-km.

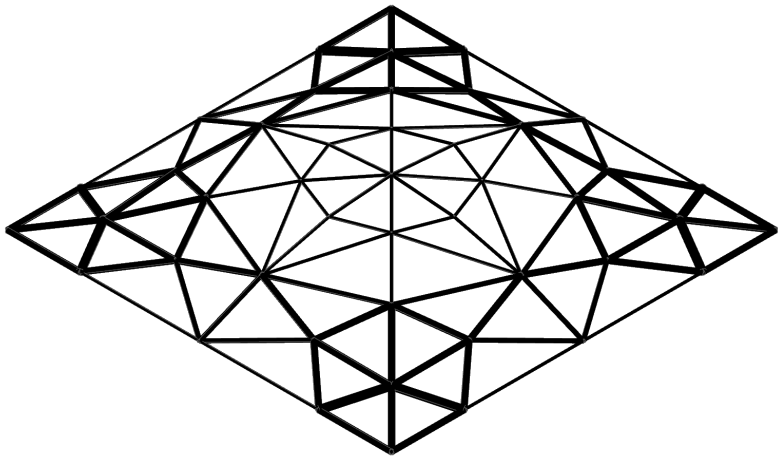
Testing scenarios

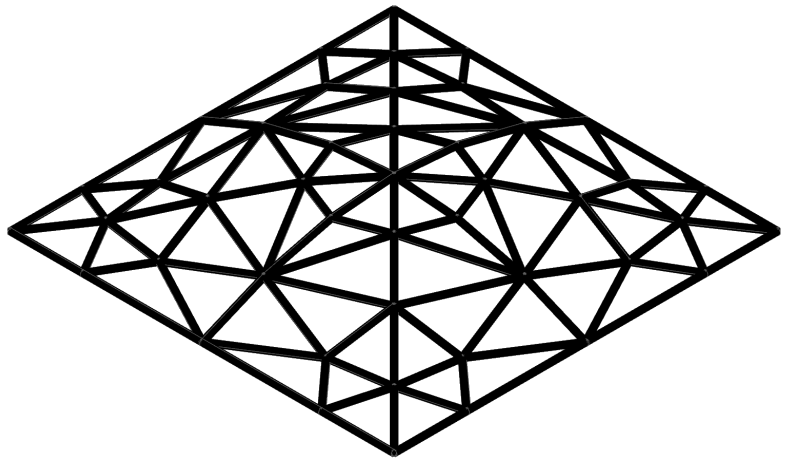


1073,5 kg to 1704,8 kg



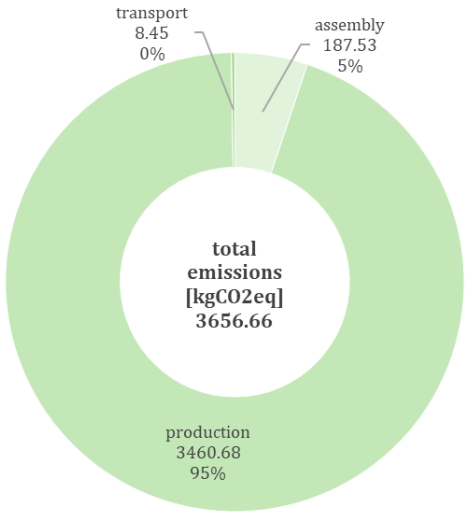
Increase of 37%





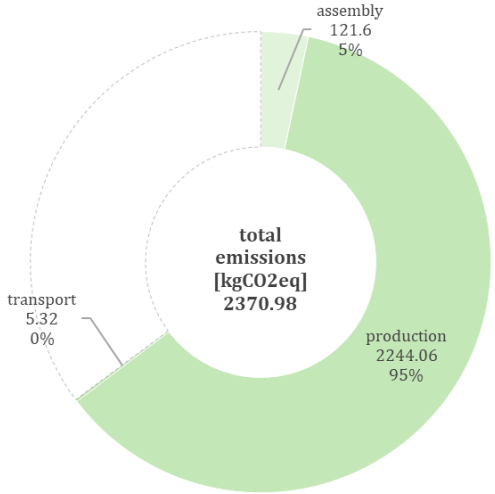
Testing scenarios

New production,
single cross-section



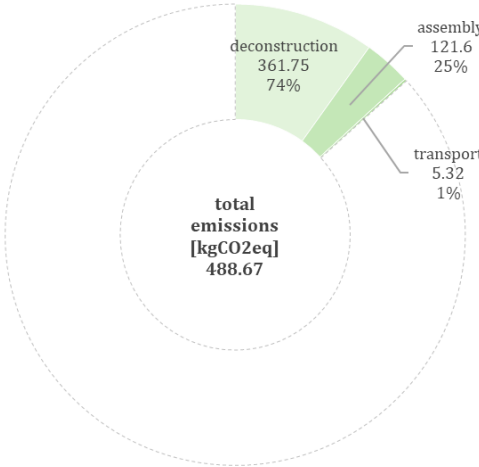
-35%

New production,
optimized cross-sections



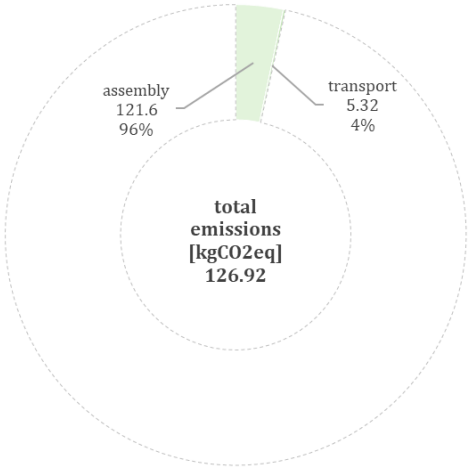
-79%

Deconstruction,
optimized cross-sections



-74%

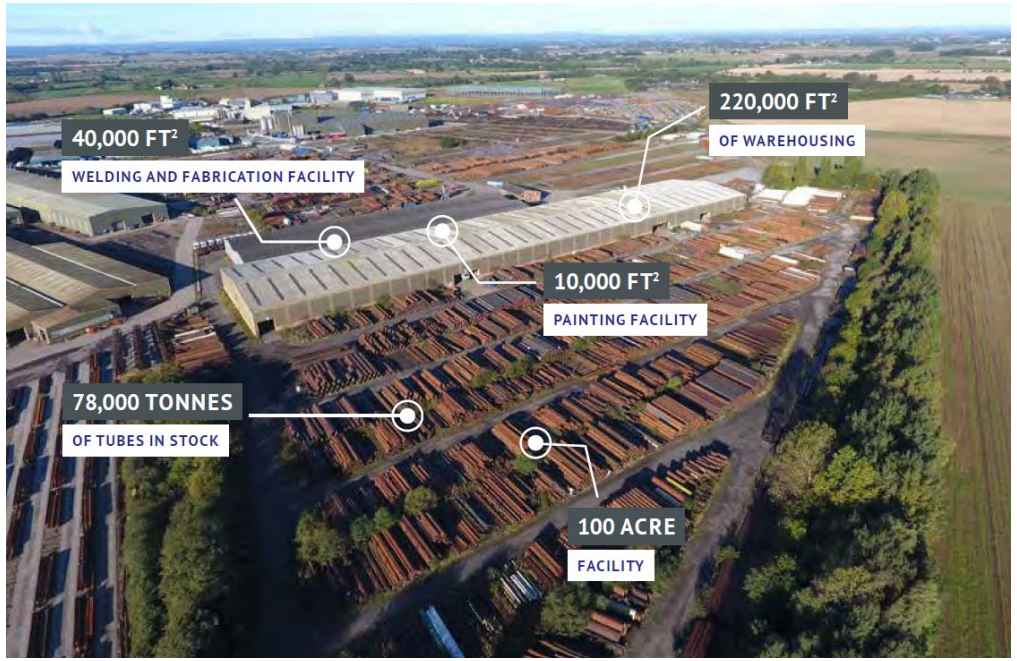
Stockpile,
optimized cross-sections



Total reduction of **-97%**

Testing stock-sizes

Testing stock-sizes



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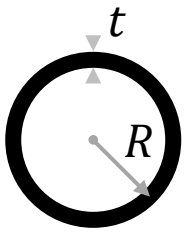

$d_{production}, d_{reuse}, d_{stockpile}$ = 70-km;
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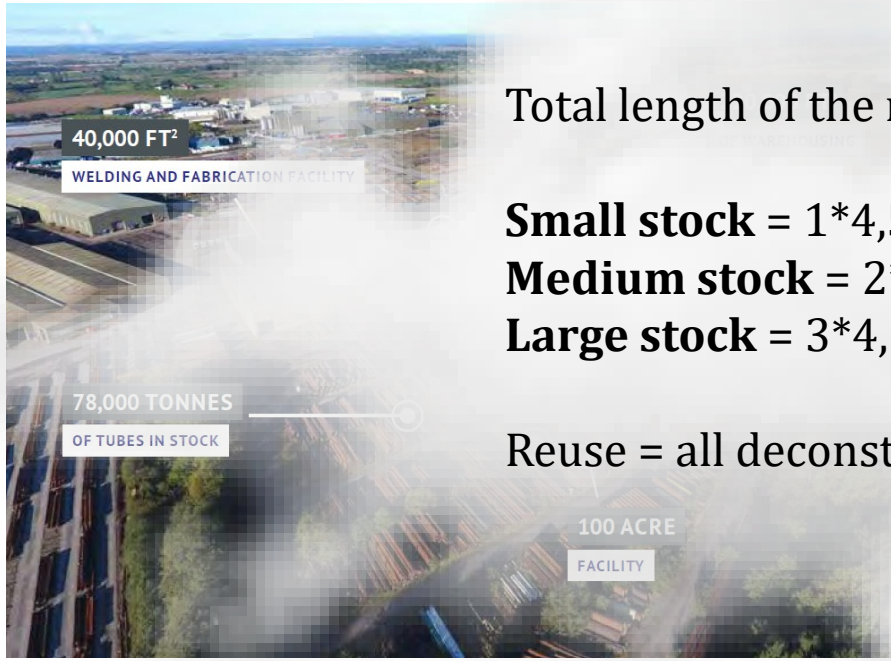
Testing stock-sizes



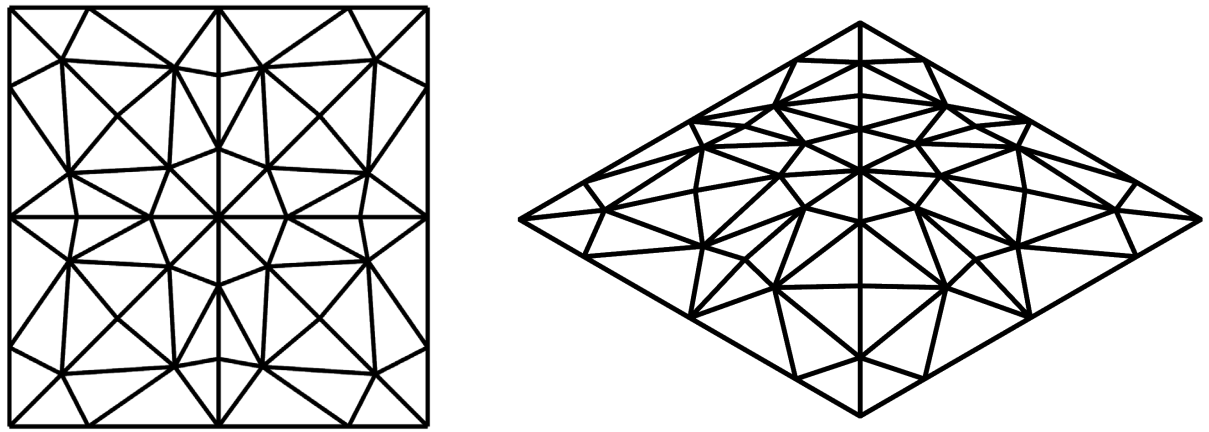
Total length of the members ≈ 183-m

Small stock = 1*4,5-meter for every unique cross-section (**56%**)
Medium stock = 2*4,5-meter for every unique cross-section (**112%**)
Large stock = 3*4,5-meter for every unique cross-section (**168%**)

Reuse = all deconstruction

Testing stock-sizes

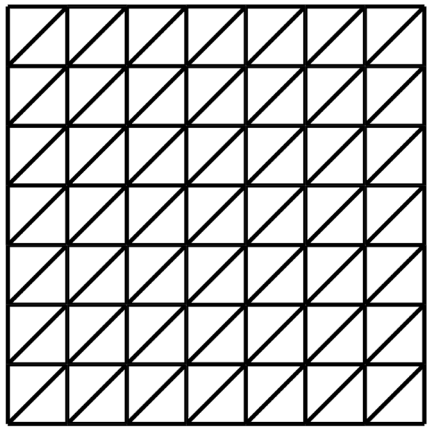
Optimized gridshell

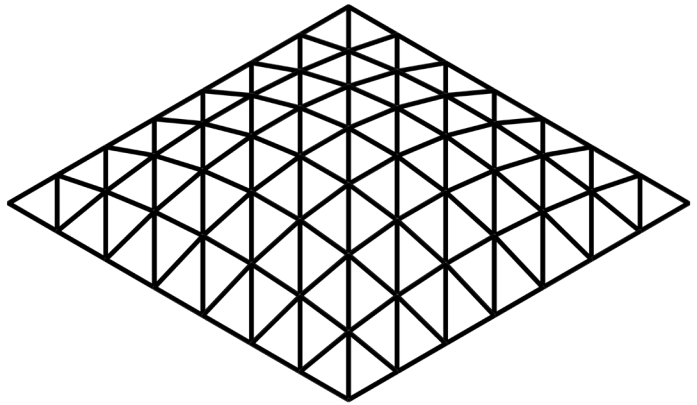


Including node-shifting

Testing stock-sizes

Standardized gridshell



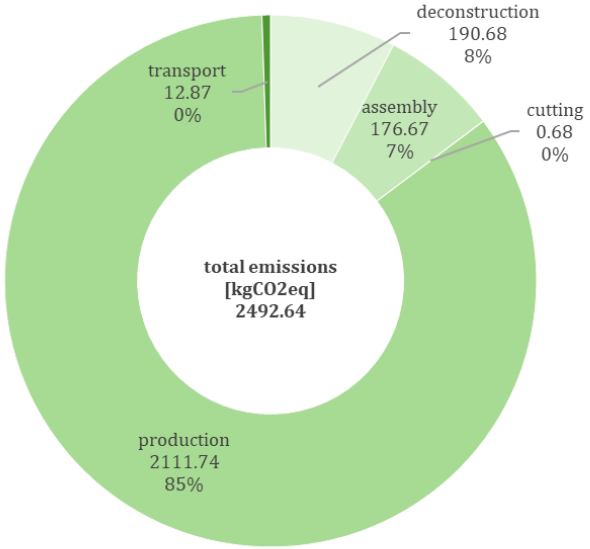


Excluding node-shifting

Testing stock-sizes

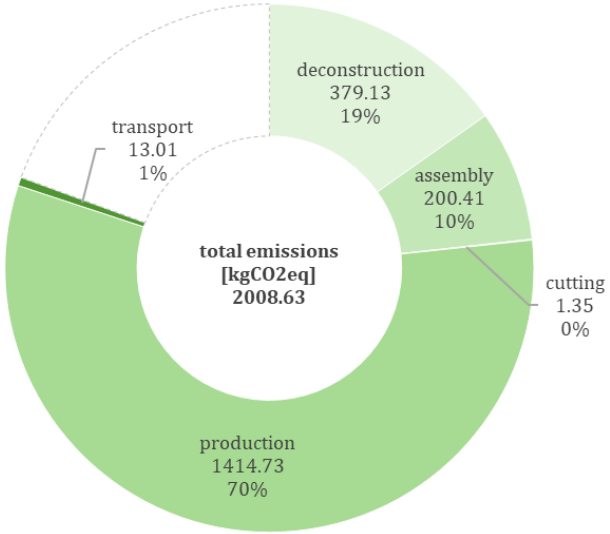
Total reduction of **-42%**

Small



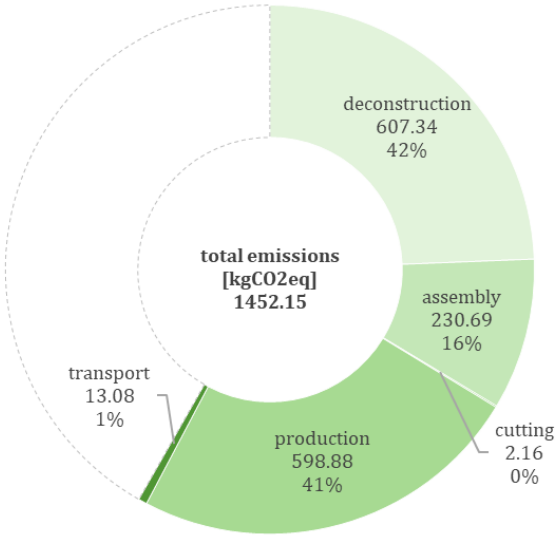
-19%

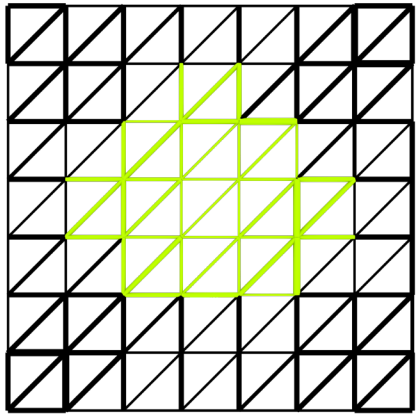
Medium

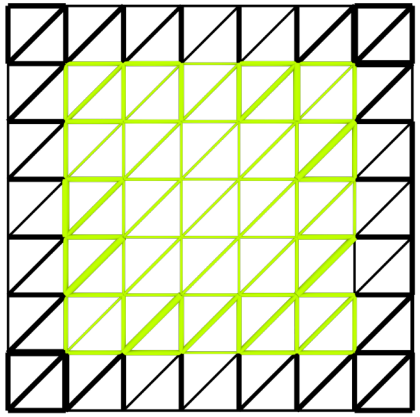


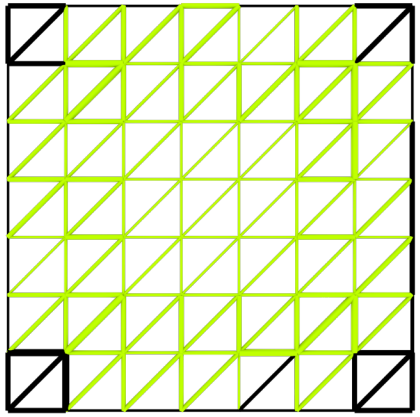
-28%

Large





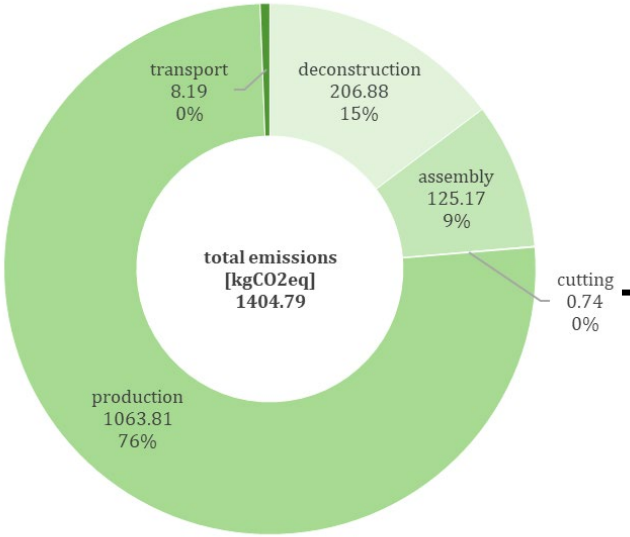




Testing stock-sizes

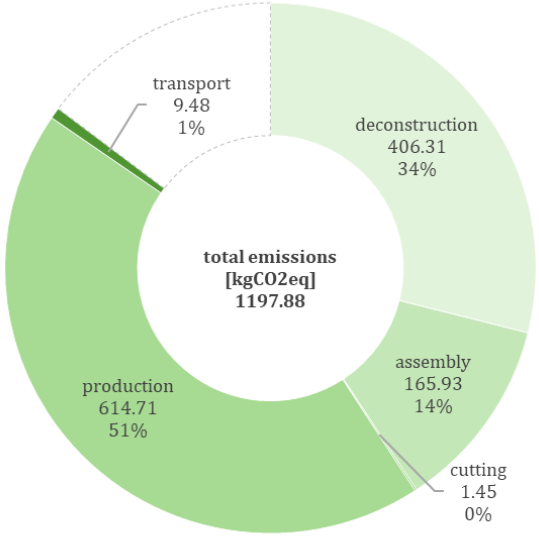
Total reduction of **-50%**

Small



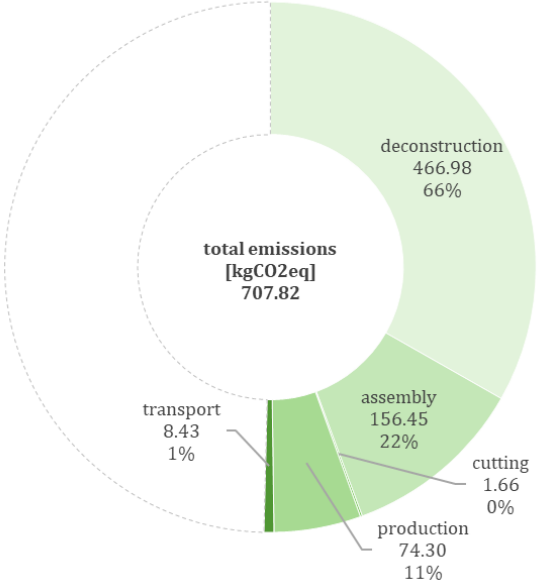
-15%

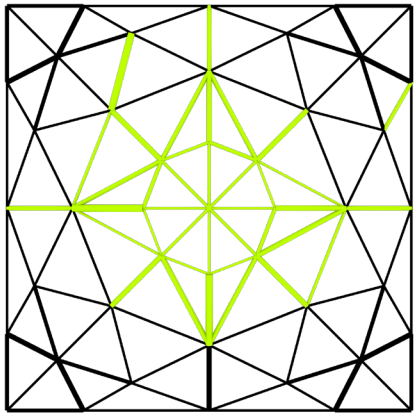
Medium

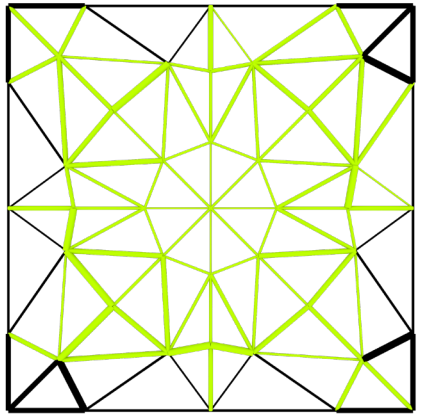


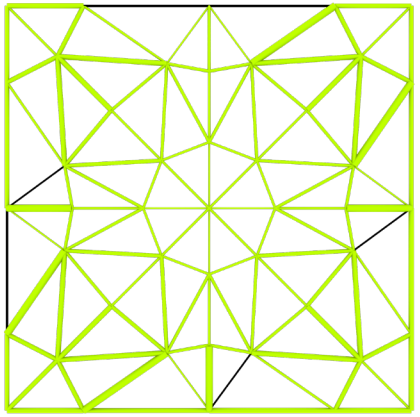
-41%

Large









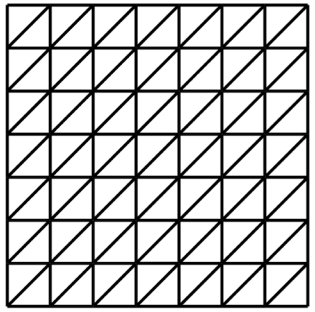
Testing stock-sizes

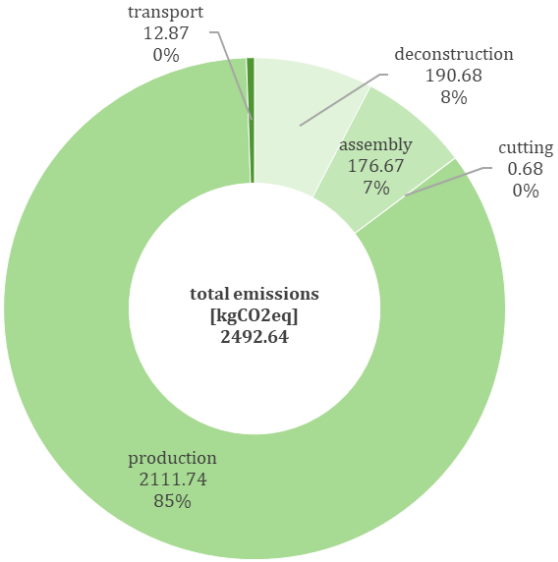
Small

Medium

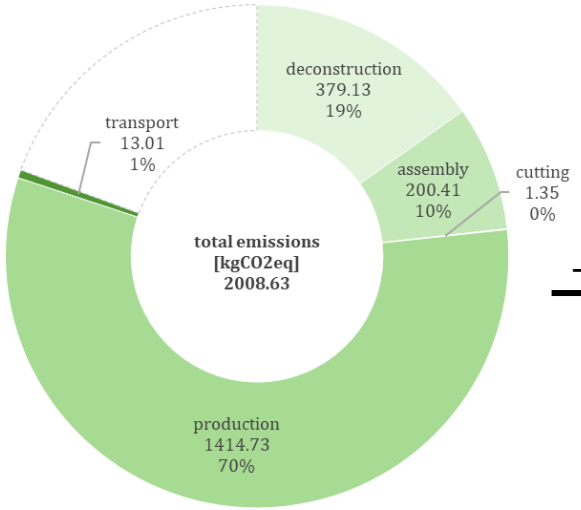
Large

Standardized

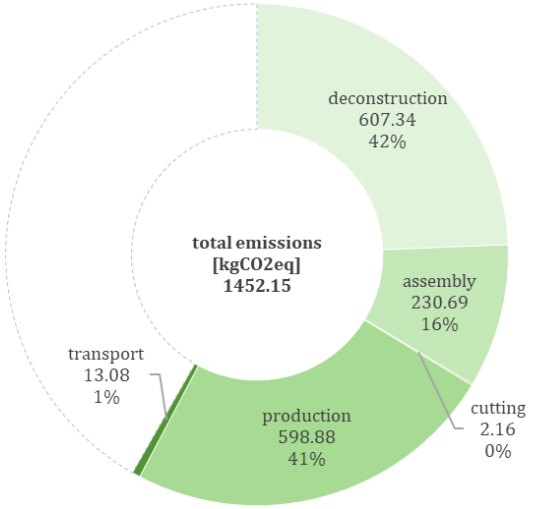




-19%



-28%

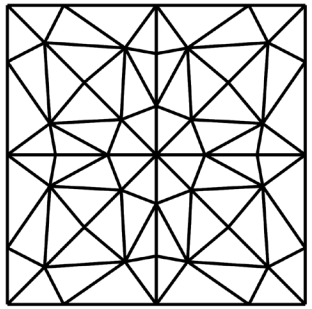


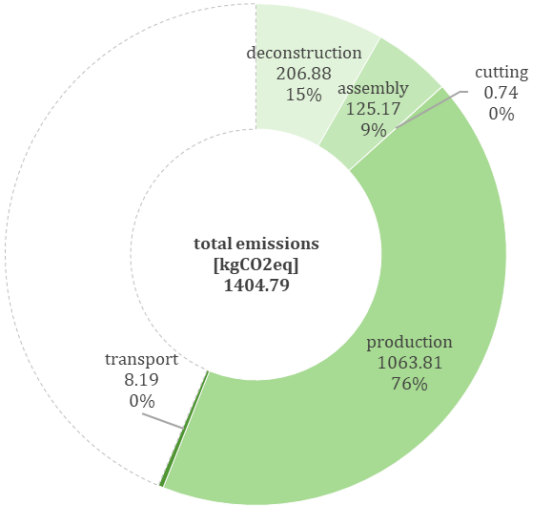
-44%

-40%

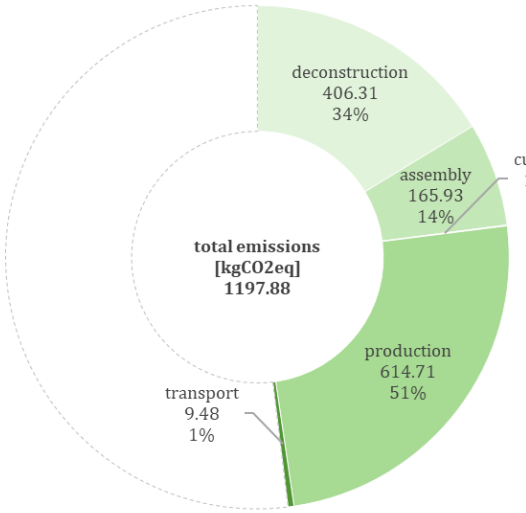
-51%

Optimized

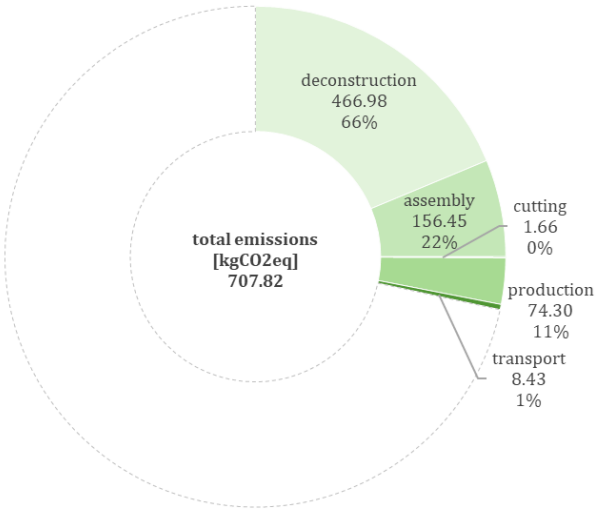




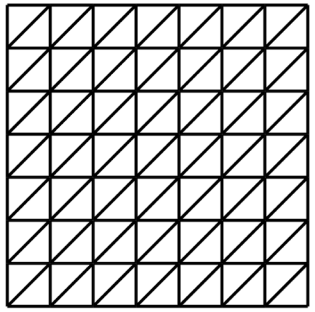
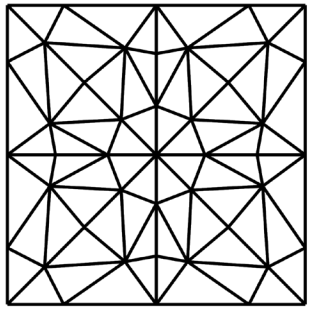
-15%



-41%

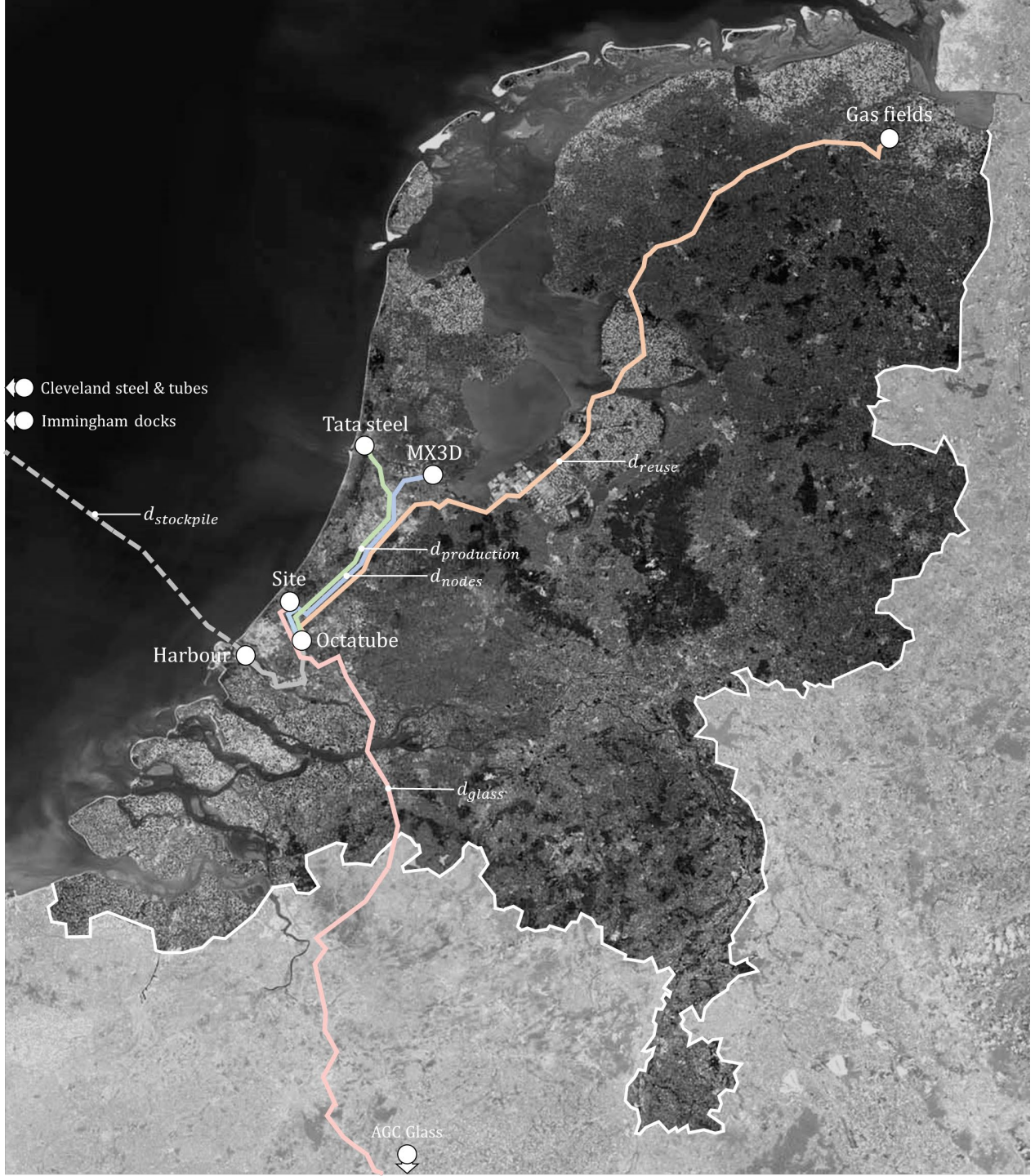


Testing stock-sizes

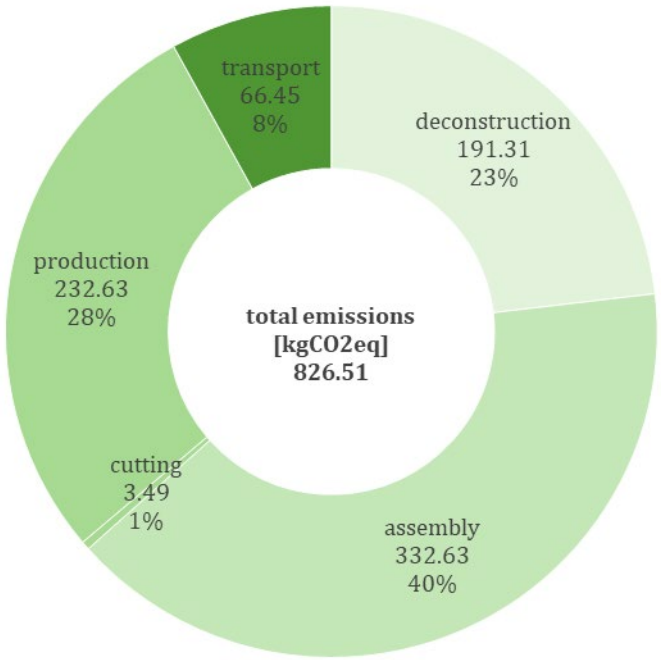
	Small	Medium	Large
Standardized	 RR = 33,5%	RR = 59,9%	RR = 84,9%
	+18,6%	+18,8%	+12,4%
Optimized	 RR = 52,1%	RR = 78,7%	RR = 97,3%

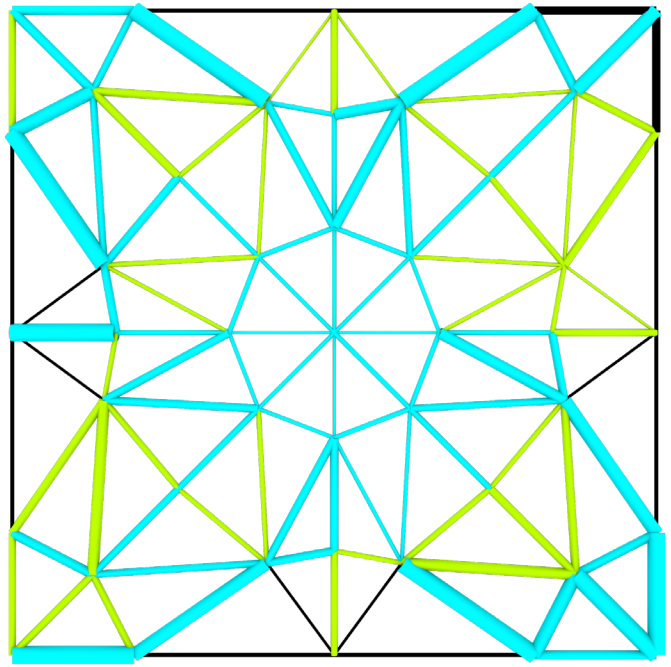
Case study

Case study


Gas fields
Cleveland steel & tubes
Immingham docks
Tata steel
MX3D
d_{reuse}
$d_{stockpile}$
$d_{production}$
d_{nodes}
Site
Octatube
Harbour
d_{glass}
AGC Glass

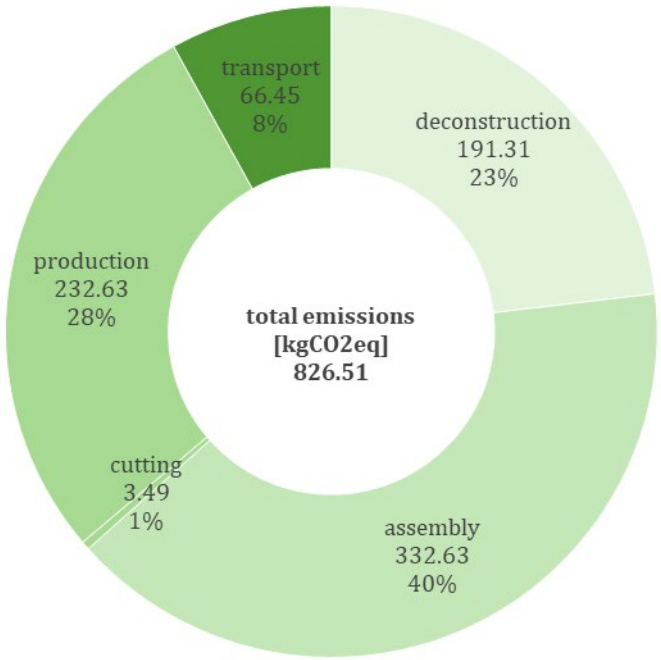
Case study

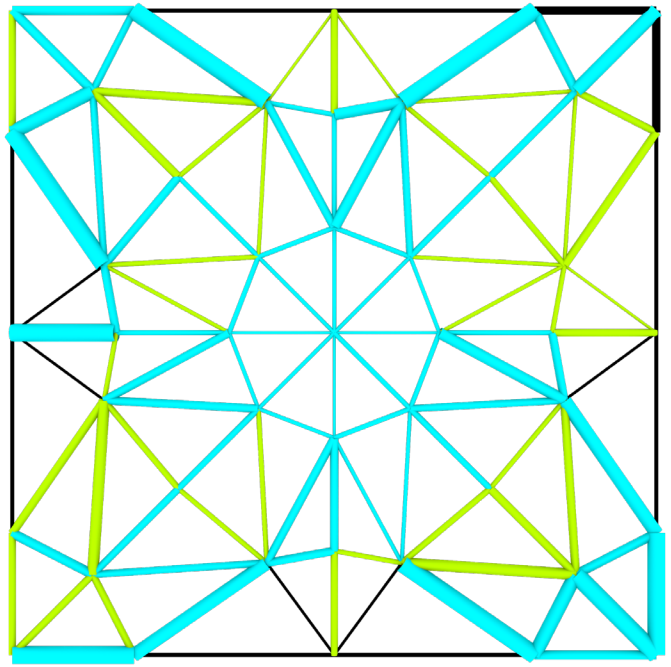




GHG emissions [$kgCO_{2eq}$]	Reuse-rate [%]	Structure mass [kg]	Waste [cm]	Waste [%]	Deconstruction stock used from total [%]	Stockpile stock used from total [%]
826,51	95,97	6404,38	1805,35	11,8	57,84	88,34

Case study



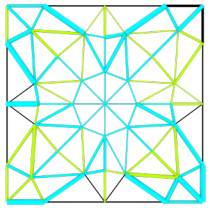


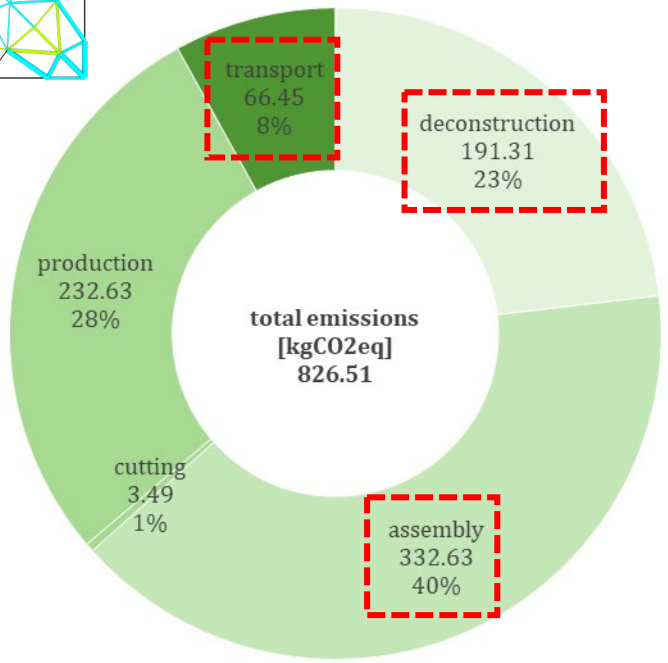
GHG emissions [$kgCO_{2eq}$]	Reuse-rate [%]	Structure mass [kg]	Waste [cm]	Waste [%]	Deconstruction stock used from total [%]	Stockpile stock used from total [%]
826,51	95,97	6404,38	1805,35	11,8	57,84	88,34

Case study

Stock size == Medium stock

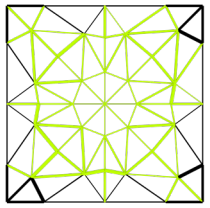
Case study hybrid stock
incl. stockpile

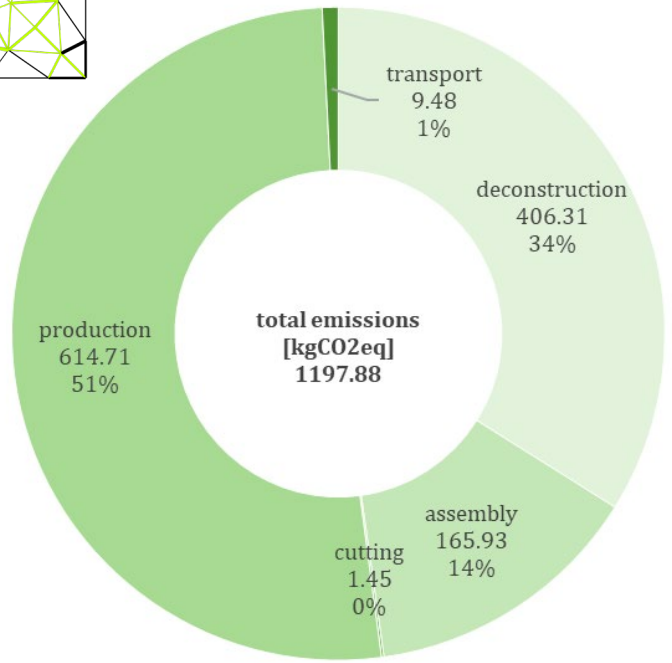




+44,9%

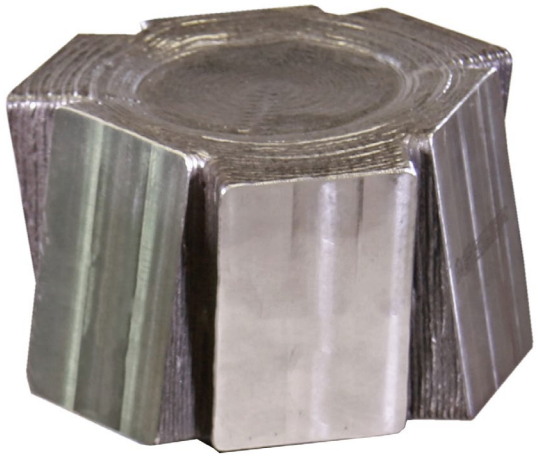
Medium stock-size
only deconstruction

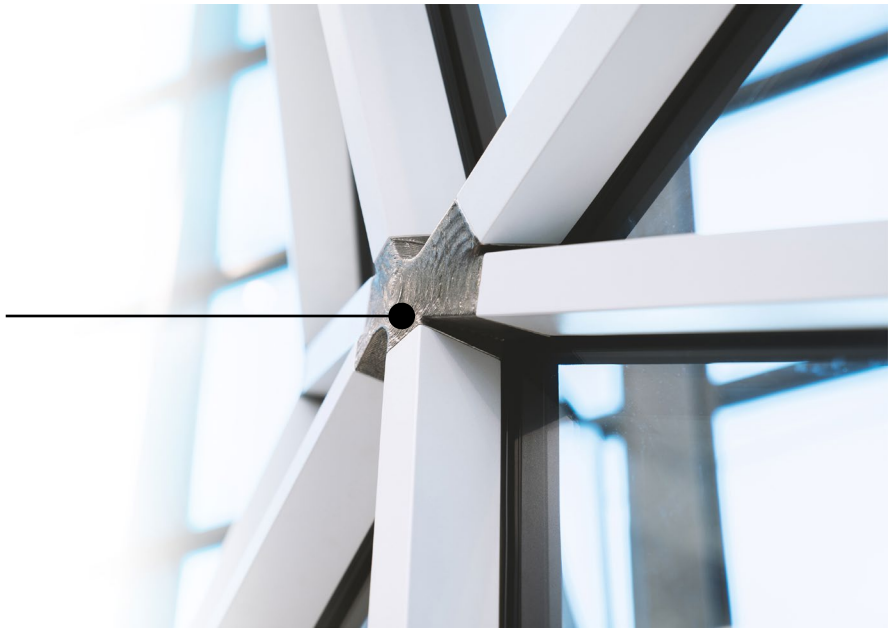




Relation glass and nodes

Calculation nodes





Calculation nodes

$$GHG_{node} = \frac{\pi}{4} * D^2 - (D - 2t)^2 * L * \rho * (EC_{WAAM} + EC_A + EC_T * d_{phase}) \ [\mathrm{kgCO_{2eq}}]$$

Calculation nodes

WAAM manufacturing

Transportation

$$GHG_{node} = \frac{\pi}{4} * D^2 - (D - 2t)^2 * L * \rho * (EC_{WAAM} + EC_A + EC_T * d_{phase}) \ [\mathrm{kgCO_{2eq}}]$$

Assembly

Calculation glass

6-mm heat strengthened glass
6-mm heat strengthened glass
8-mm tempered glass

Calculation glass

$$GHG_{glass} = A * \left(EC_M + EC_{LAM} + z * EC_{INT} + t * \rho_{glass} * EC_A + EC_T * d_{phase}\right) [\mathrm{kgCO_{2eq}}]$$

Calculation glass

Production glass

Interlayer

Transportation

$$GHG_{glass} = A * \left(EC_M + EC_{LAM} + z * EC_{INT} + t * \rho_{glass} * (EC_A + EC_T * d_{phase})\right) [\mathrm{kgCO_{2eq}}]$$

Lamination

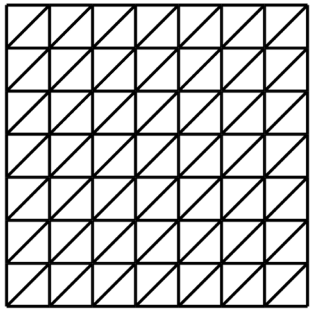
Assembly

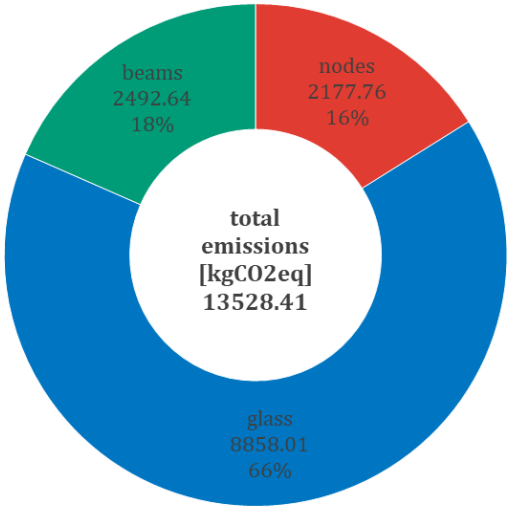
Relation components

Small

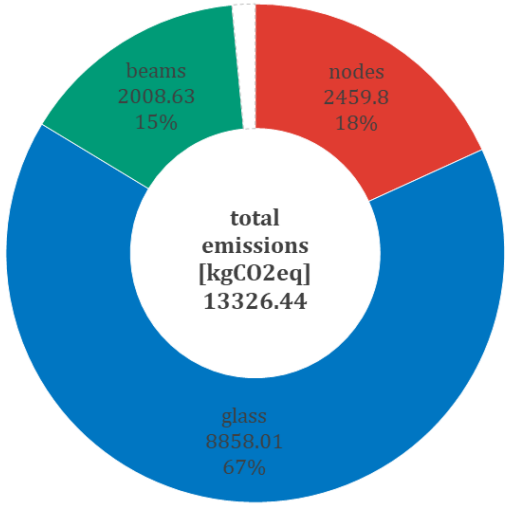
Medium

Large

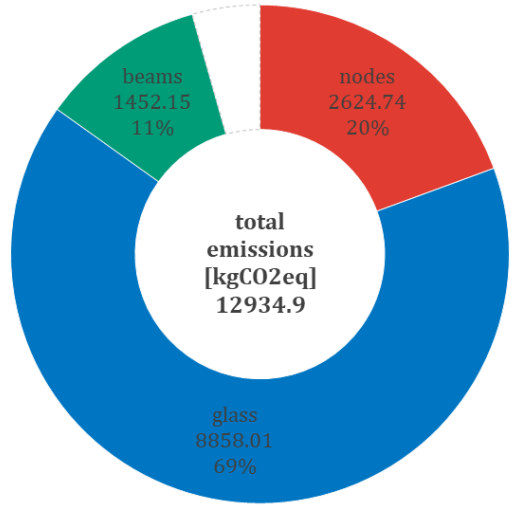




-1,5%



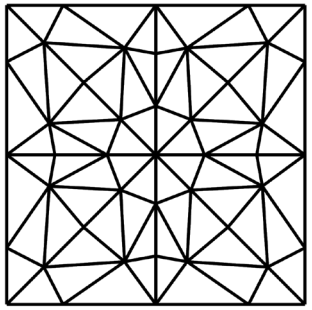
-2,9%

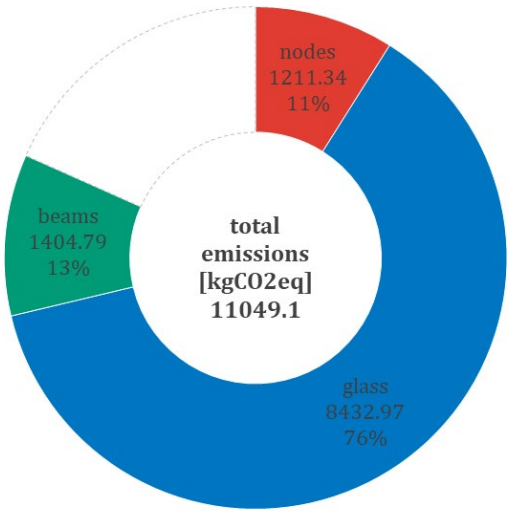


-18,3%

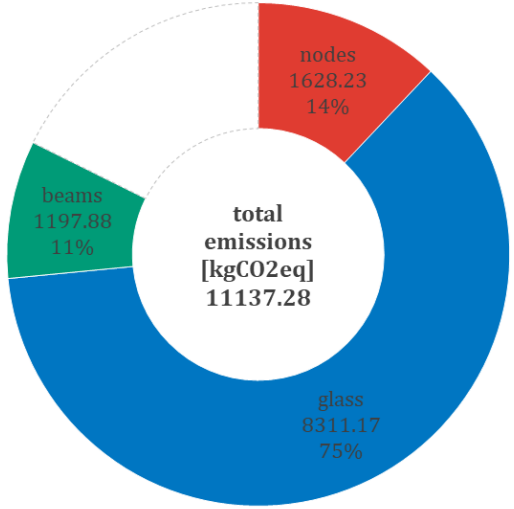
-16,4%

-19,3%

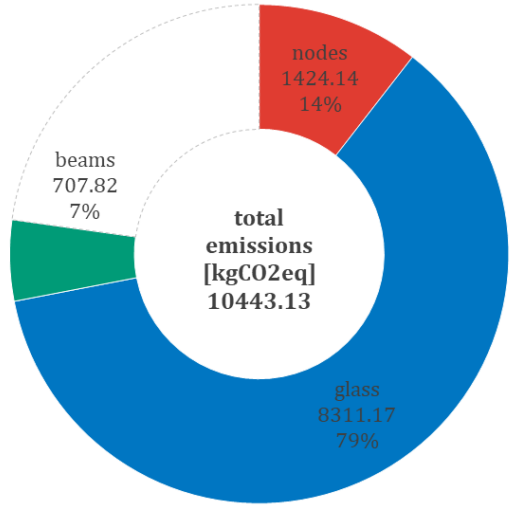




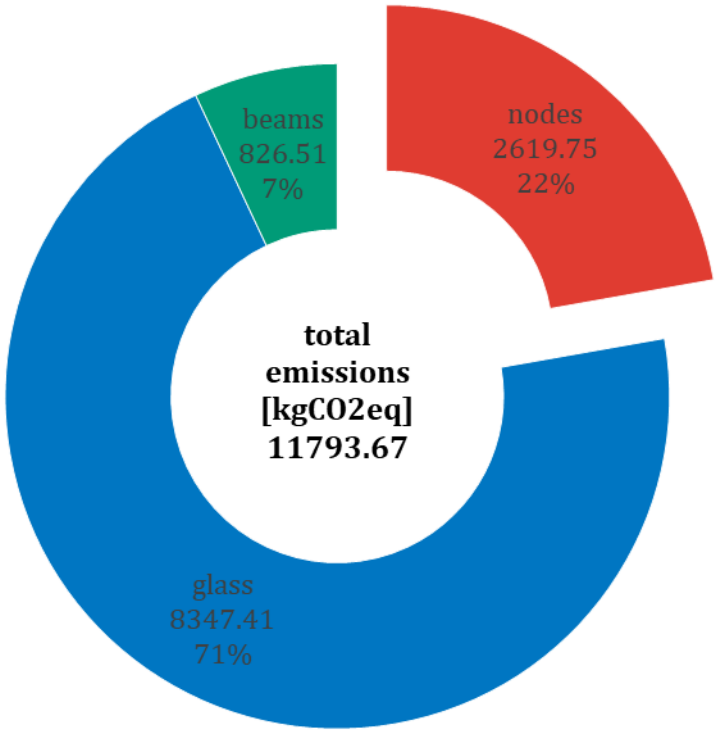
+0,8%



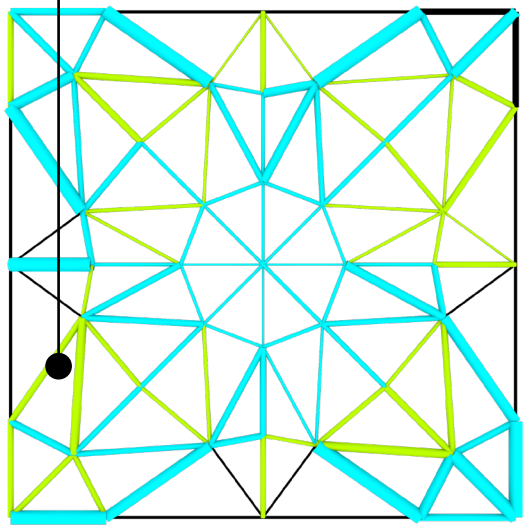
-6,2%



Relation components

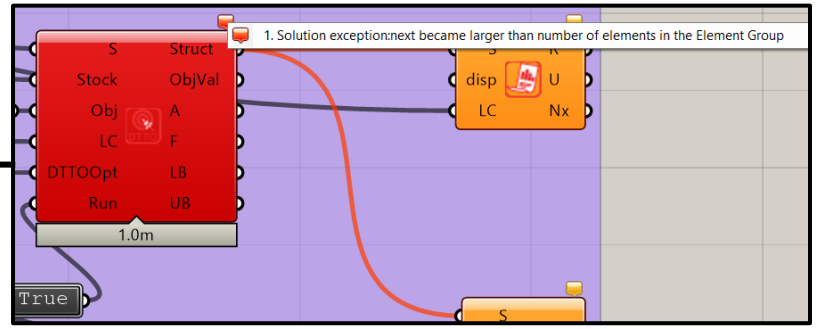


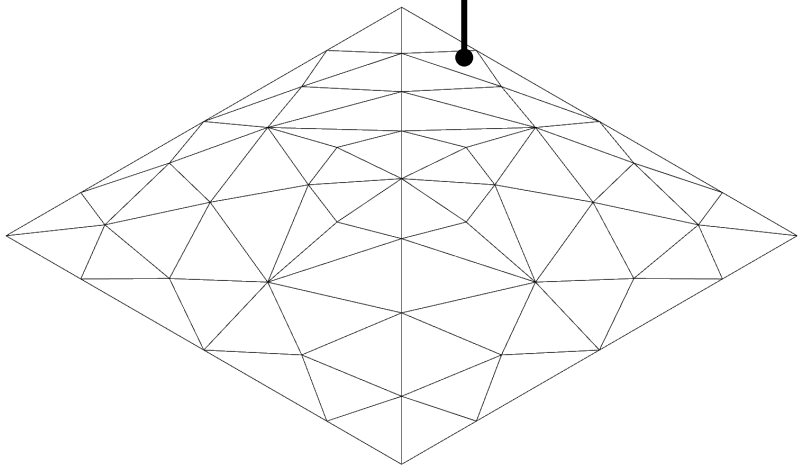
Calculation of emissions for individual beam members, therefore more biased towards big cross-sections of an overall better scenario.



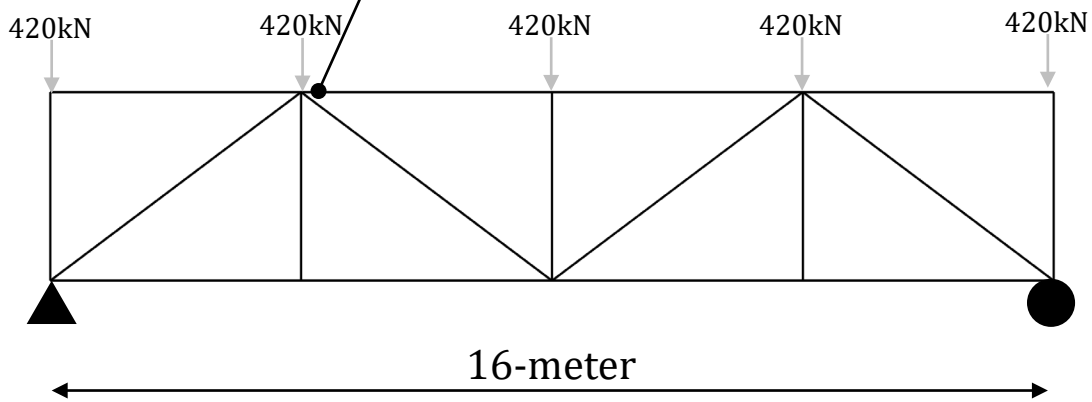
Benchmark Phoenix3D

Benchmark Phoenix3D



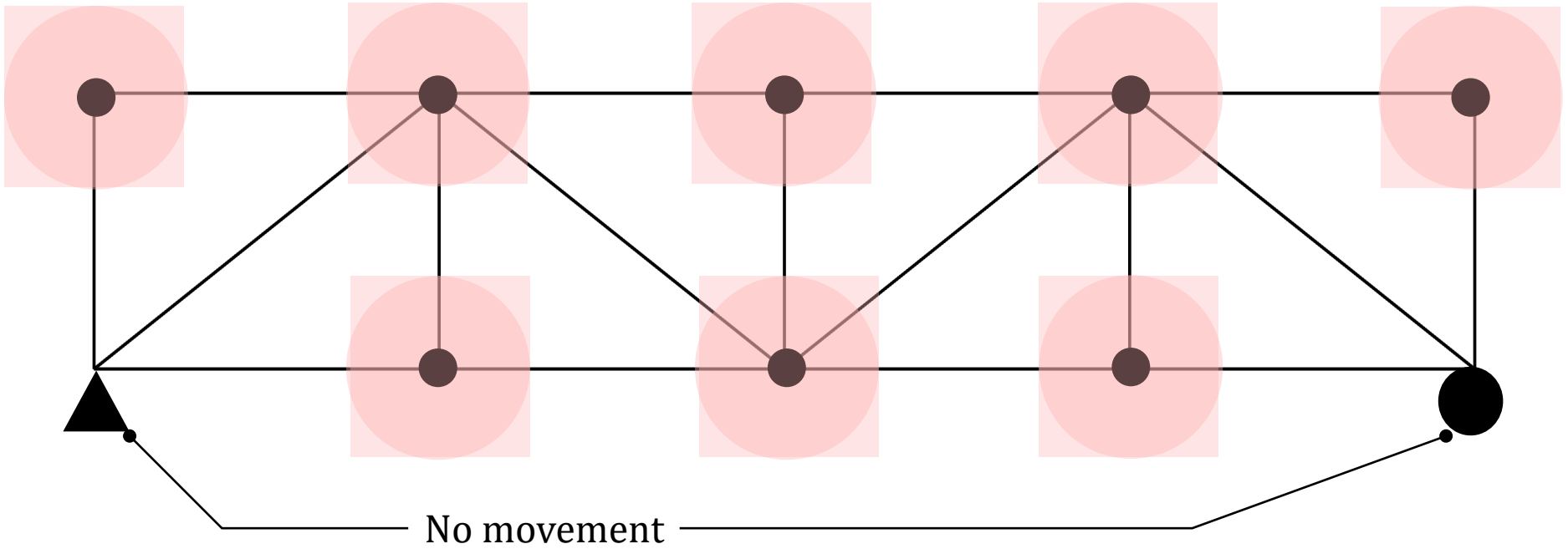


Simplified to
fixed connections



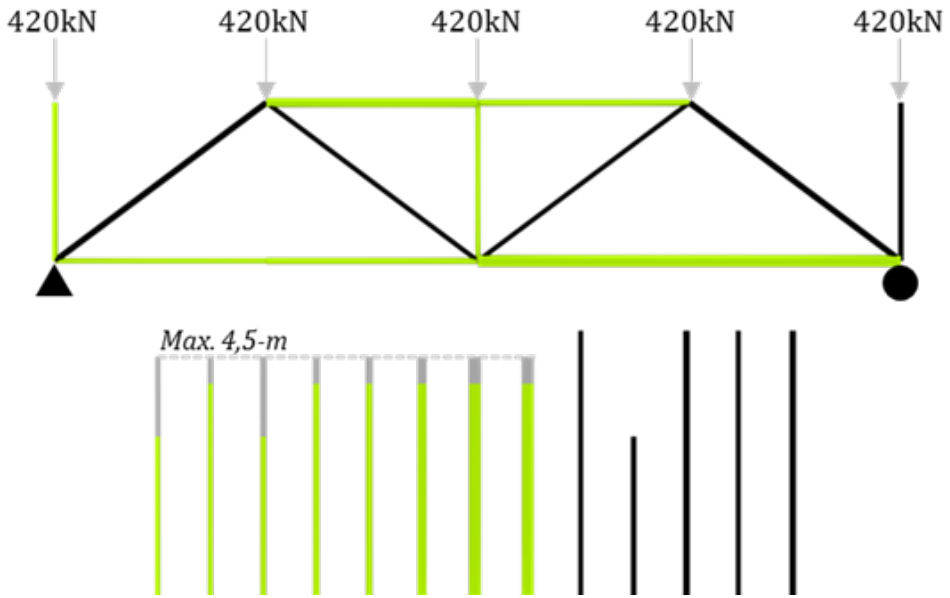
Benchmark Phoenix3D

Freedom of movement for the
developed computational method =
1-meter over the X- and Z-axis



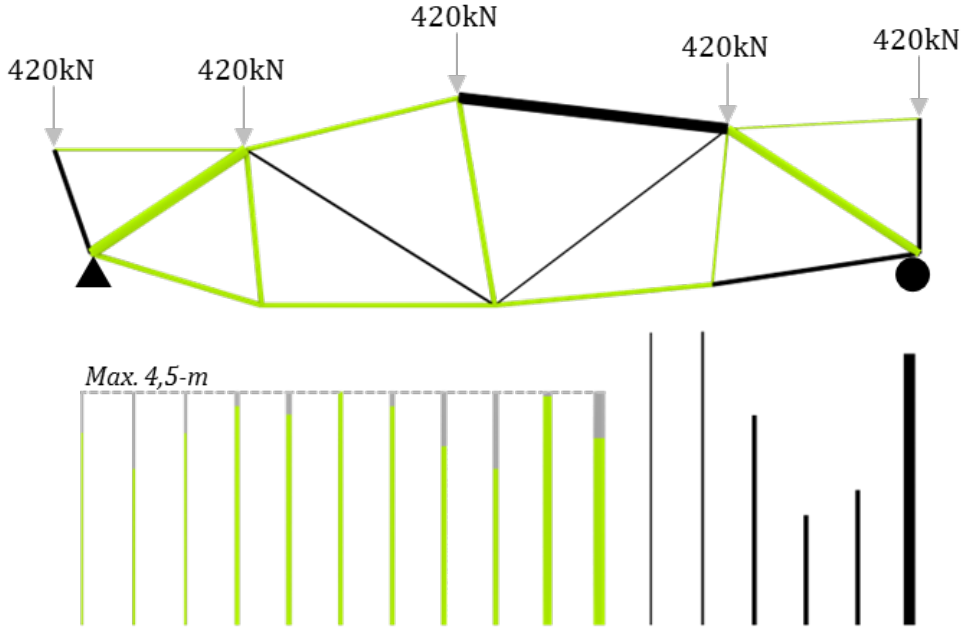
Benchmark Phoenix3D

Phoenix, MILP



GHG-emissions: 1182 $kgCO_{2eq}$
Mass structure: 1820 kg

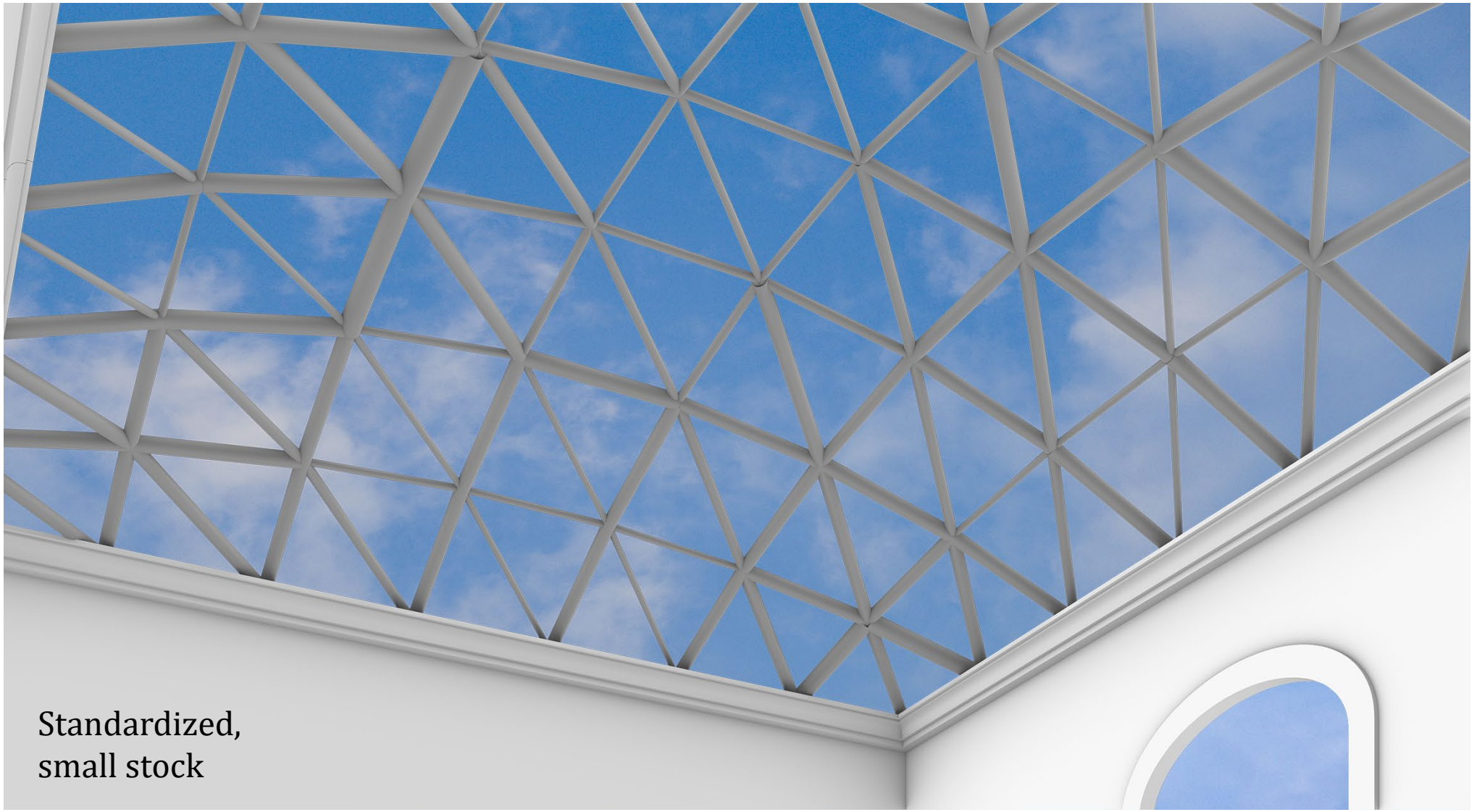
Developed node-shifting formulation



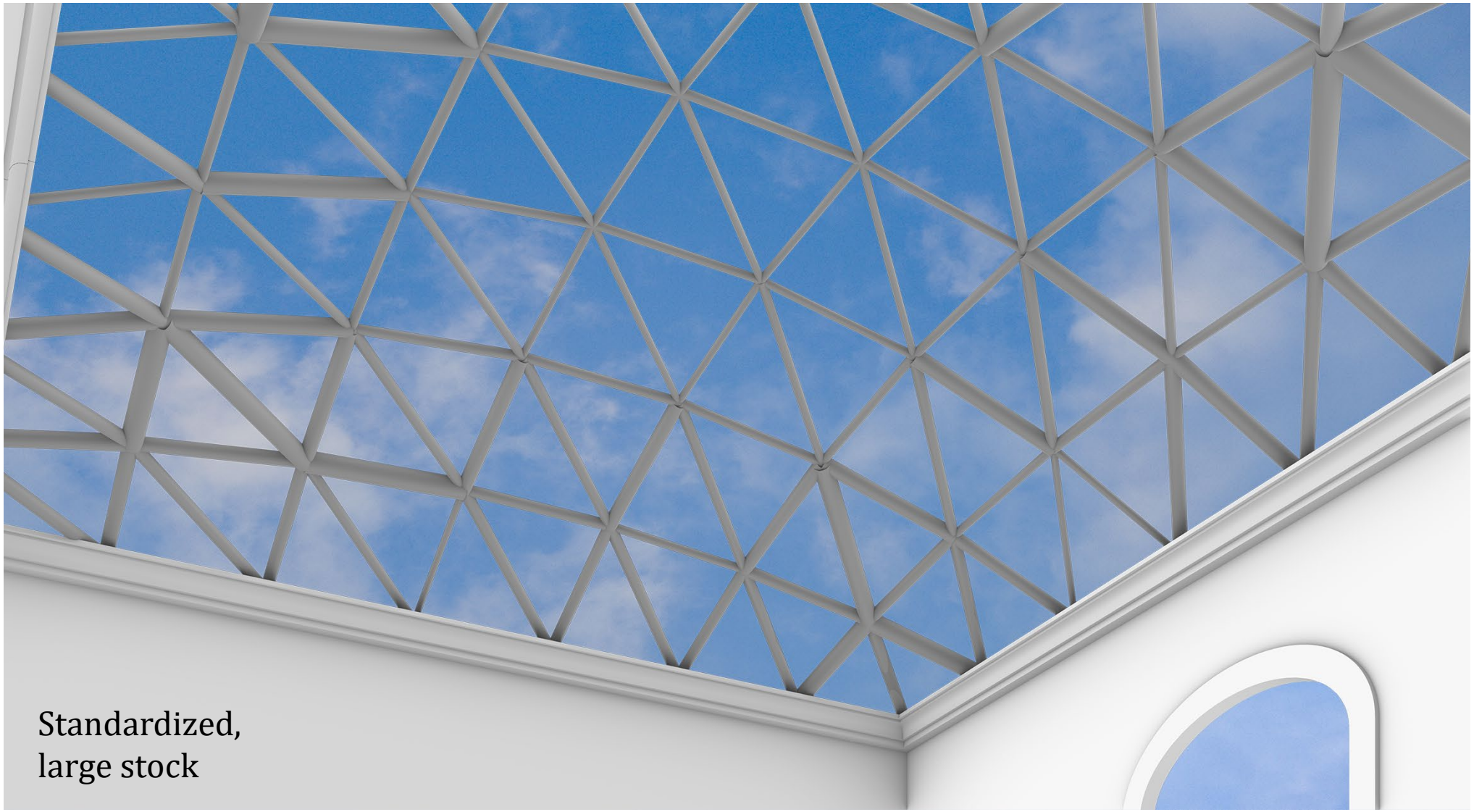
GHG-emissions: 763 $kgCO_{2eq}$
Mass structure: 1210 kg

Visualization

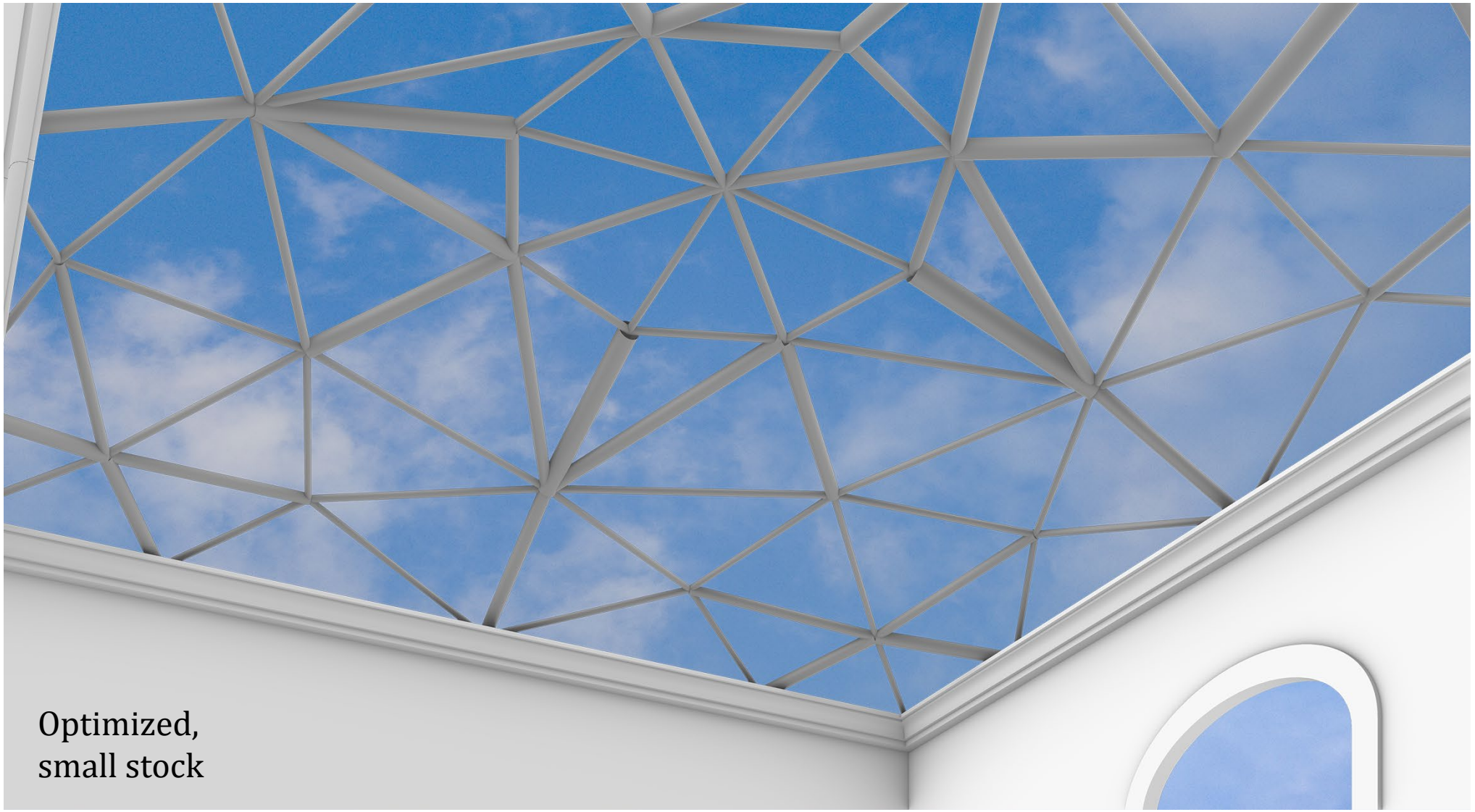
Visualization



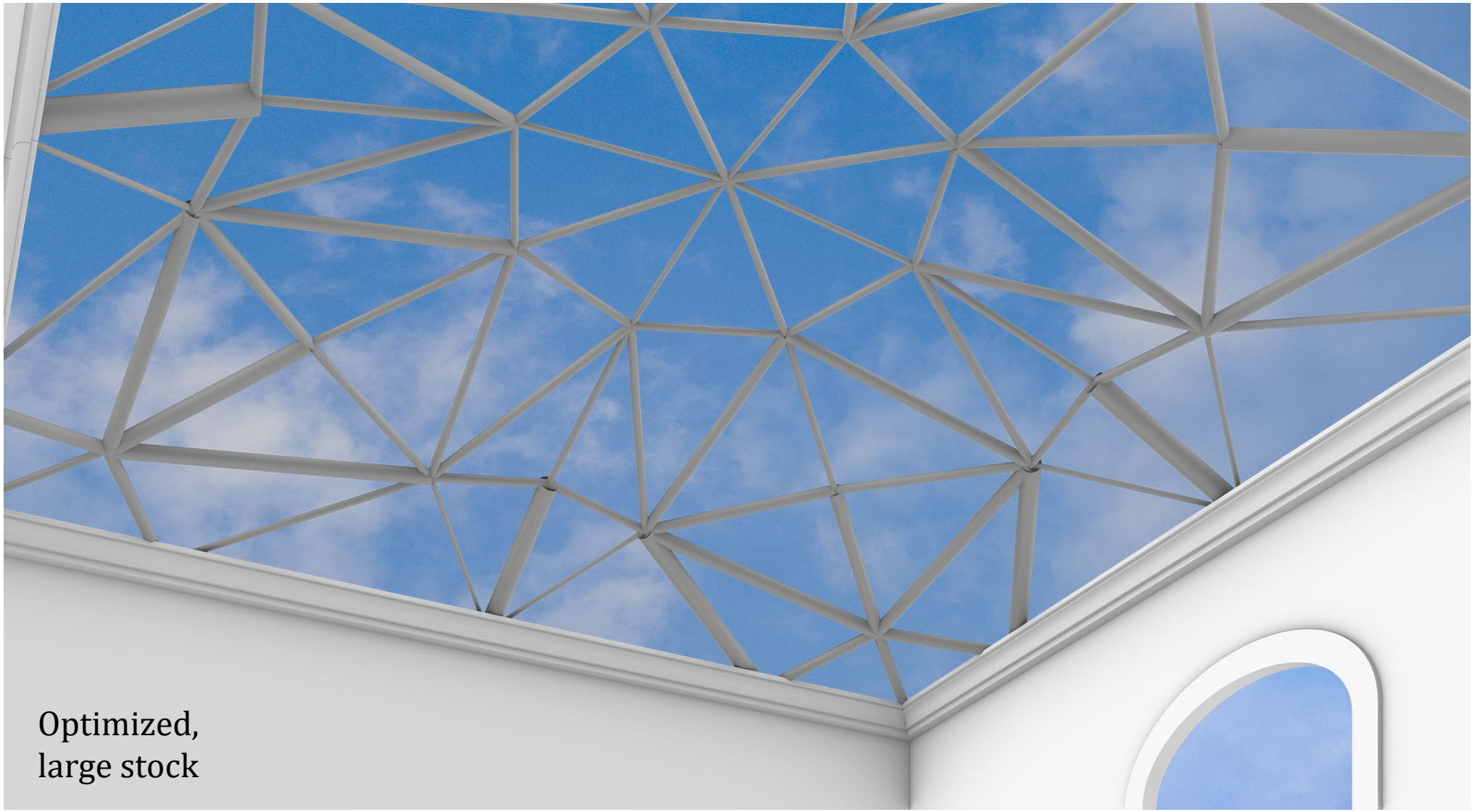
Visualization



Visualization

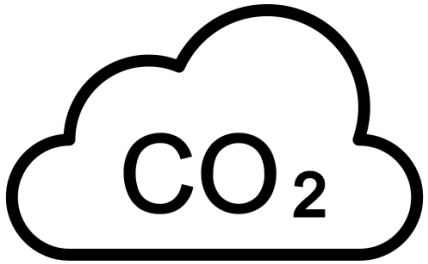


Visualization

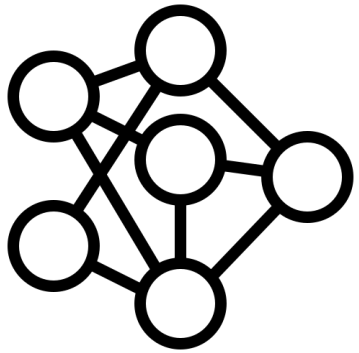


Discussion & conclusion

Discussion

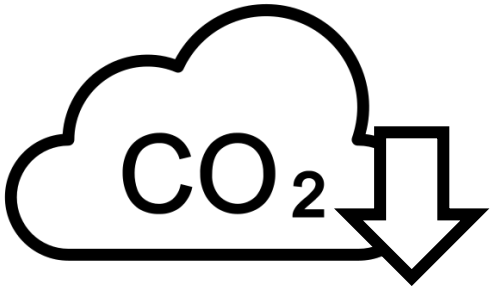


GHG-coefficients

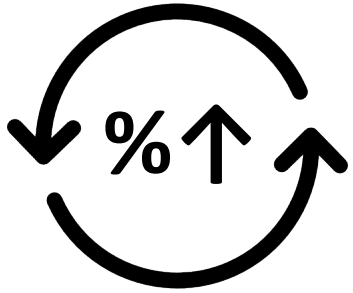


Metaheuristic algorithm

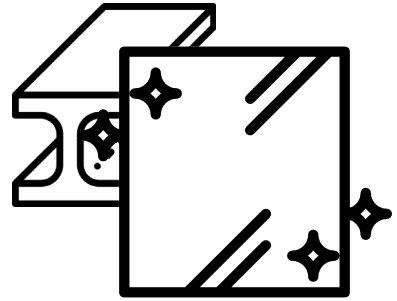
Conclusion



Reduced GHG-emissions

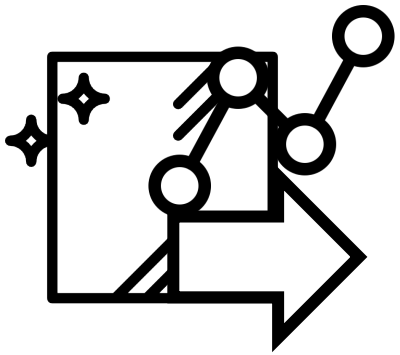


Higher RR = lower GHG

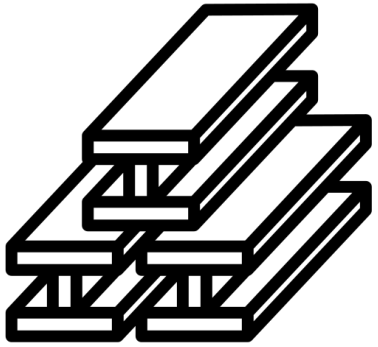


Glass of importance eco-impact

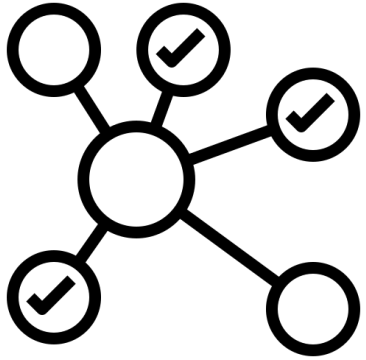
Recommendations



Further development calculation method

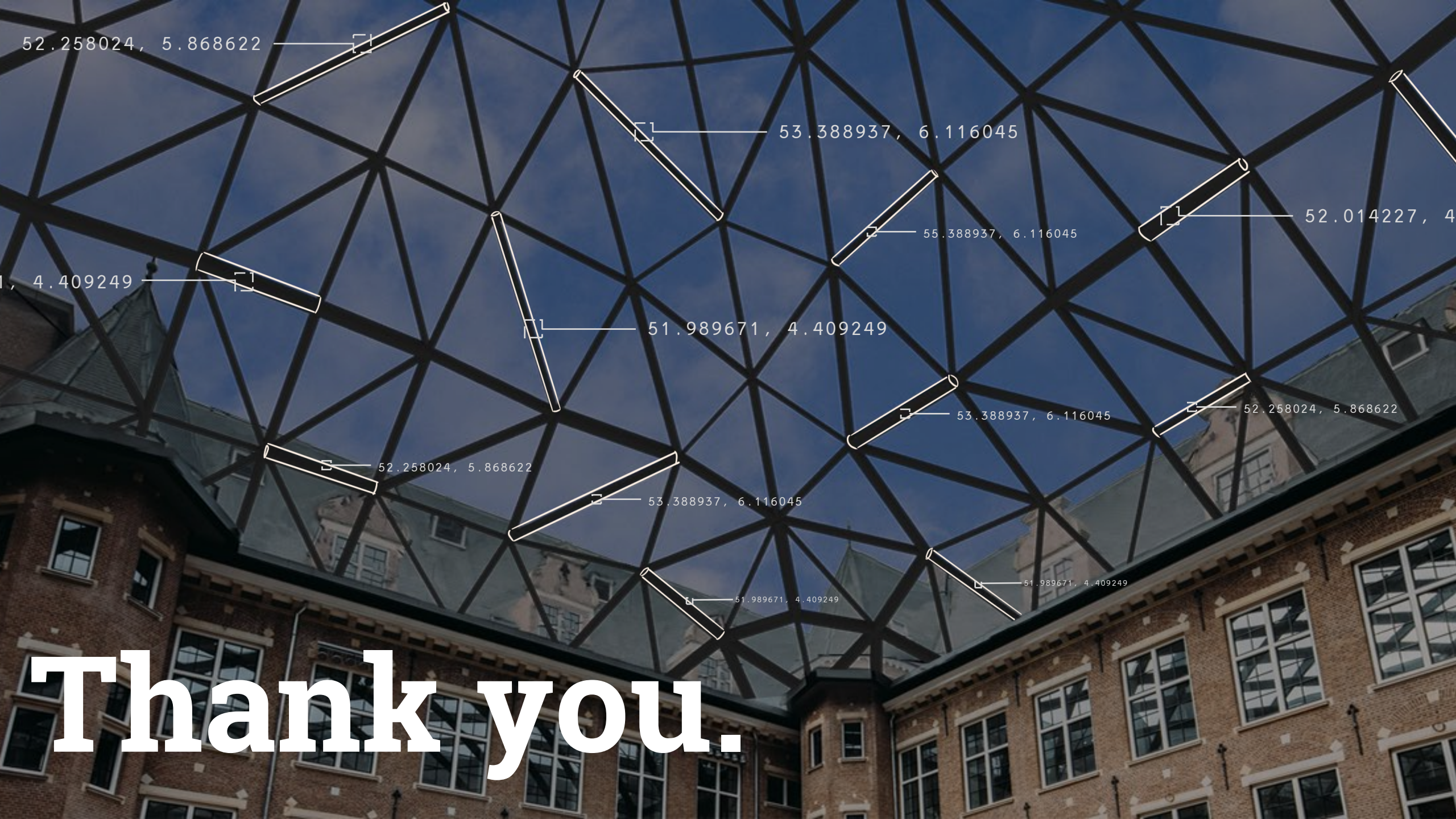


Steel dominant structures



Different contexts

Multi-criteria optimization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52.014227, 4
1, 4.409249
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53.388937, 6.116045
52.258024, 5.868622
52.258024, 5.868622
53.388937, 6.116045
51.989671, 4.409249
51.989671, 4.409249

Thank you.