Compute - Demount - Adapt

Developing a computational workflow to aid in the design of adaptable buildings

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Introduction

Current Problem

Increasing shortage of raw materials
Carbon footprint of building elements
Waste production by the building sector

> "The construction sector is responsible for circa 33% of greenhouse gas (GHG) emissions, 40% of waste generation, and 40% of raw material consumption"
>
> (Askar et al., 2022)

Circular Economy

Reducing material use and waste generation

Design for Disassembly	disassembled and reuse without processing
Design for Adaptability	**slight modifications to serve different purposes**
Design for Deconstruction	recovery for reuse, recycle, or remanufacture
Design for Reuse	applying used materials in new structures
Design for Manufacture and Assembly	using standardized components

(Smitha & Thomas, 2021)

Adaptability

Over-sizing

Image 1: Circl (de Architekten Cie, 2017).

Demountable connections

Image 2: Tijdelijke rechtbank Amsterdam (cepezed, 2015).

Adaptability

Over-sizing

No need for structural adaptations
Increase in material use

Demountable connections

Alterations needed for transformations
Less material use

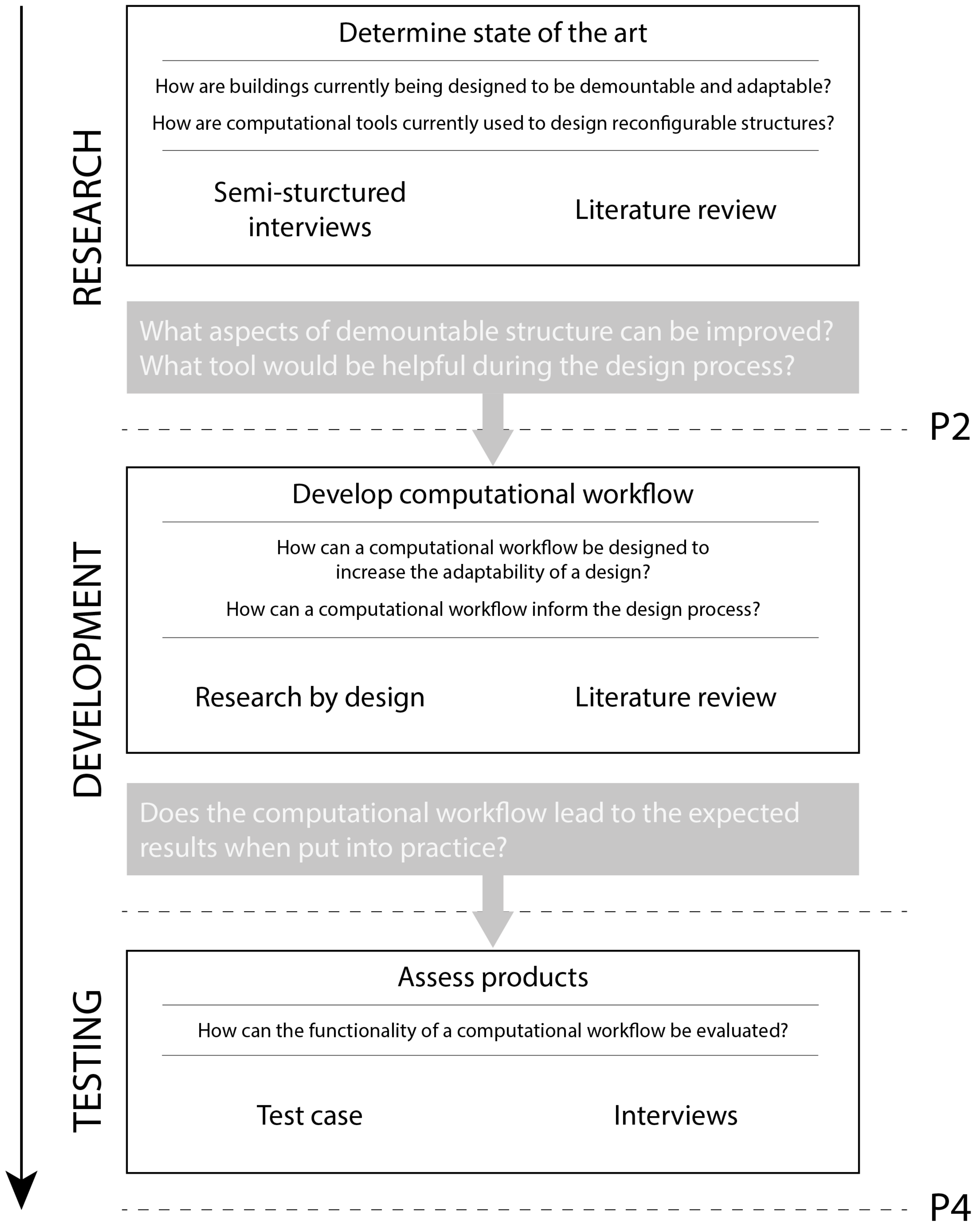
Research Question

How can a computational workflow be used to increase the amount of **adaptability** in a design, while **minimizing material use**?

Research structure

Divided into three stages

Stages inform each other



Preliminary Research

Advantages

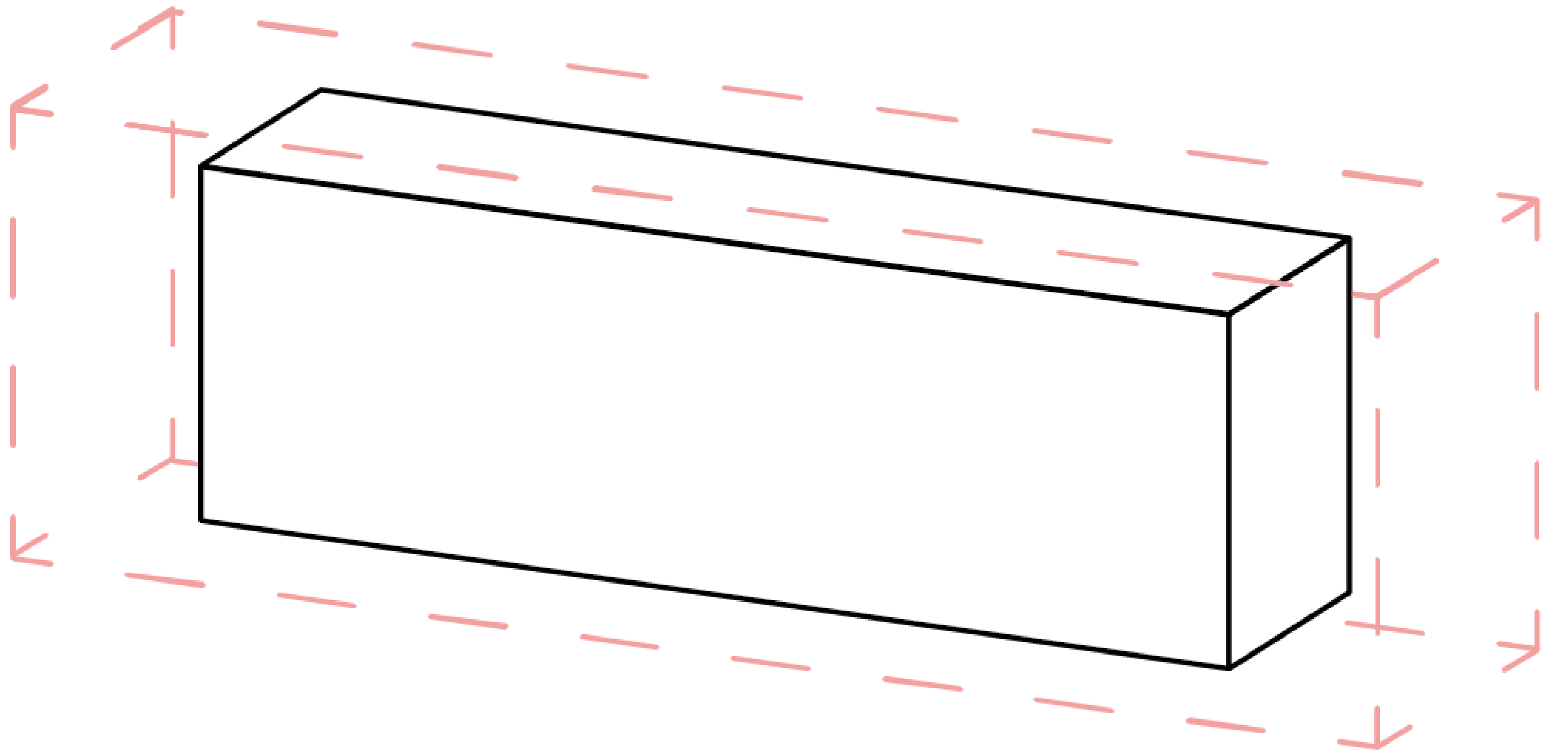
Order of priority for sustainable buildings

1. Creating adaptability
2. Minimize material usage
3. Creating demountability → Prefabrication, Flexibility, Reuse possibilities

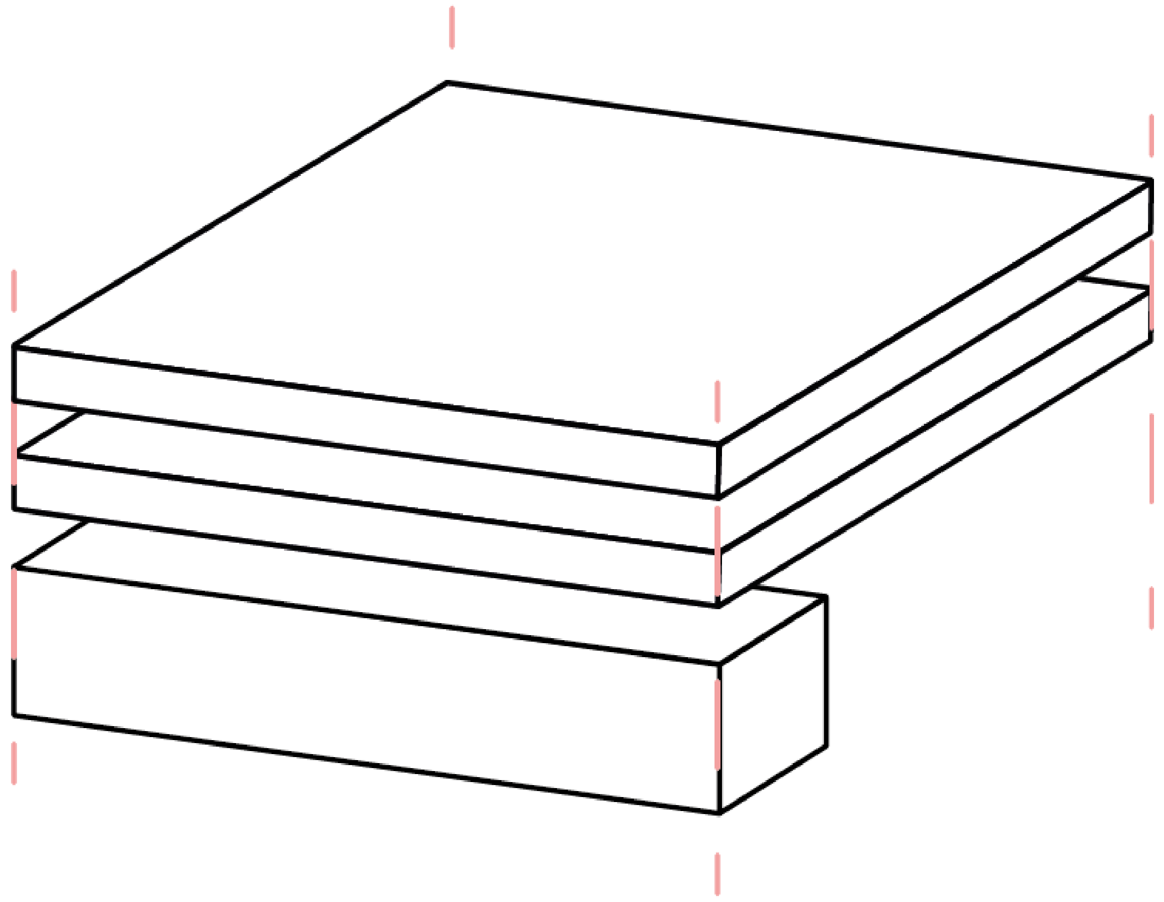
Prefabrication → Increased quality, Faster production, More production possibilities

Methods

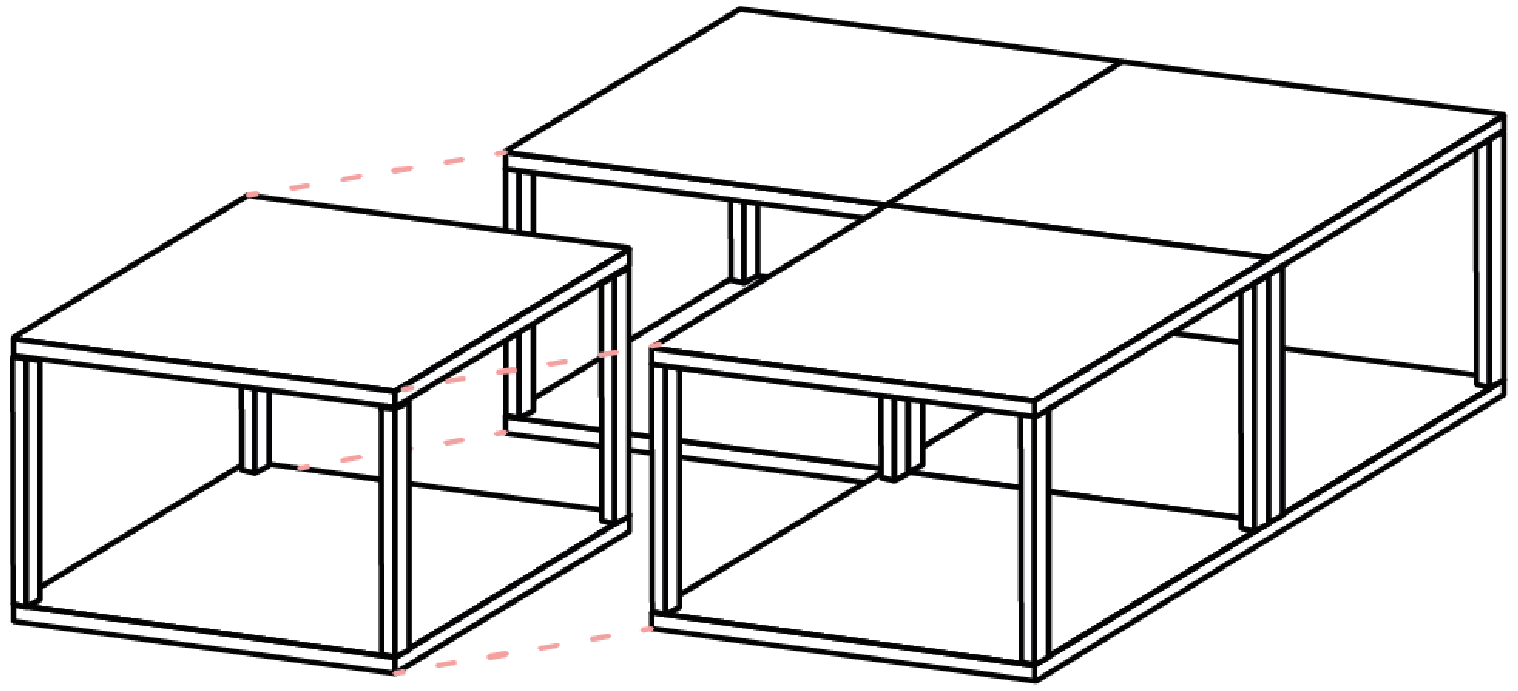
Oversizing elements
Reduce need to replace elements



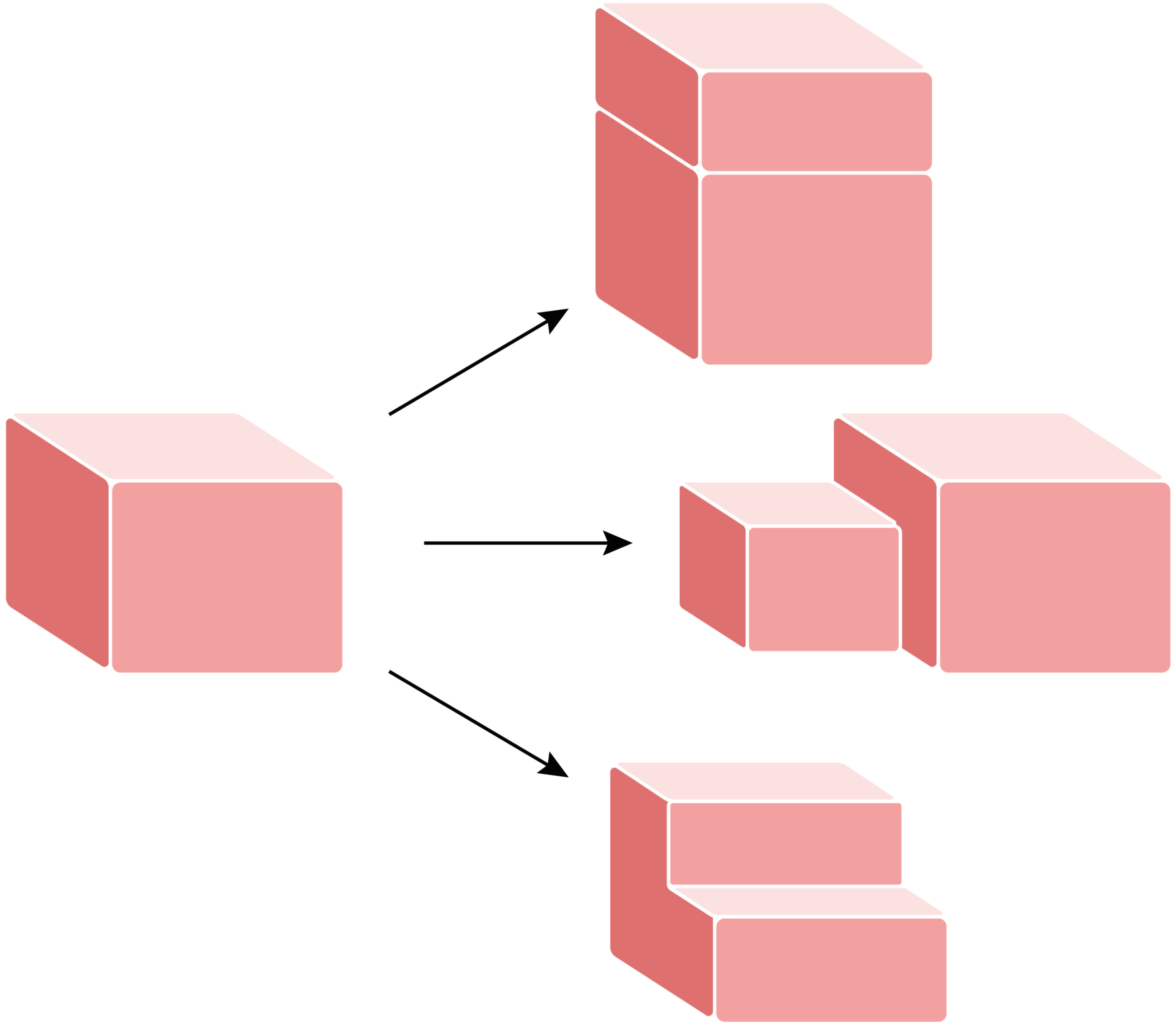
Seperating layers
Easier to replace elements



Modular structure
Easier to replace and reuse elements



Scenario-based Design



Assess how design can be adapted to the different scenarios

Test for possible future needs

Difficulties

Cost

Unwillingness to implement adaptability

Does not fit into budget

Computational Workflow

Goal

1. Lower costs

High costs lead to limited possibilities to increase adaptability of a building

Focus adaptable measures where they are needed

2. Balance material use

Find balance between creating adaptability and minimizing material use

State-of the art

Focused on reusing elements in other configurations

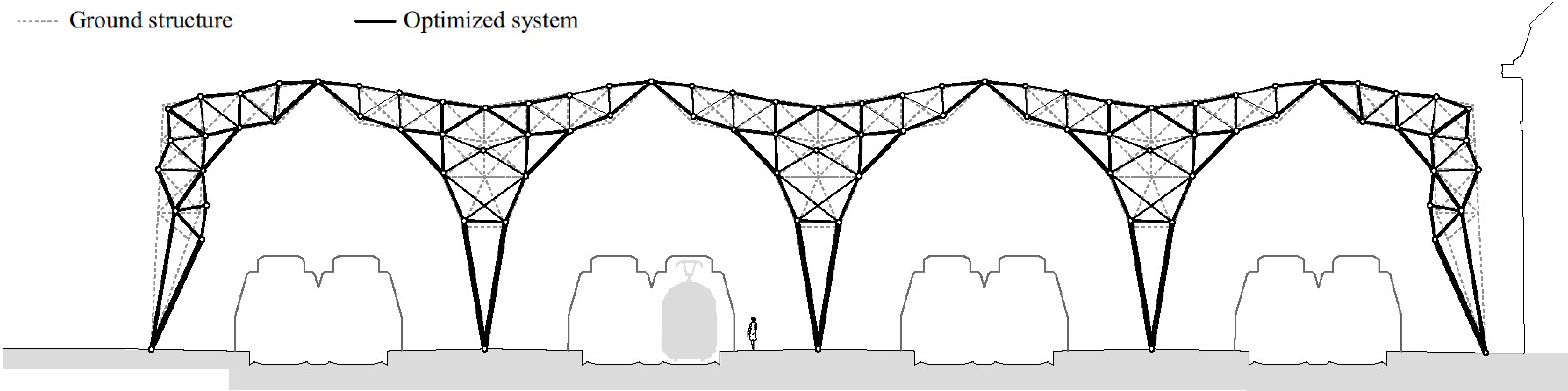


Image 3: Train structure (Brütting et al., 2018)

Computational Workflow

Used by architect or structural engineer

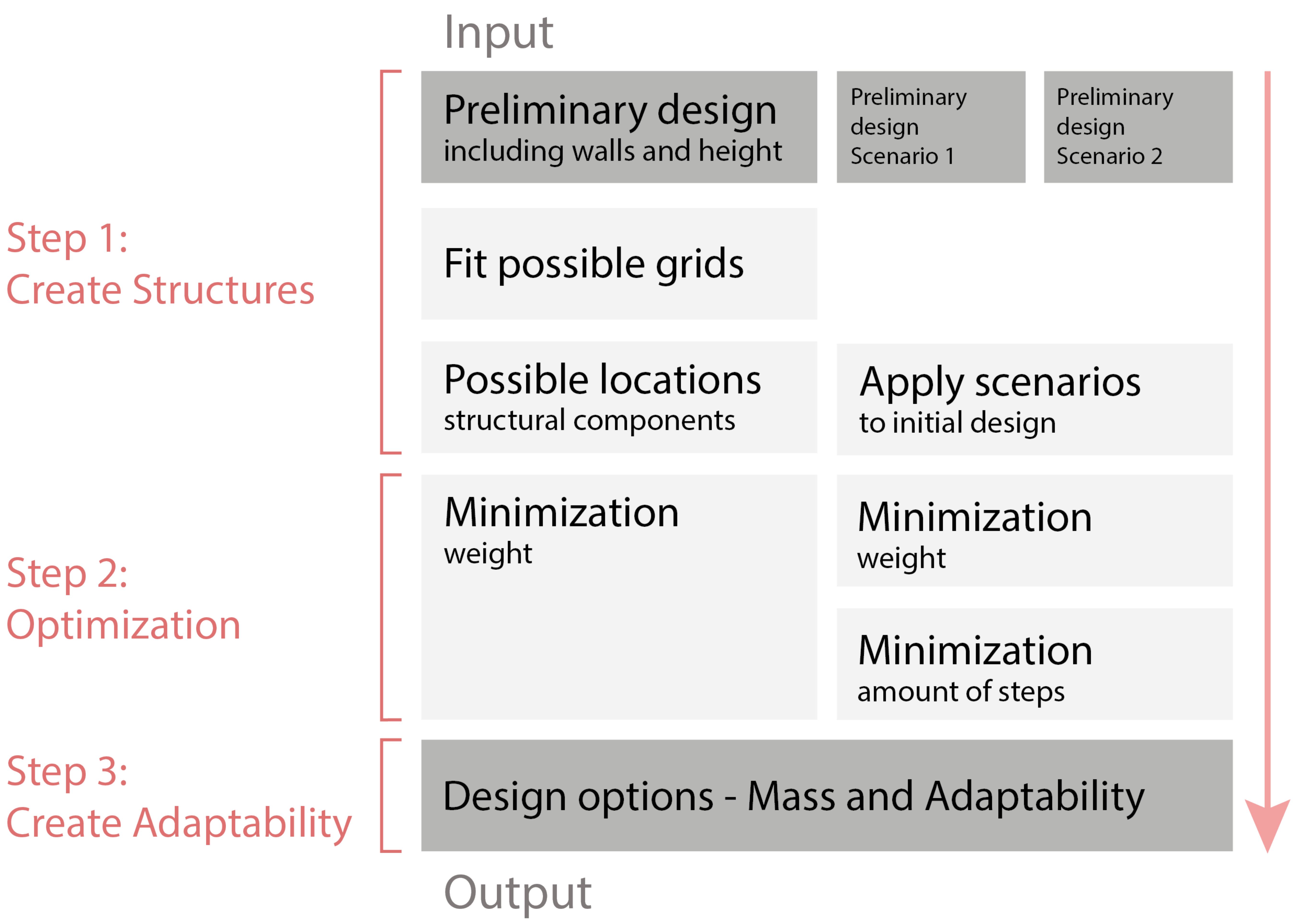
Preliminary design stage

Grasshopper and Karamba
- Test many scenarios and variants

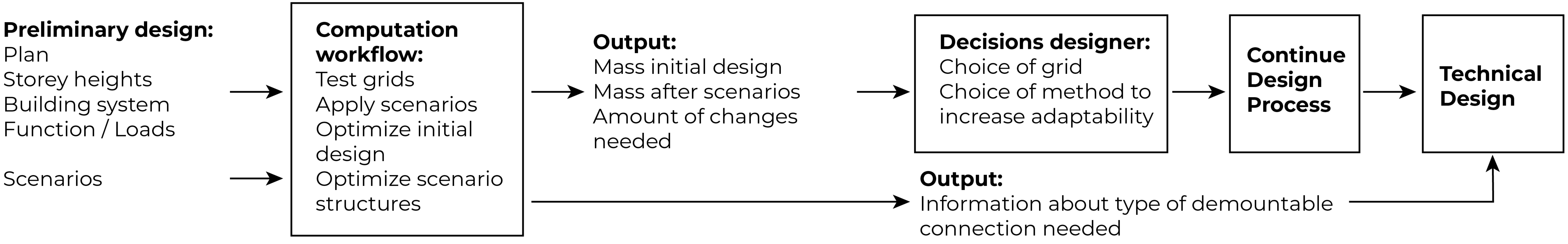
grasshopper

Karamba
parametric engineering

Overview workflow



Design process



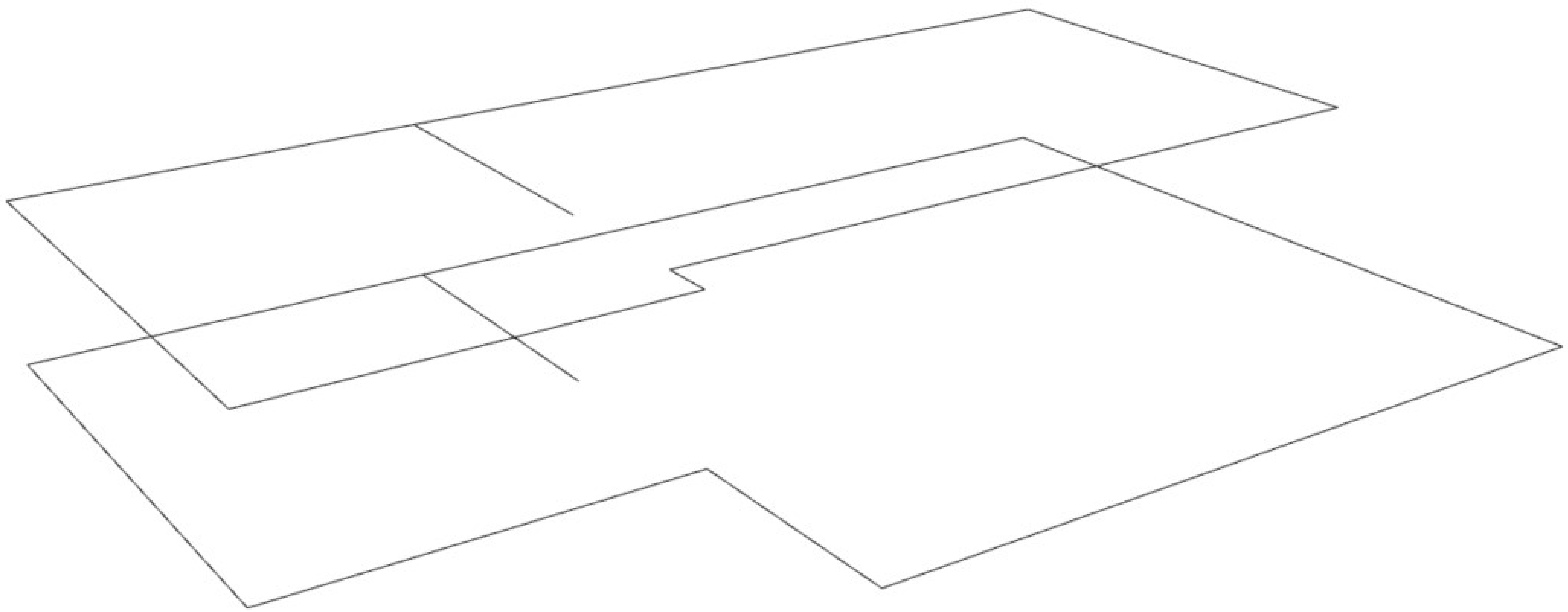
Test-case

Set-up

Input

Location of interior and exterior walls

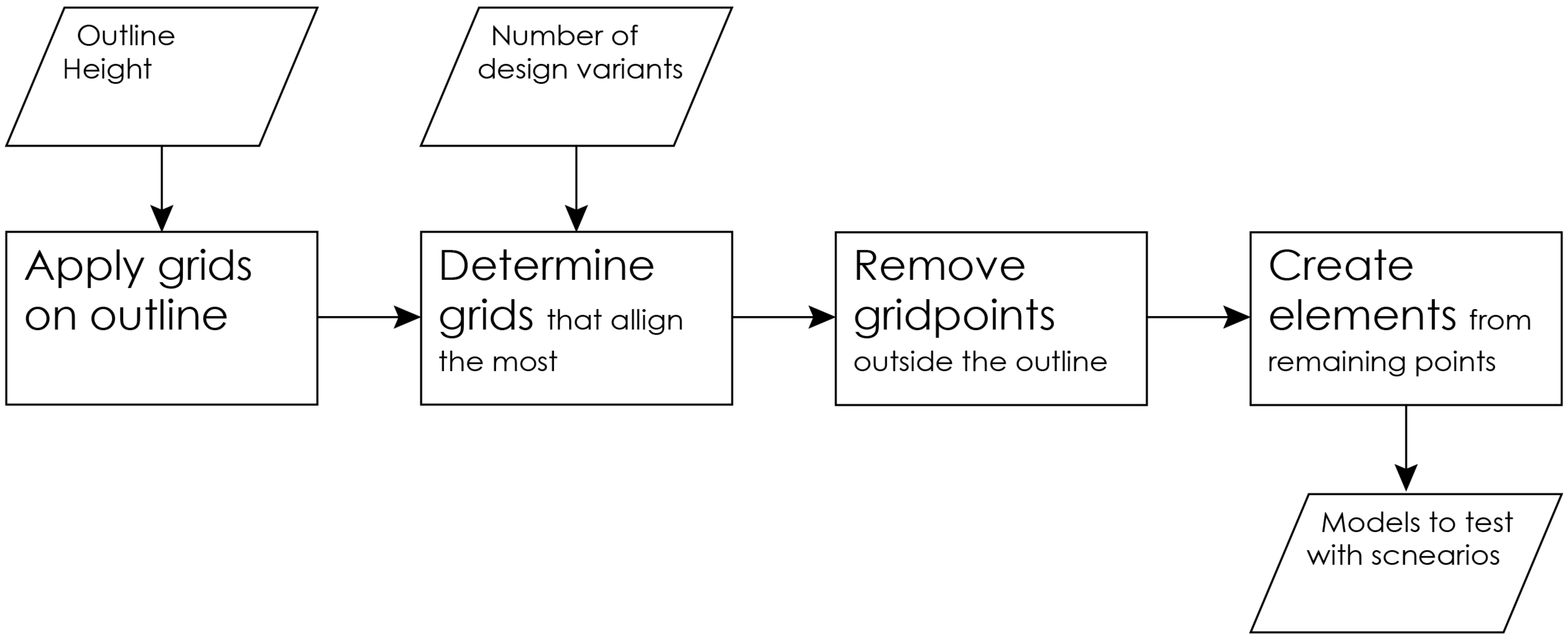
Height of building



Office Building
Floorplan of about 22m by 15m
2 storeys of 3m high

Design variants

Gridsize influences
- Adaptability
- Material use

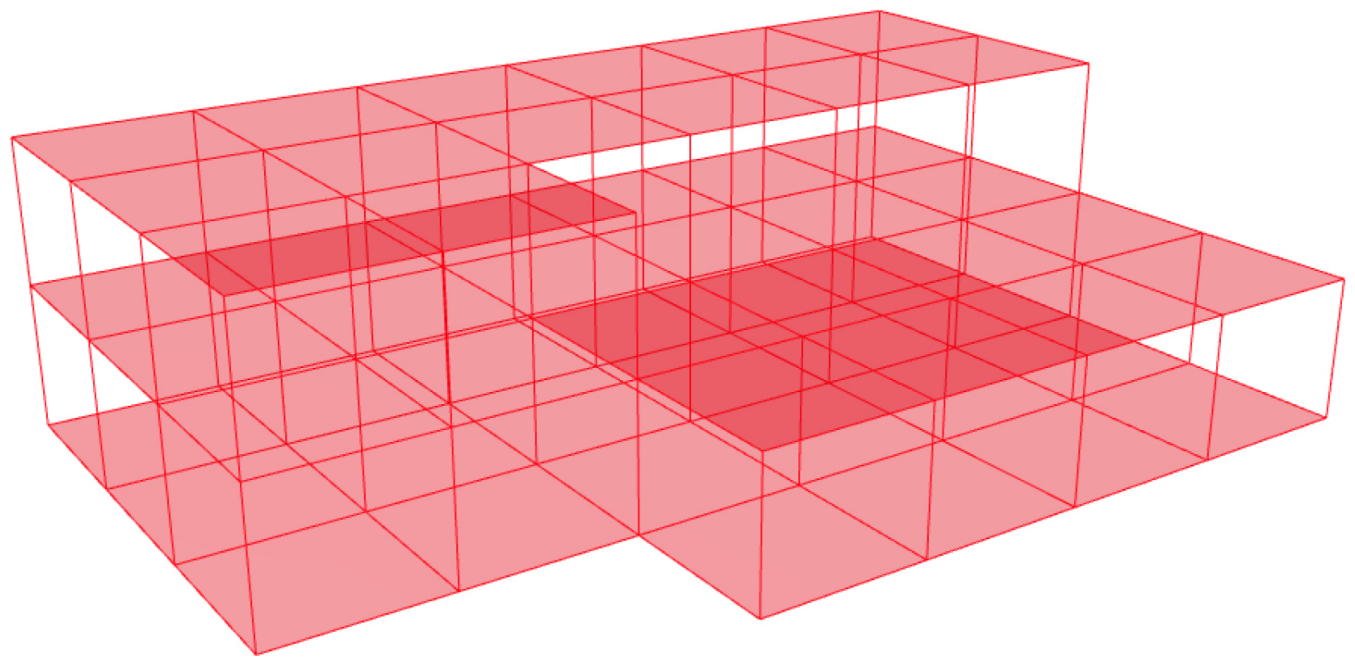


Design variants

Create Structures

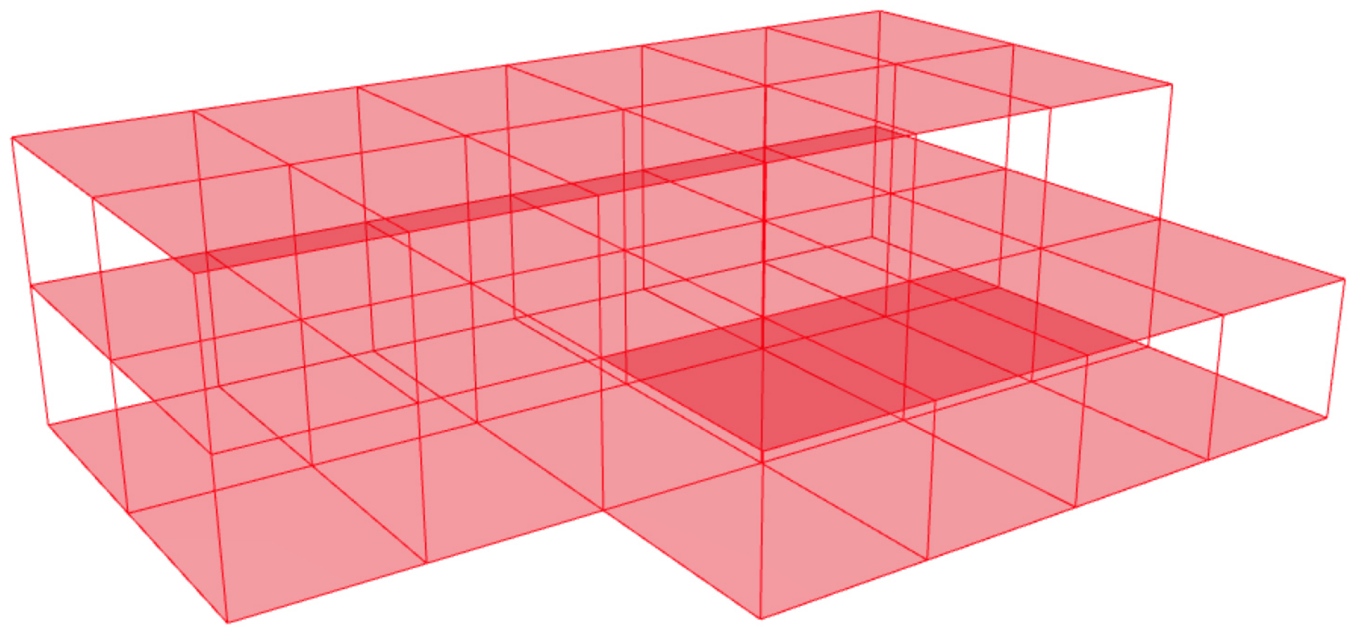
Optimize

Create Adaptability



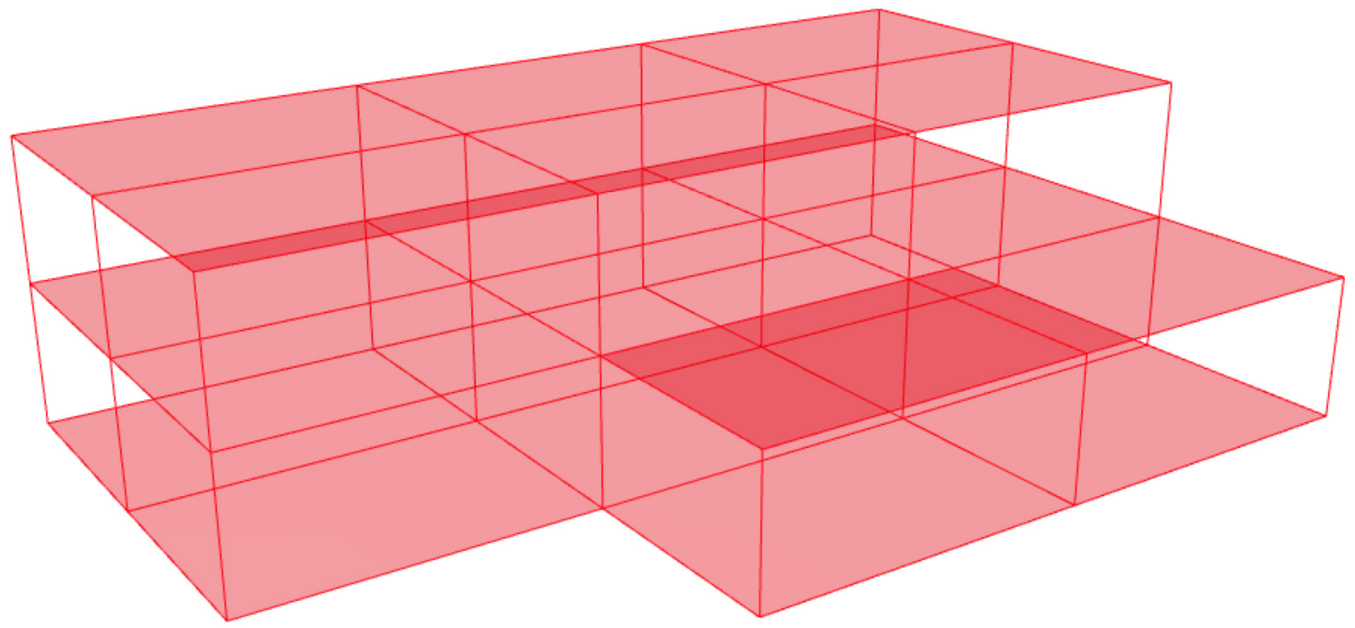
Grid 1

3.6 x 3.6 meter



Grid 2

3.6 x 4.8 meter



Grid 3

7.2 x 4.8 meter

Scenario types

Create Structures | Optimize | Create Adaptability

Transformation
- Grid is similar
- Grid is larger than needed

→ Type 1: **Removing elements**

Adding extra floors
- Limited amount of extra floors
- Separate structure needed

→ Type 2: **Adding floors**

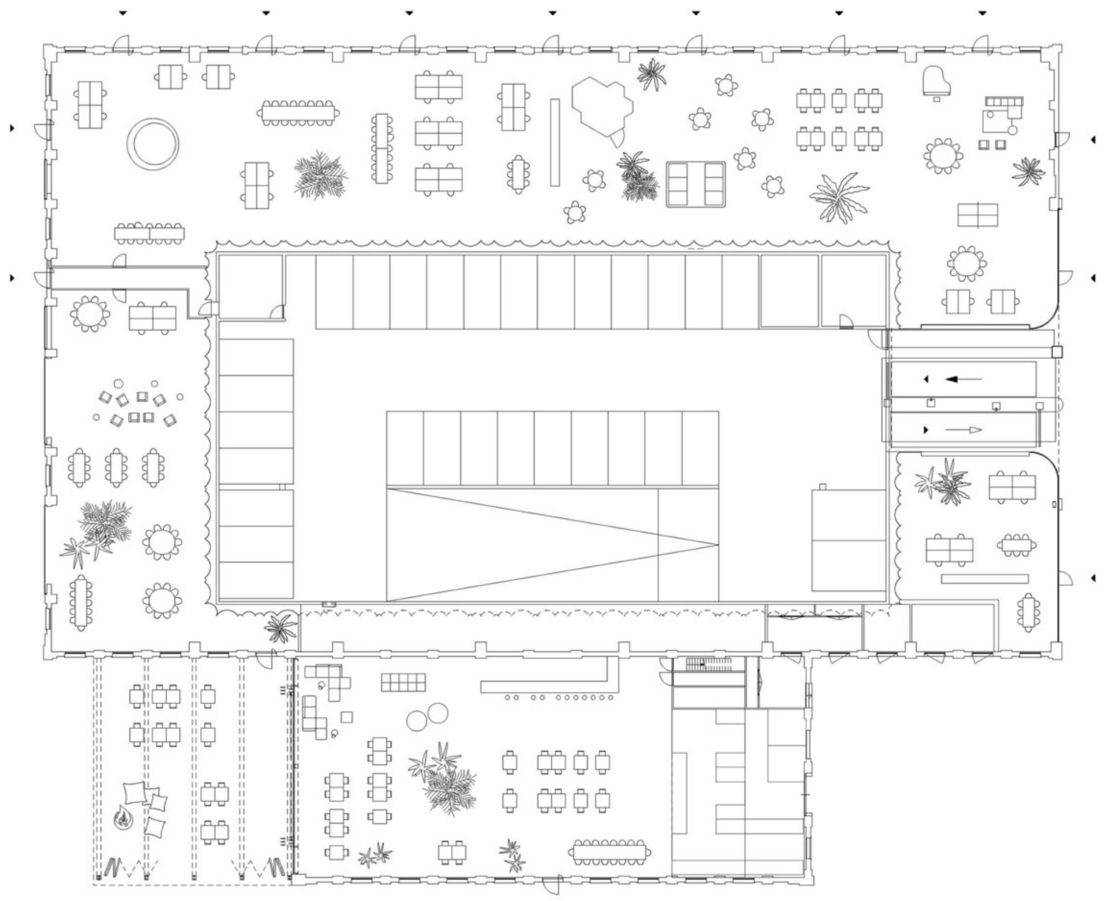


Image 4: Ground Floor (KCAP, 2022)

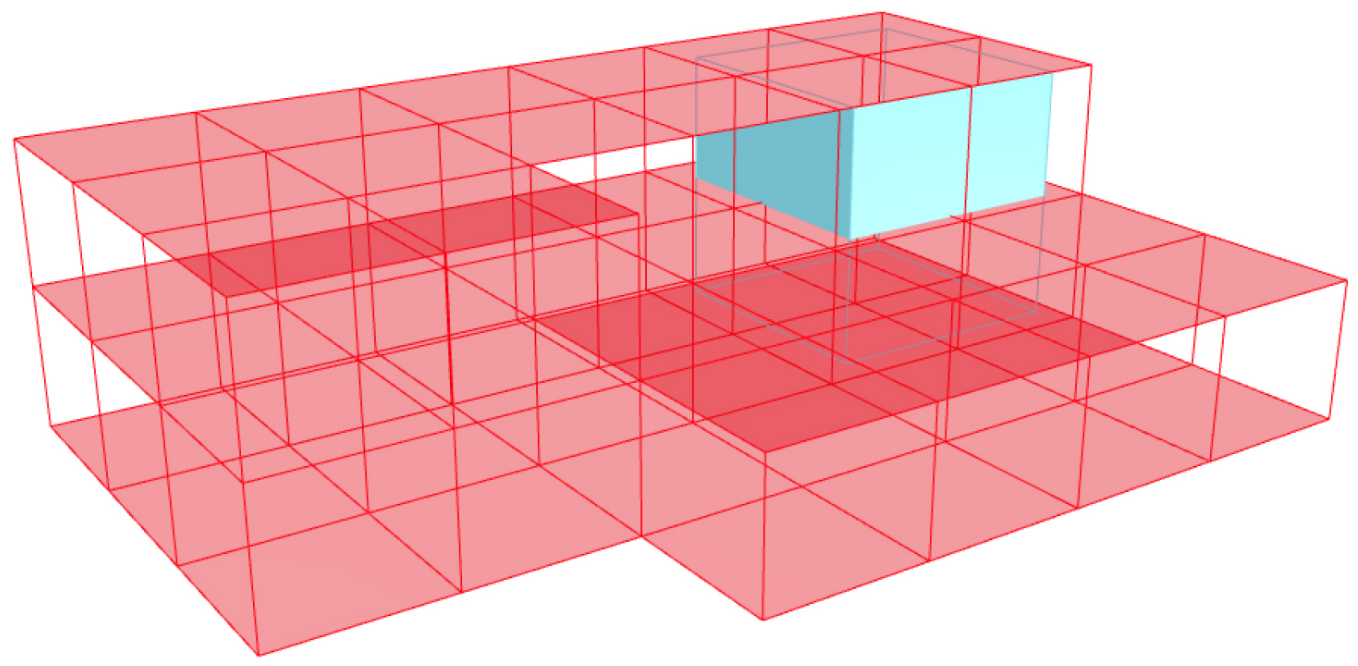
Image 5: Fenix I (Mei architect and planners, 2019)

Image 6: Jobsveem (Mei architects and planners, 2008)

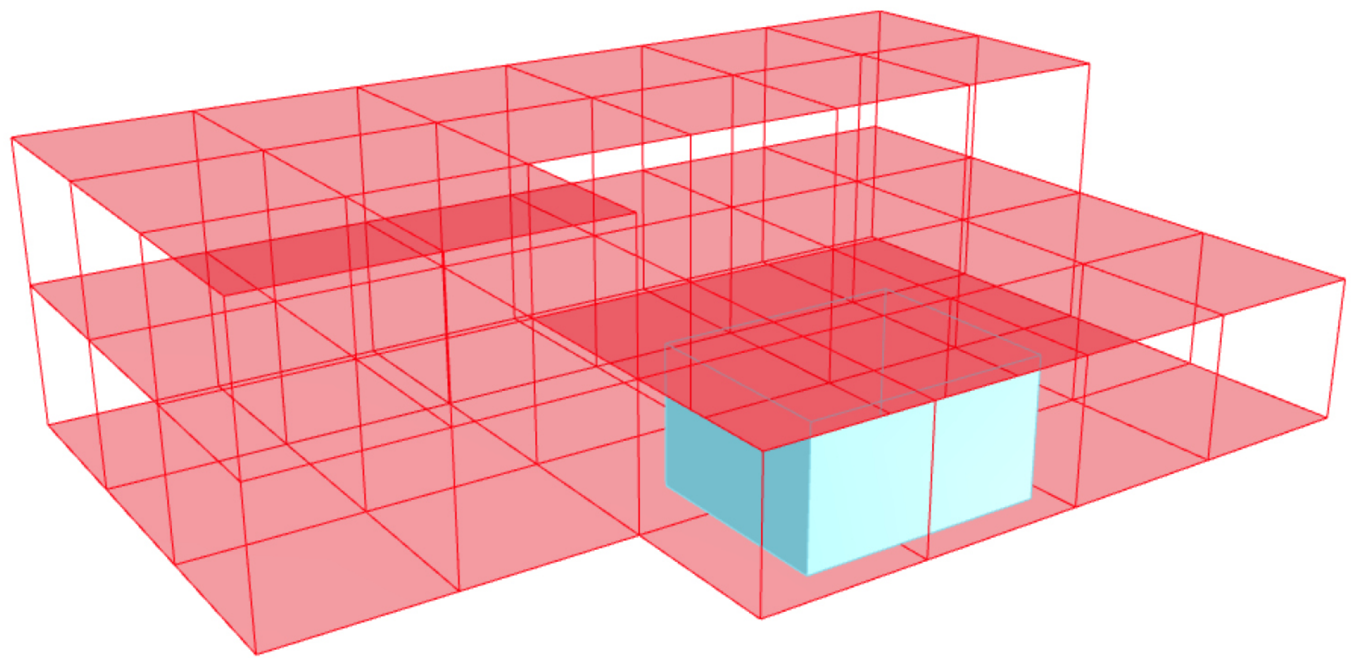
Image 7: VIPP Chimney House (Studio David Thulstrup, 2019)

Scenarios

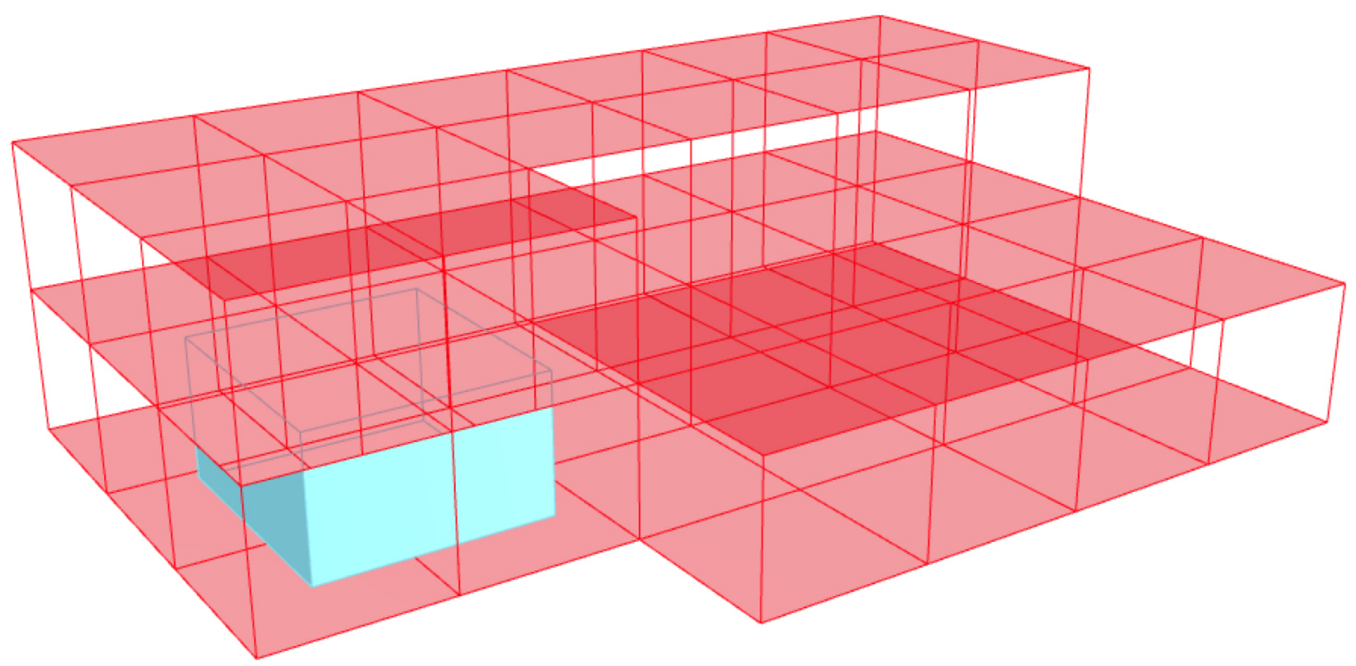
1 - Removing elements



A

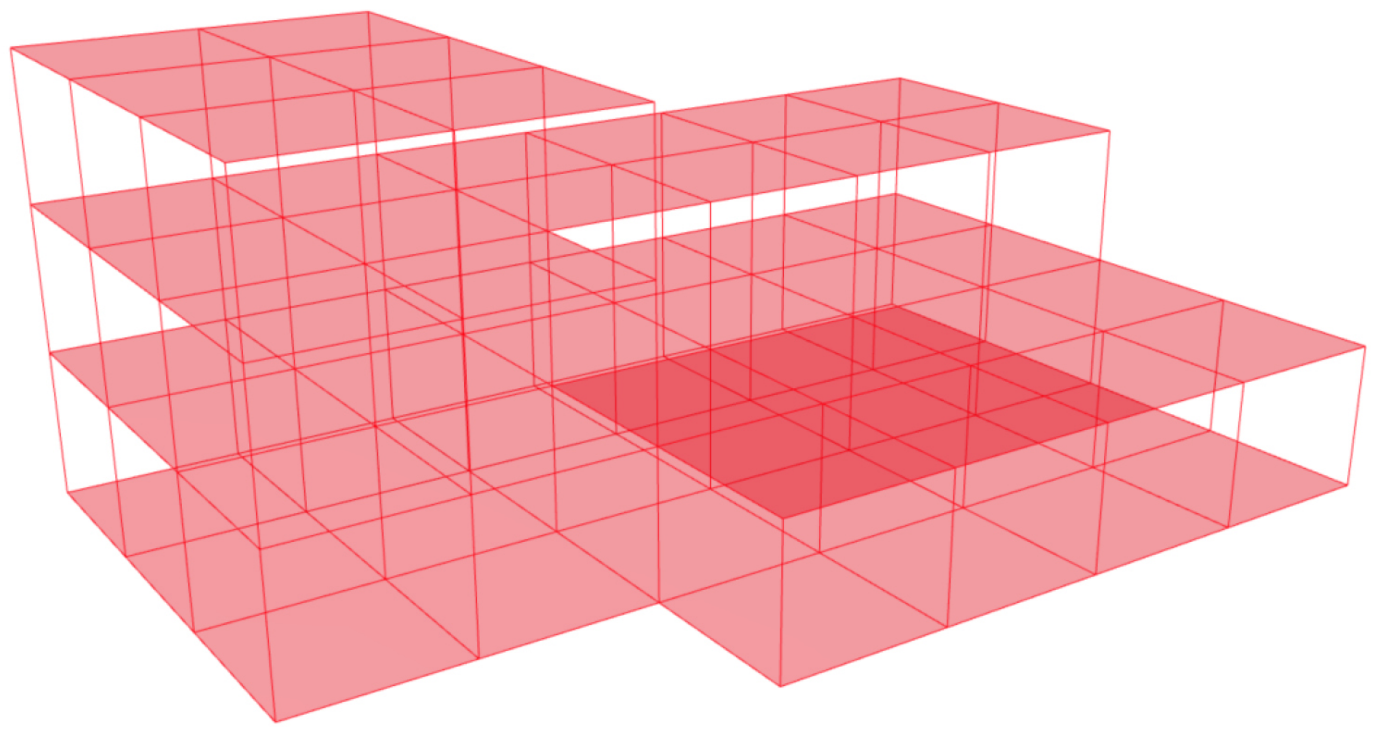


B



C

2 - Adding floors



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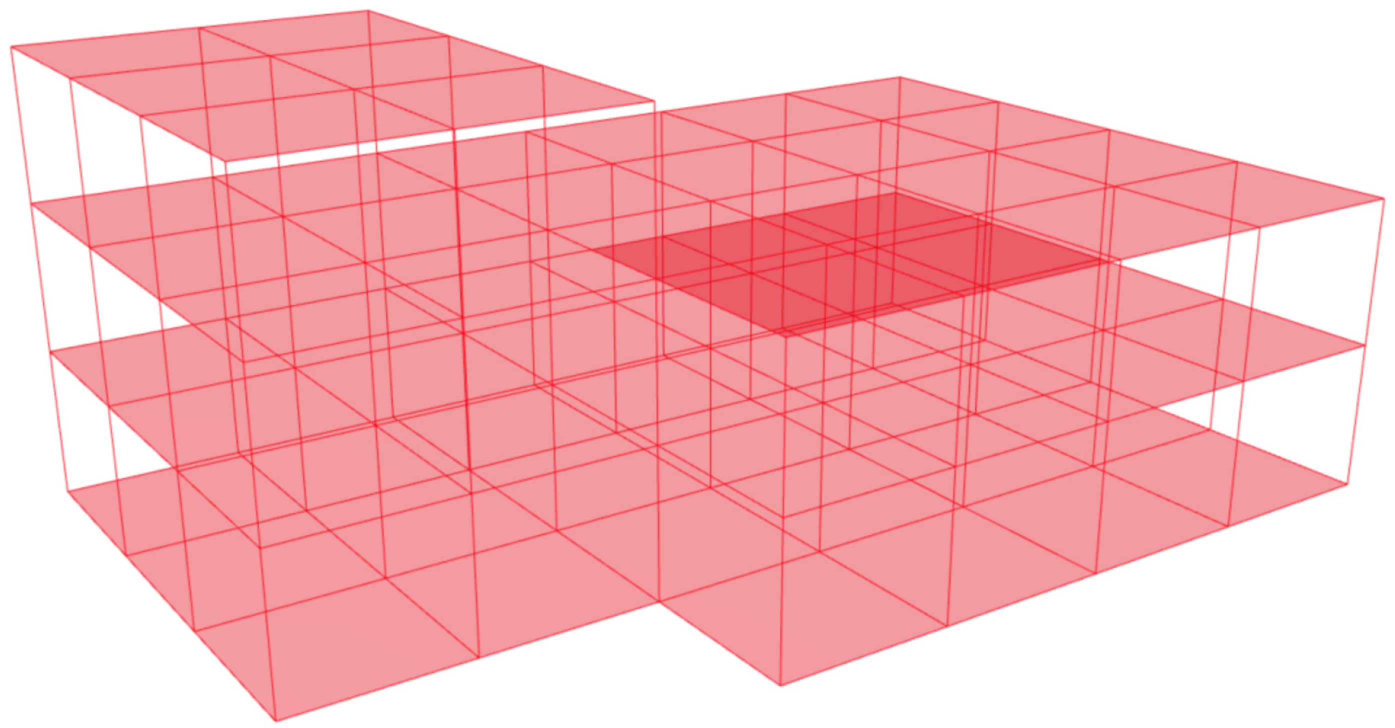

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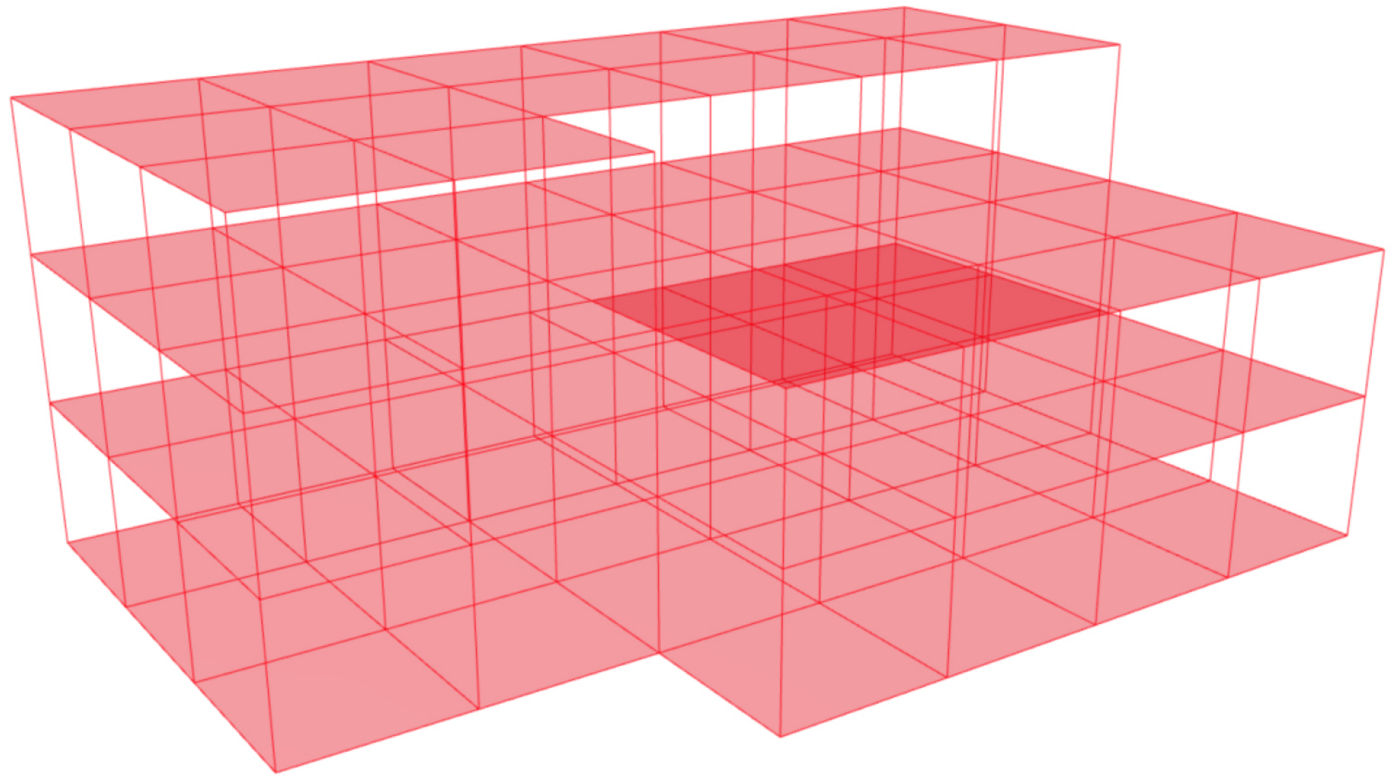

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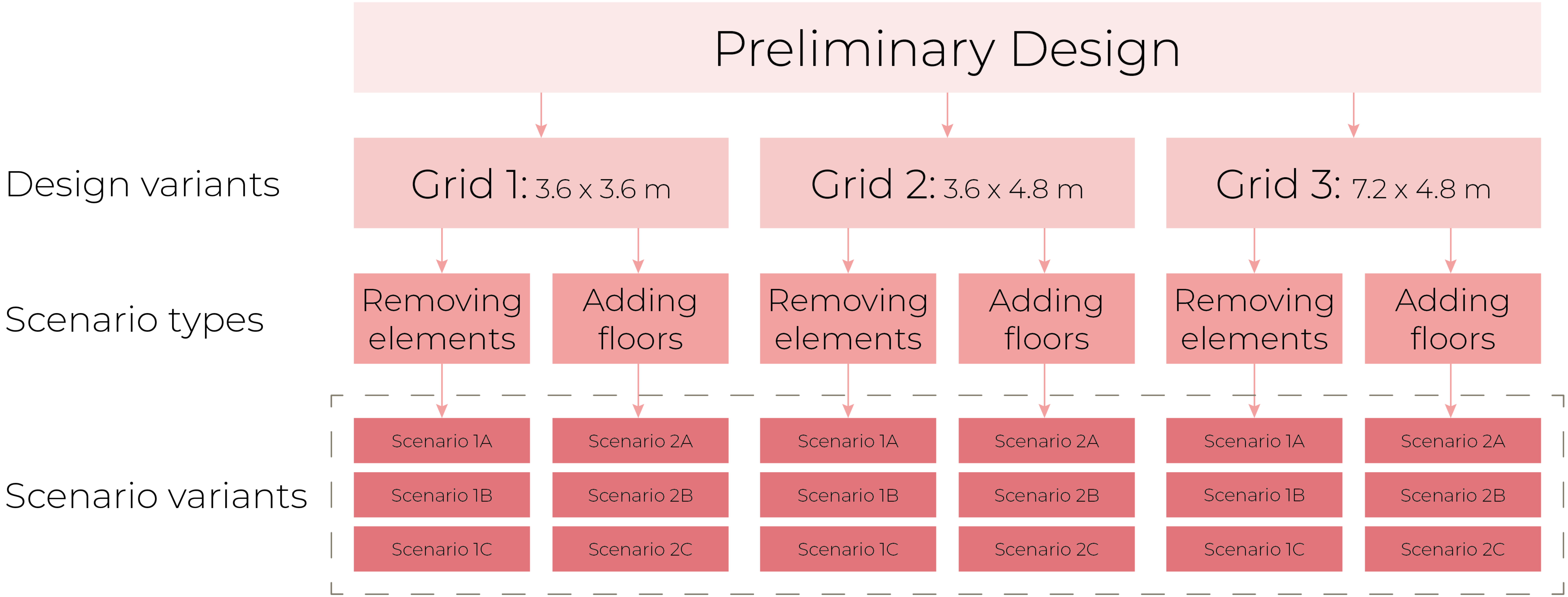
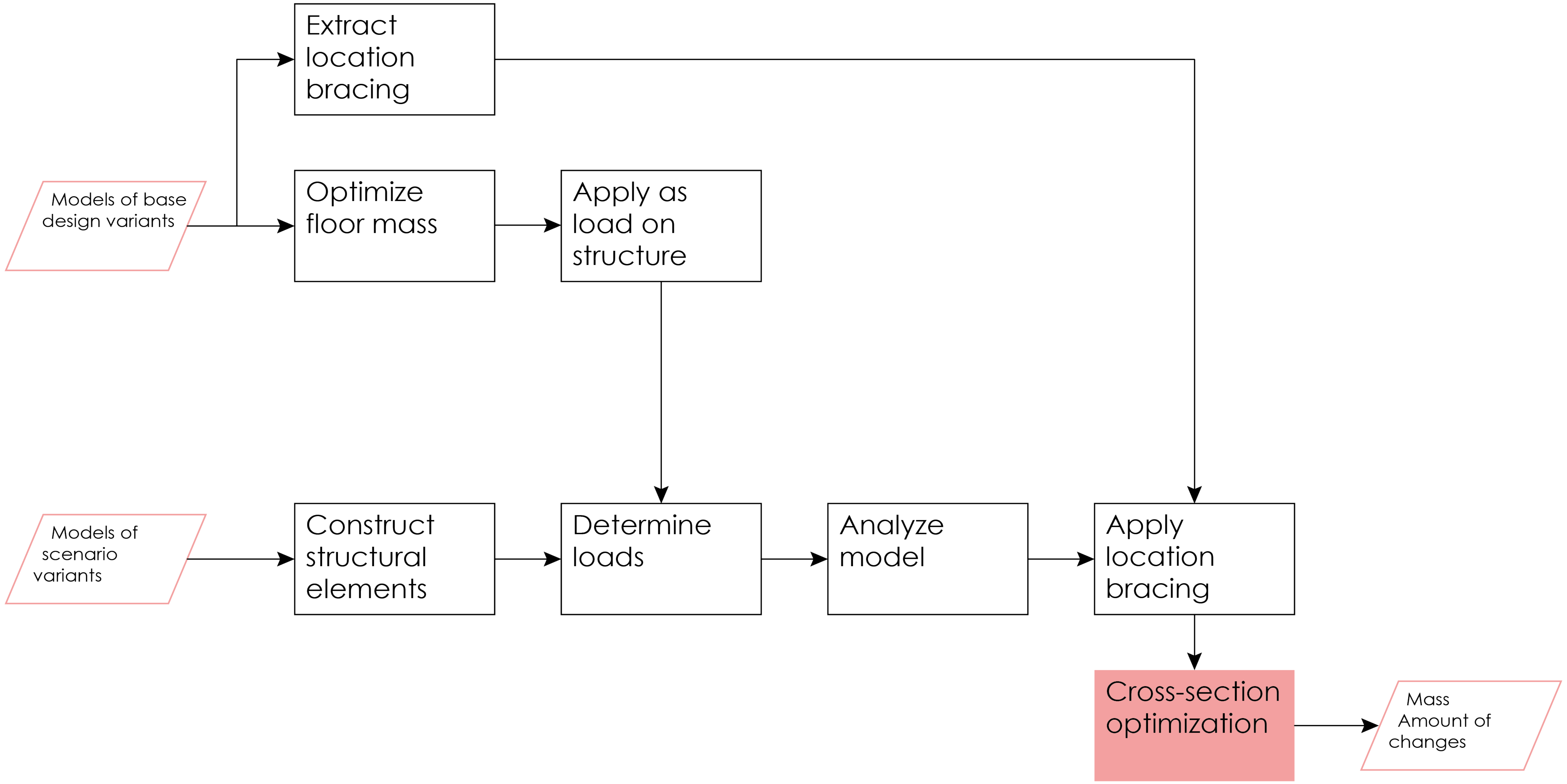
Data structure



Approach 1

Minimal mass

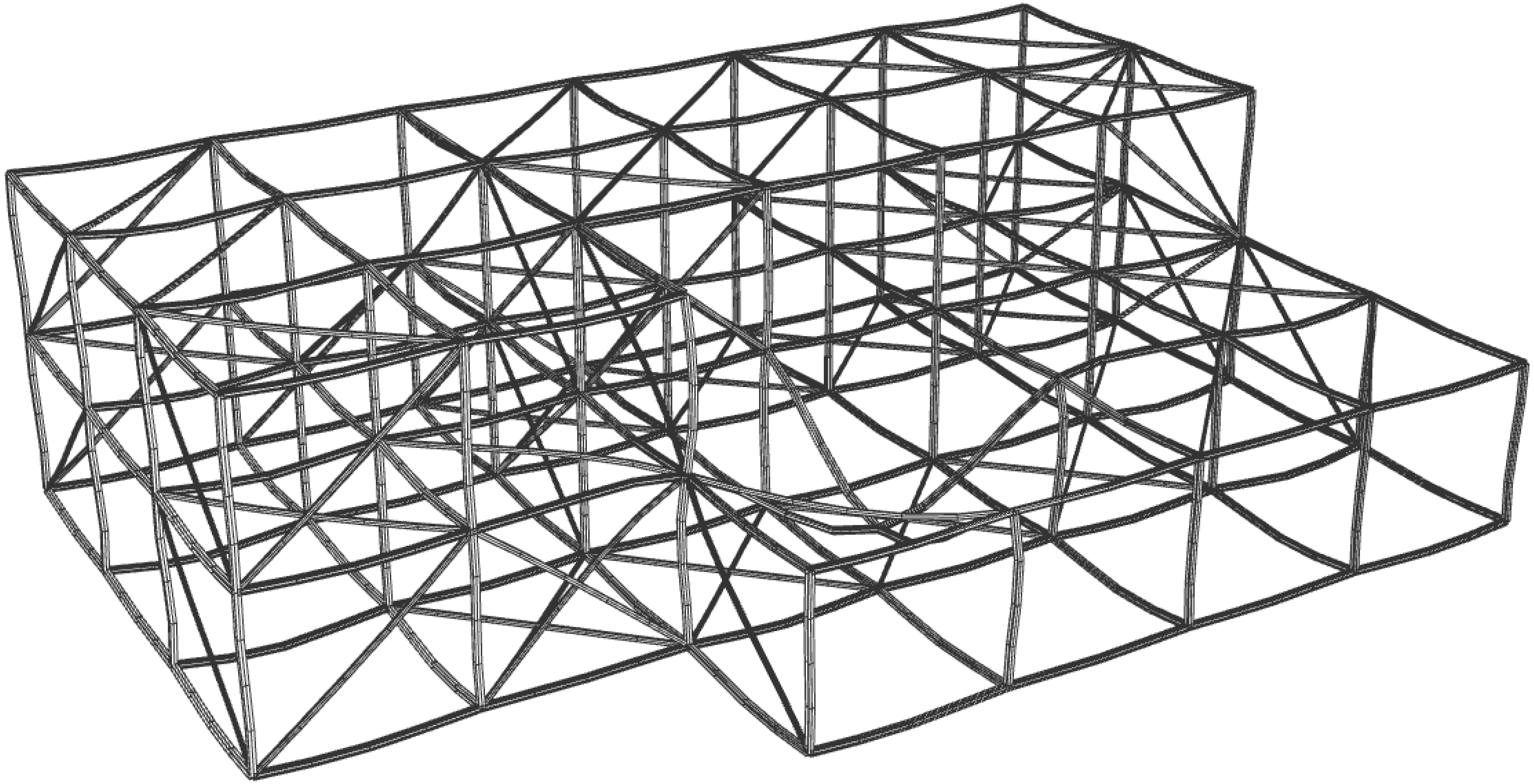


Approach 1

Minimal mass

Scenario 1

before optimization

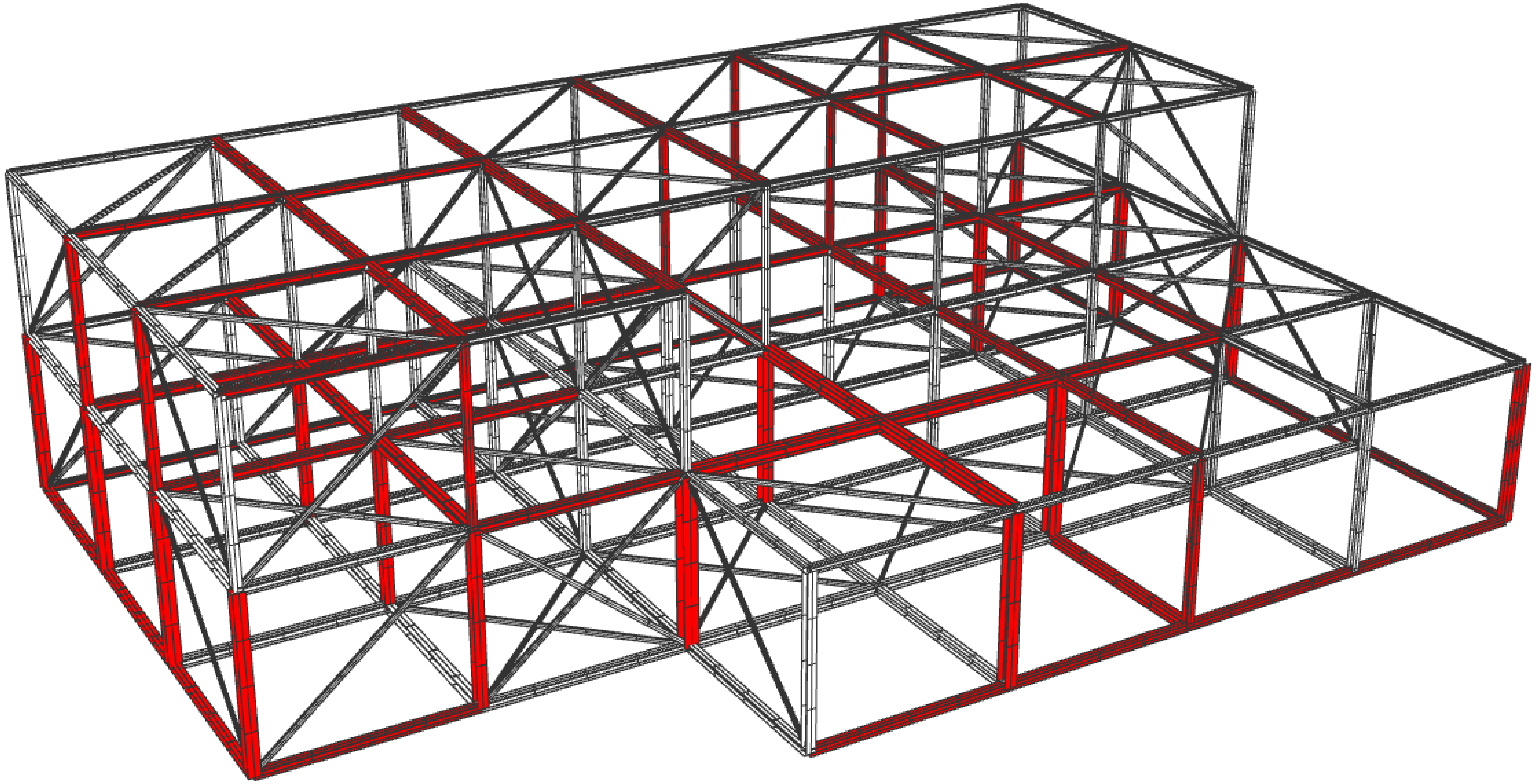


Approach 1

Minimal mass

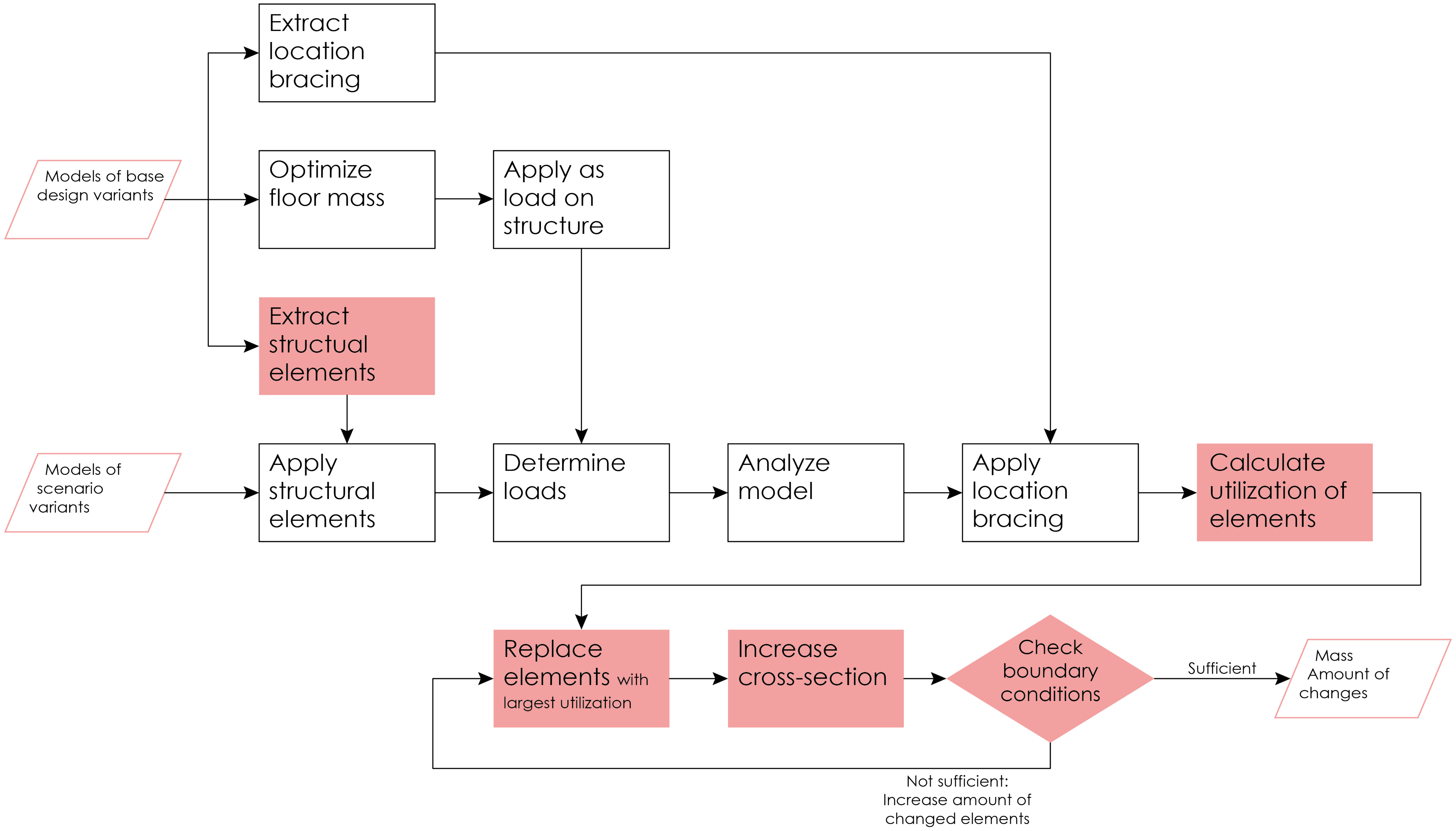
Scenario 1

after optimization



Approach 2

Minimal changes

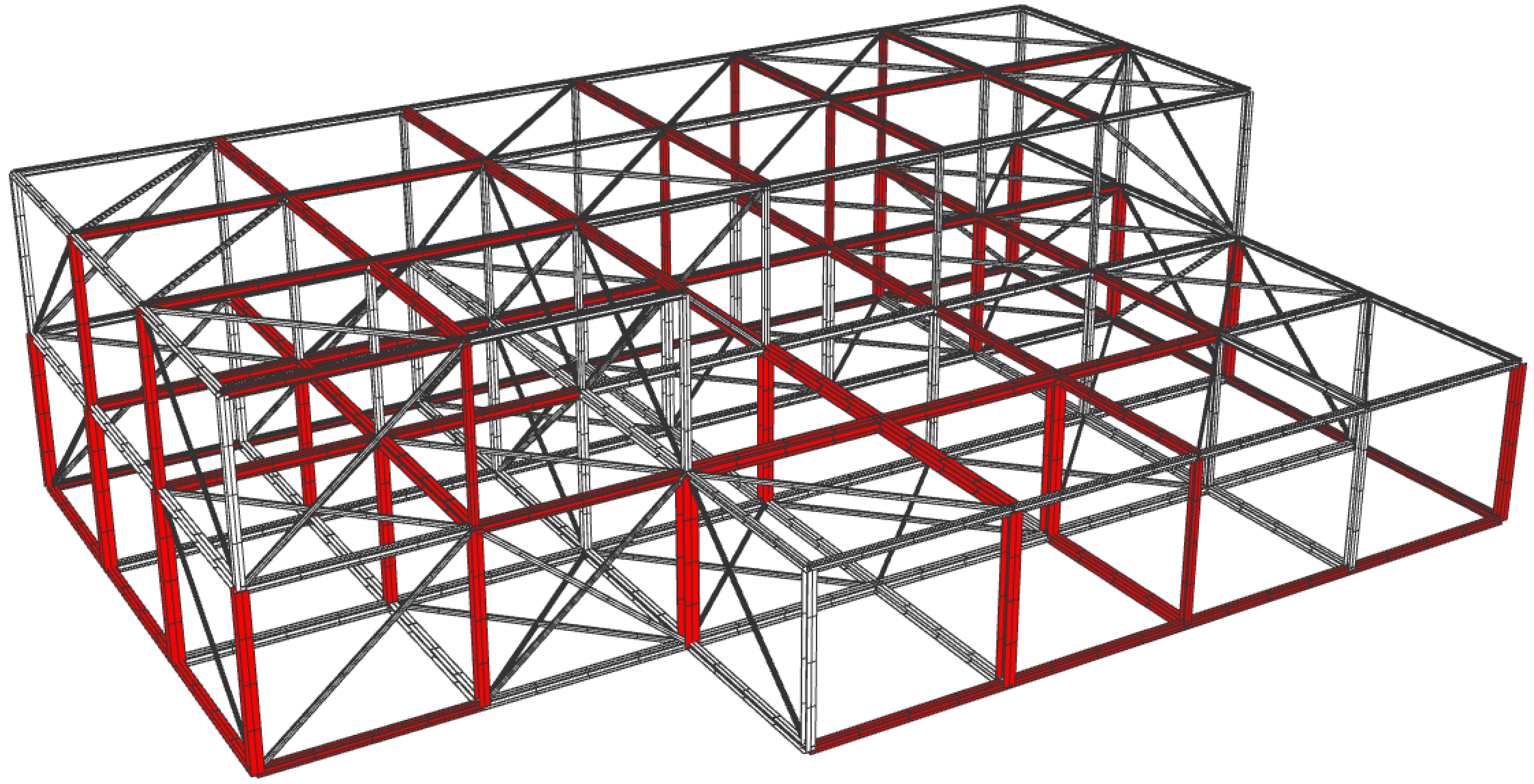


Approach 2

Minimal changes

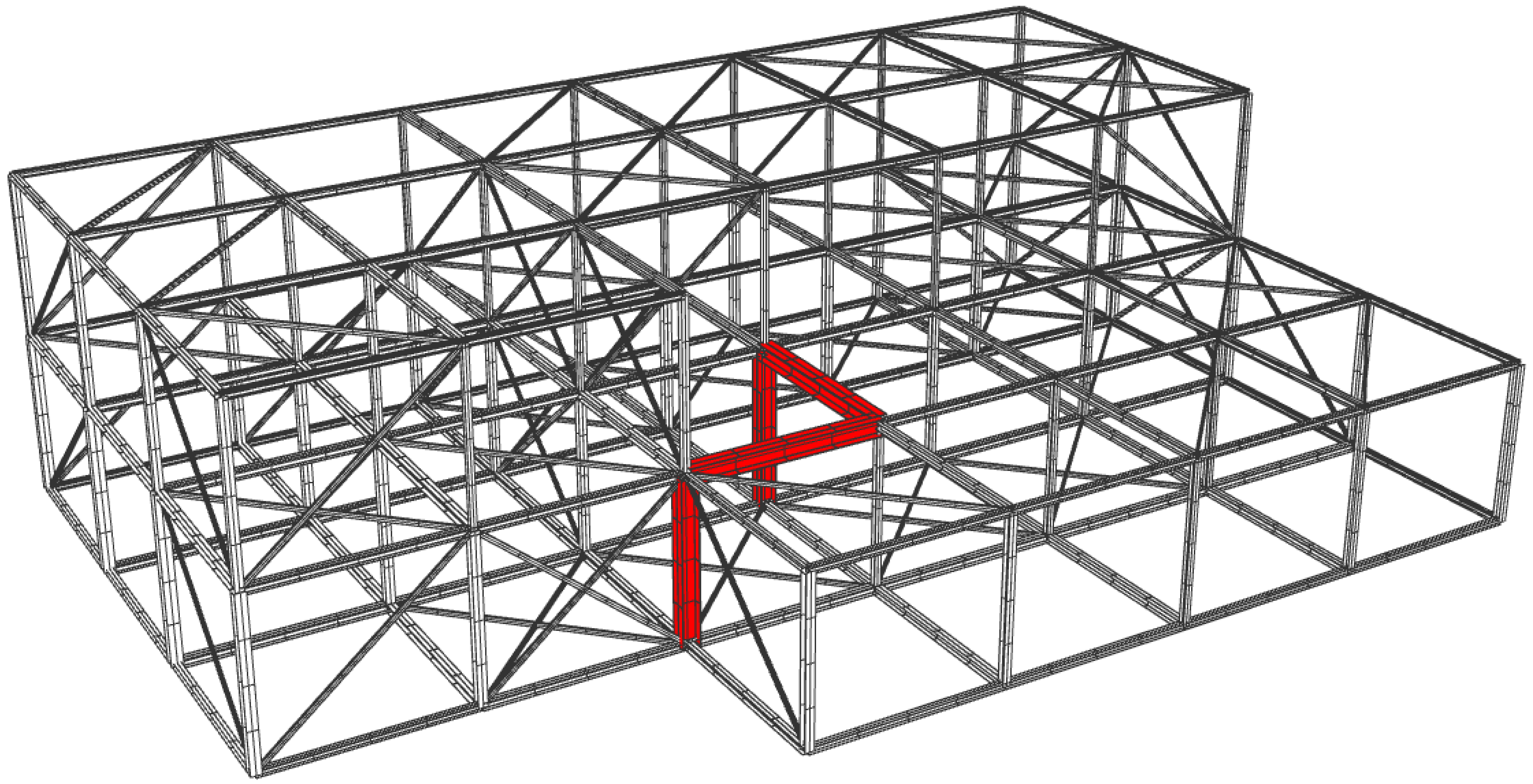
Approaches

Approach 1 - Minimal mass



Mass 19.782
Changes 130

Approach 2 - Minimal changes

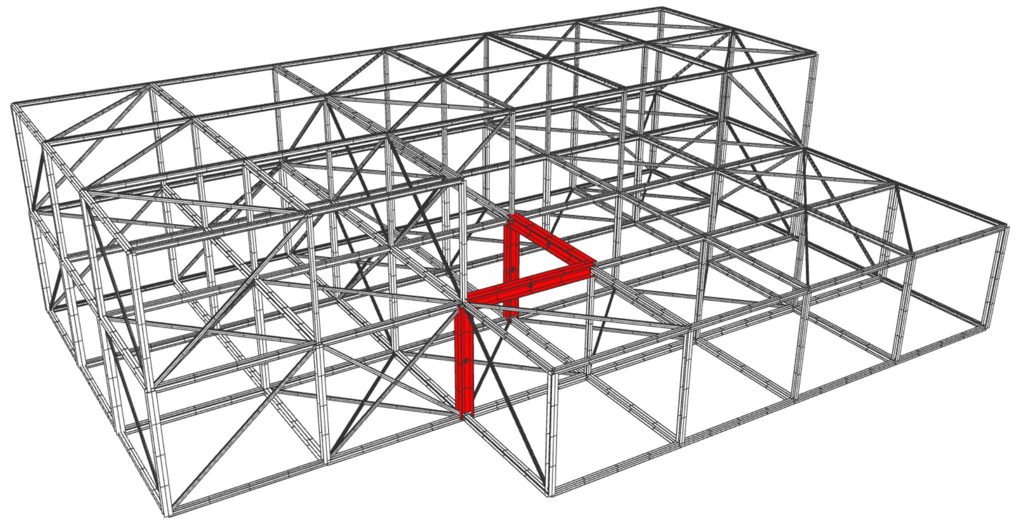


Mass 17.706
Changes 4

Combine Results

Removing elements

A



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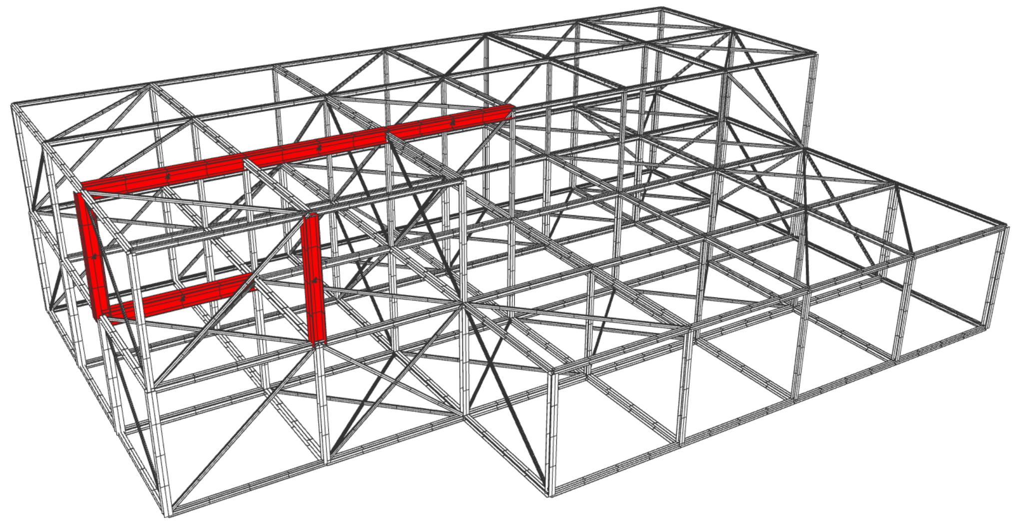

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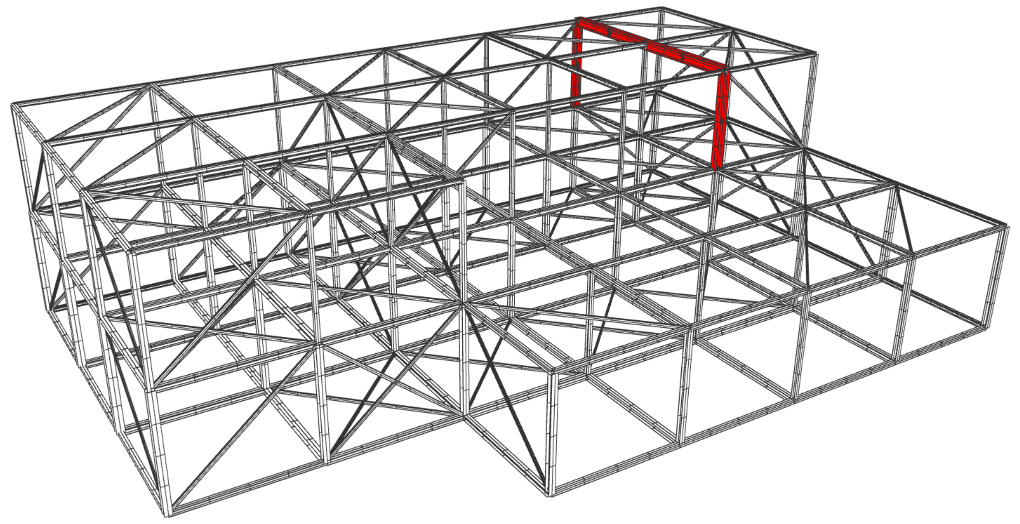
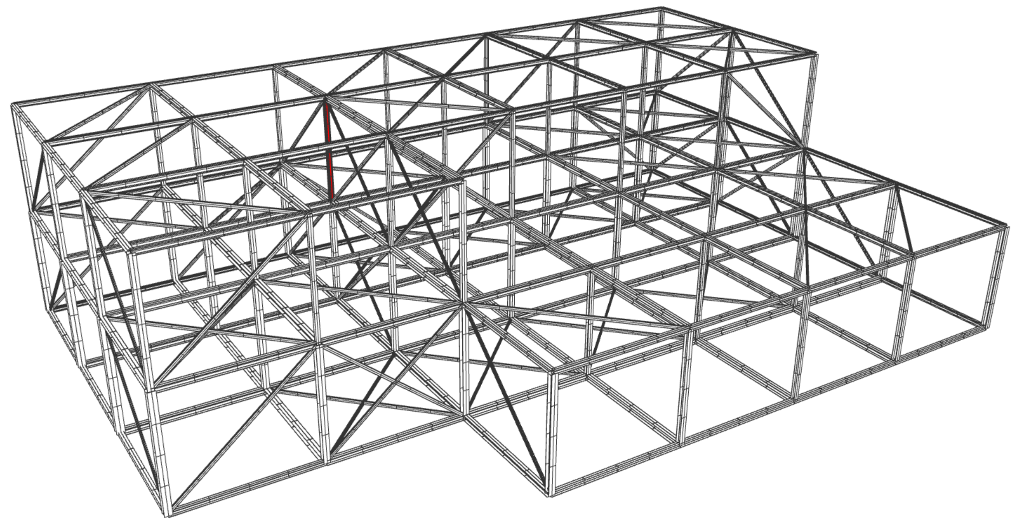


Adding floors

A



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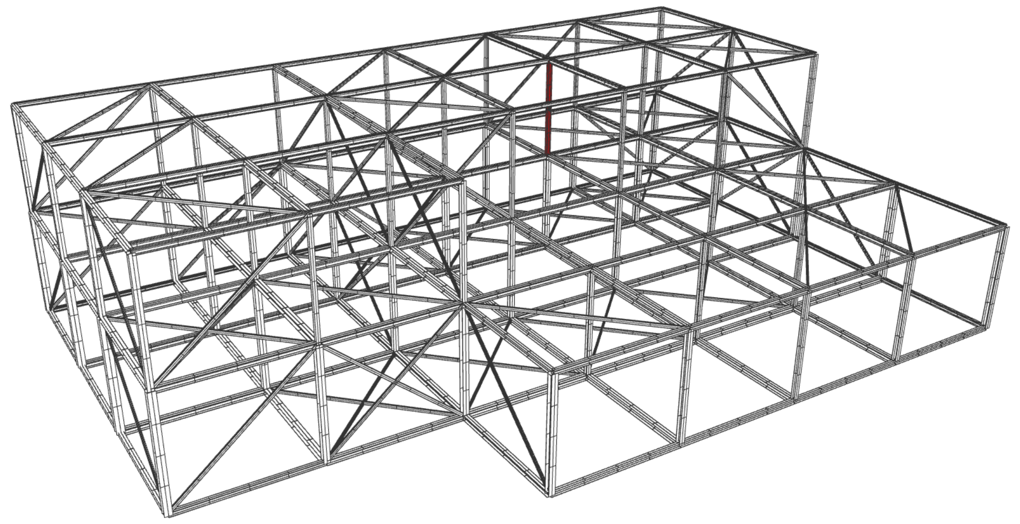

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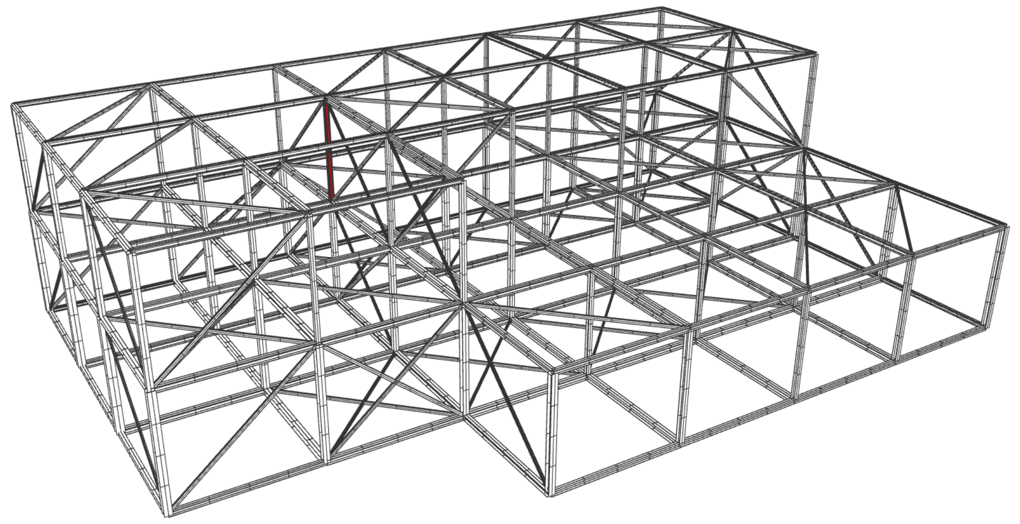
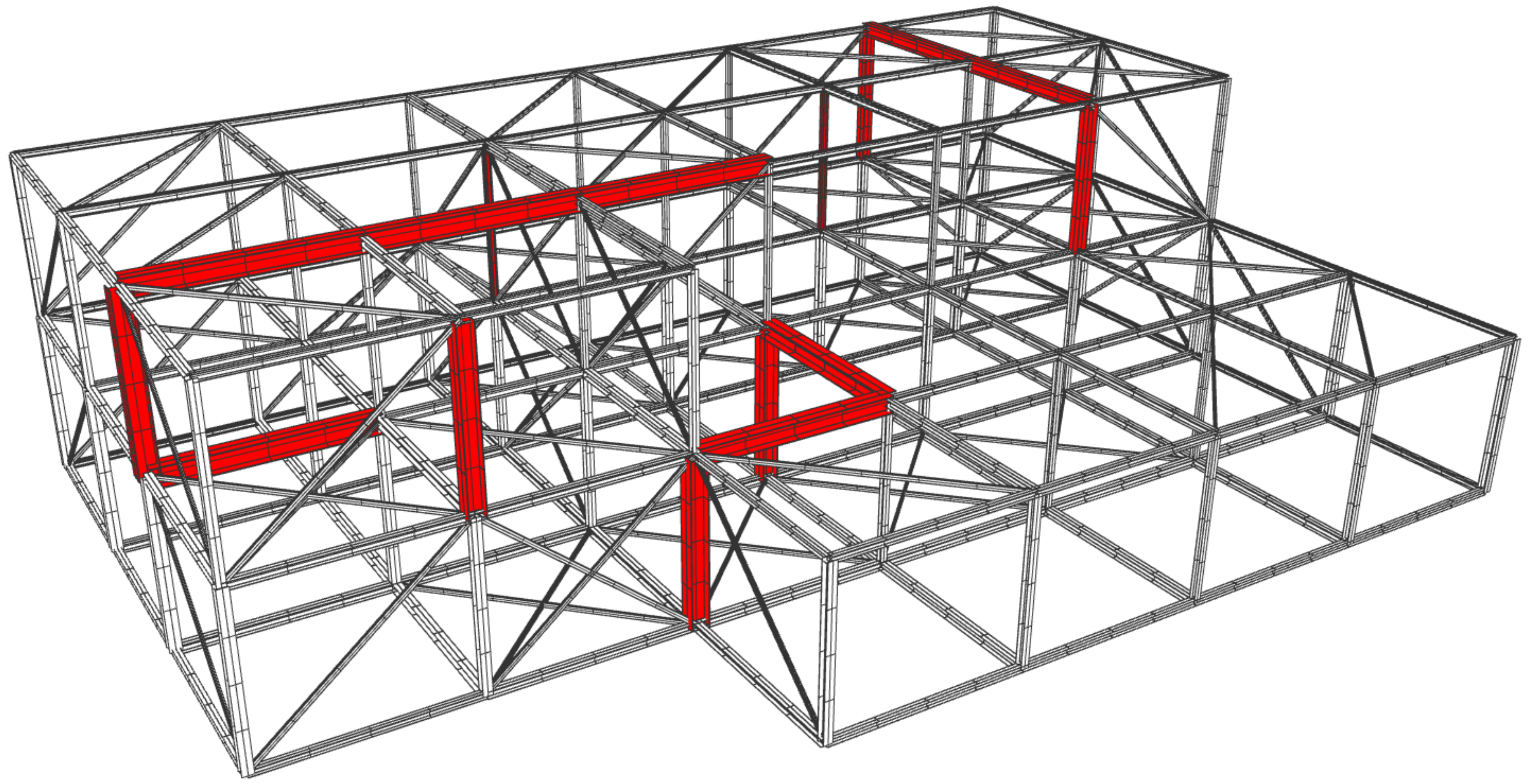
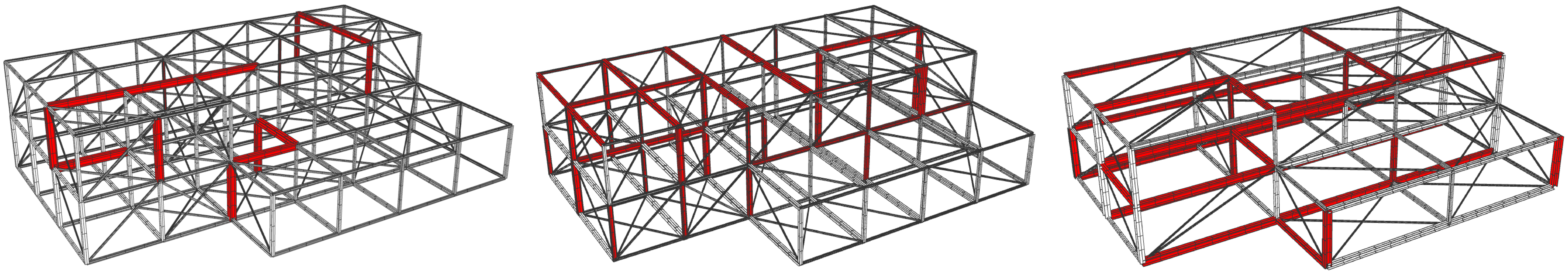




Compare Design Variants



Grid 1: 3,6 x 3,6 meter

Mass steel	16.867 kg
Mass steel oversized	19.921 kg
Number of changes	25

Grid 2: 3,6 x 4,8 meter

Mass steel	18.144 kg
Mass steel oversized	21.761 kg
Number of changes	51

Grid 3: 7,2 x 4,8 meter

Mass steel	23.701 kg
Mass steel oversized	29.650 kg
Number of changes	32

Increasing Adaptability

Demountable connections

Higher costs & lower material use

Over-sizing elements

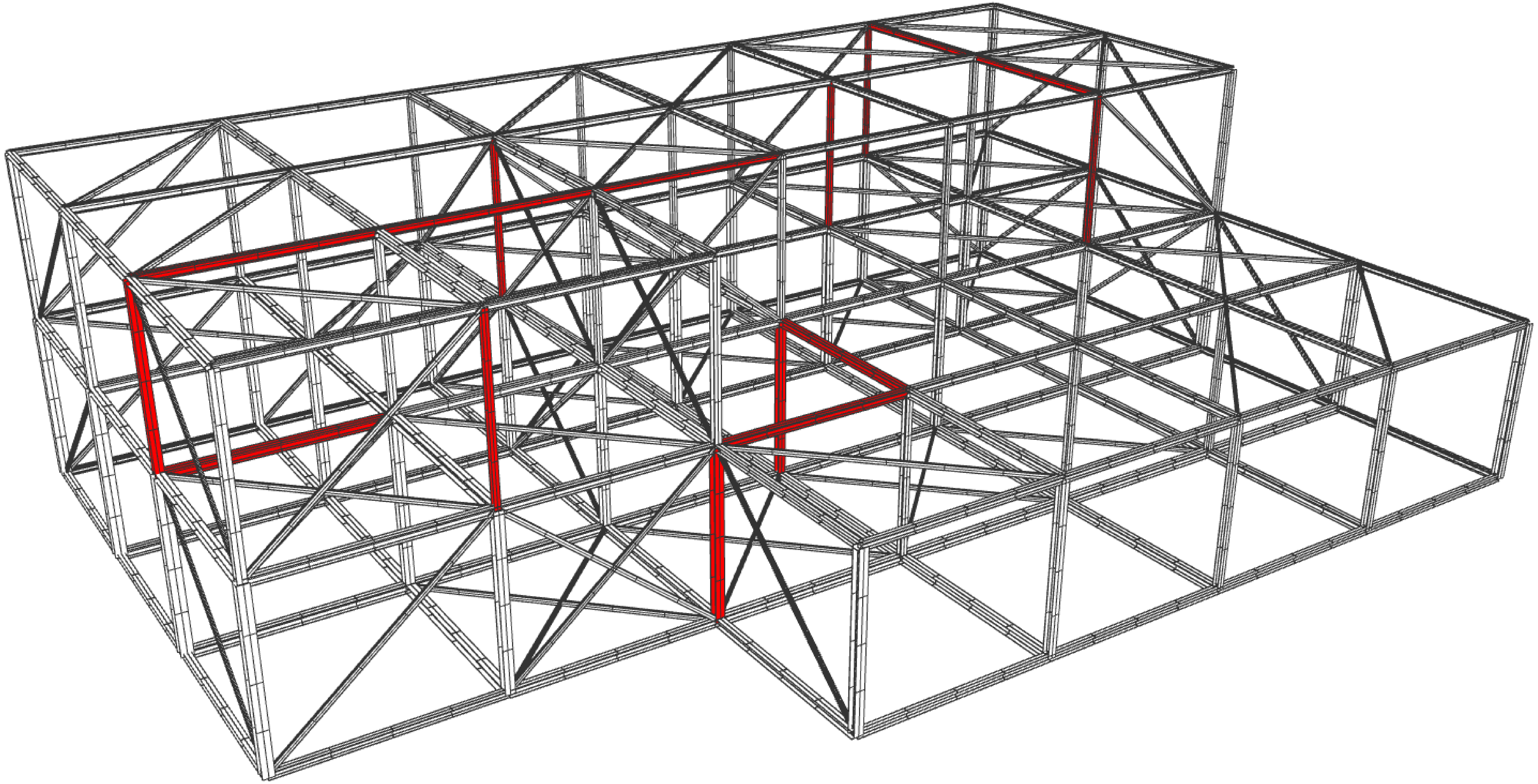
Higher material use & lower costs

Apply measures only where necessary

Reduce costs & material use

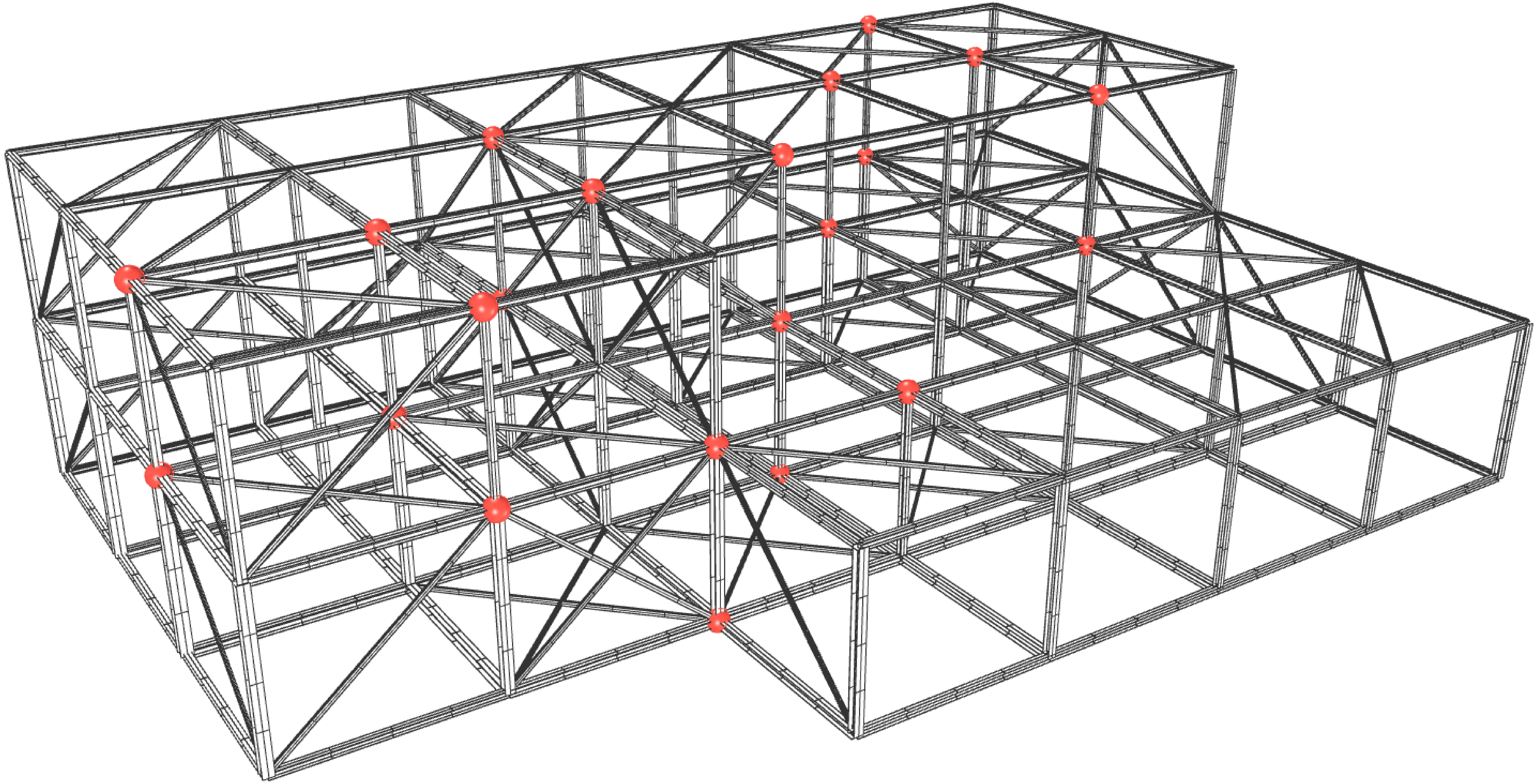
Demountable connections

Elements that might need to be replaced



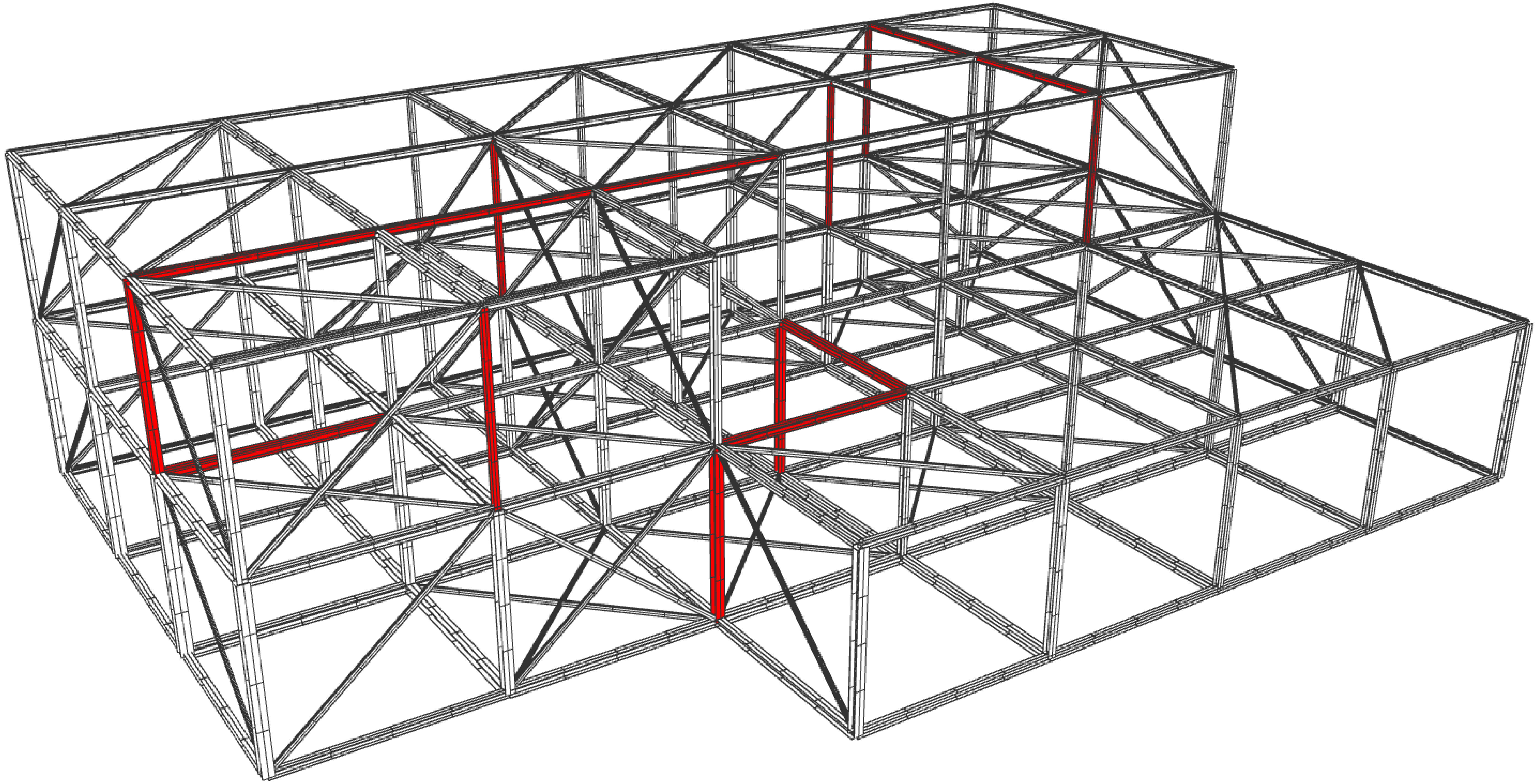
Demountable connections

Focus demountable connections on these elements



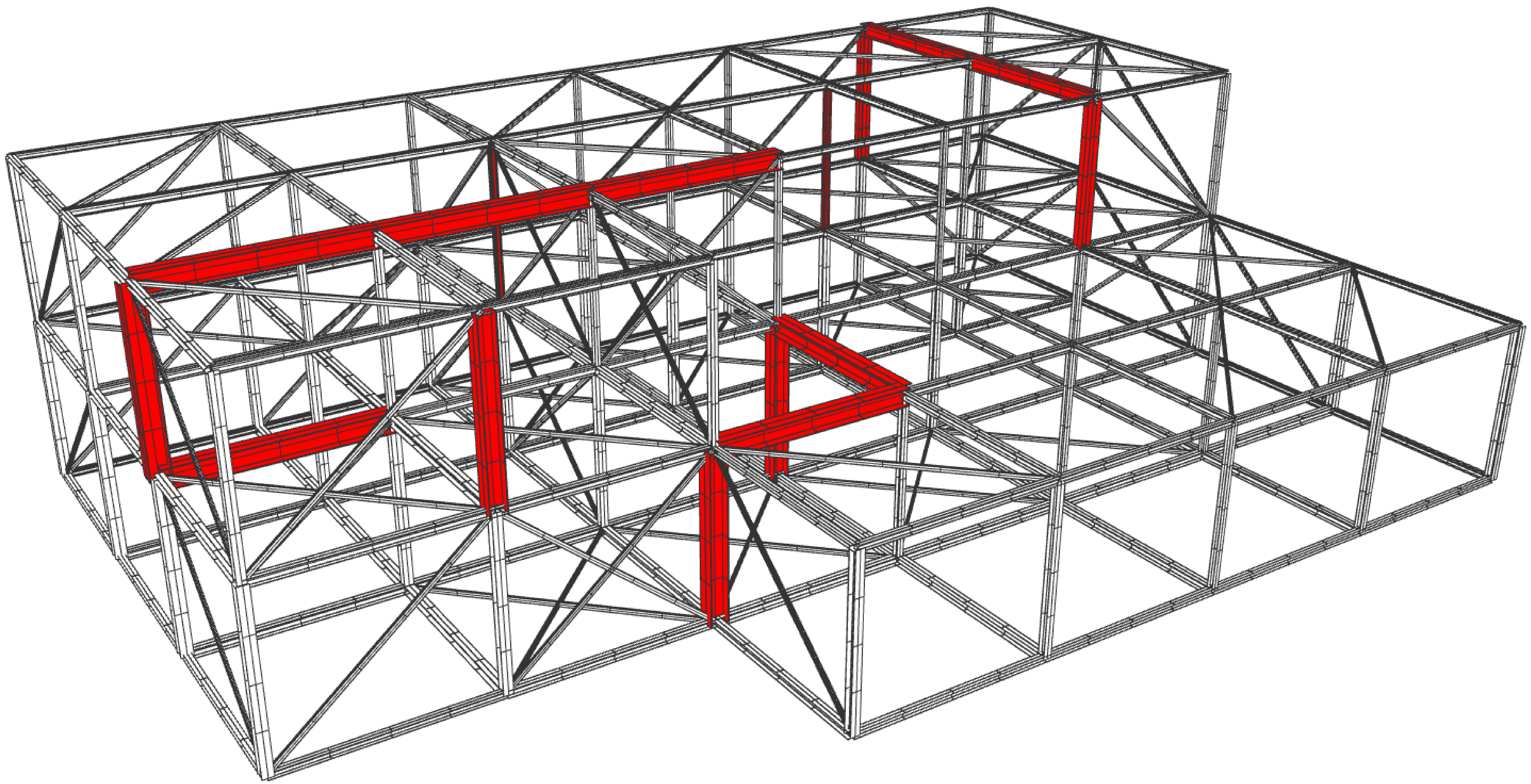
Oversizing elements

Create Structures | Optimize | Create Adaptability



Elements that might need to be replaced

Oversizing elements



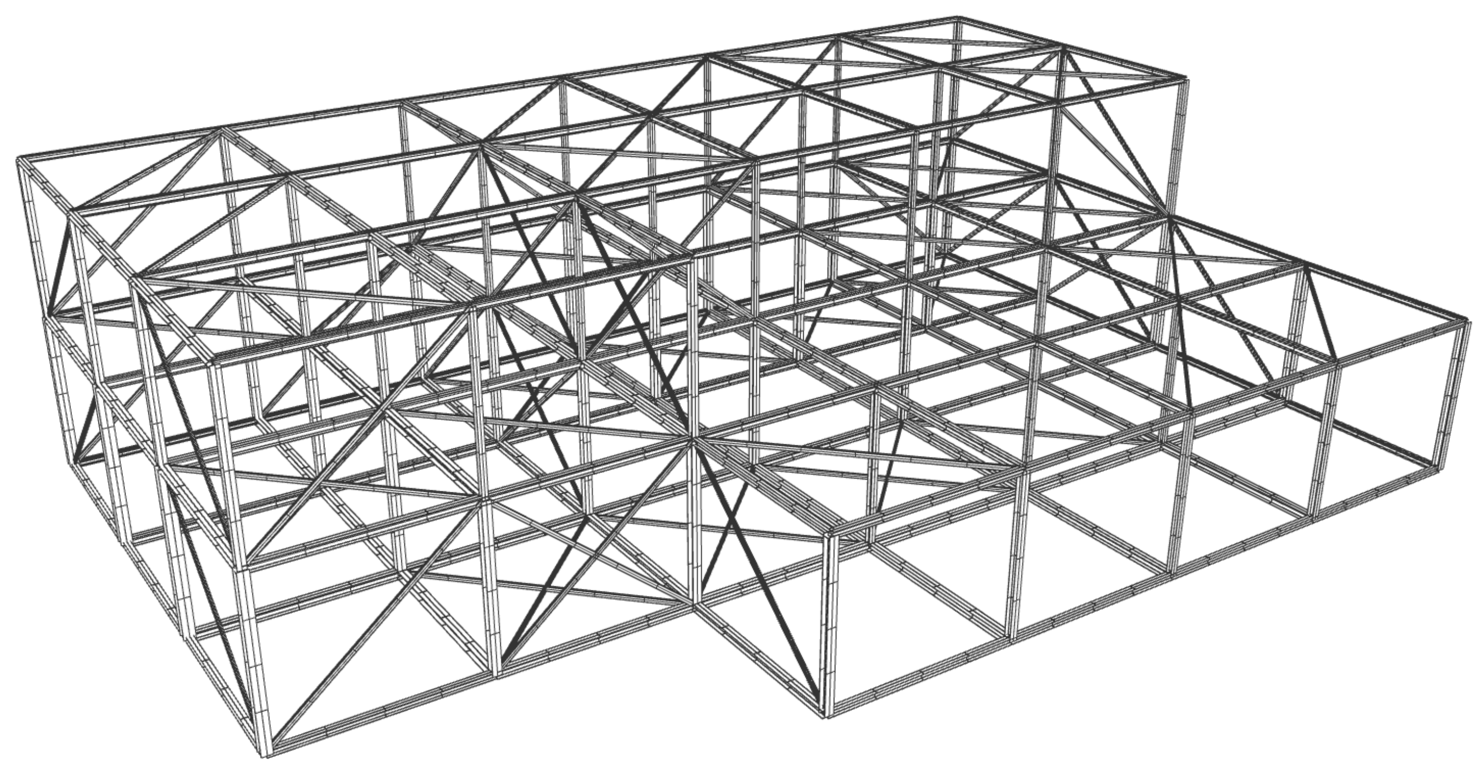
Apply larger cross-section from scenarios

Test-case

Life-cycles

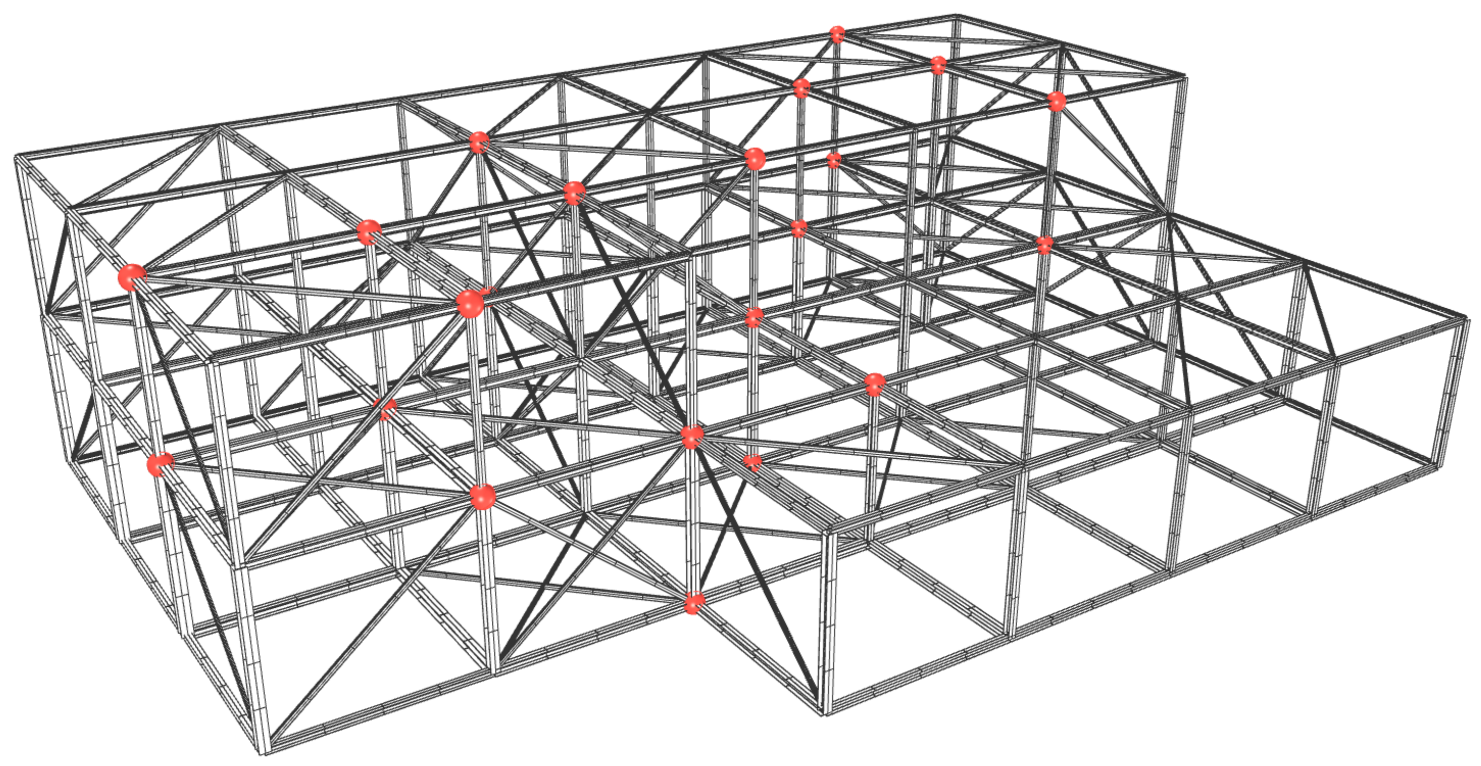
Structures

Standard structure



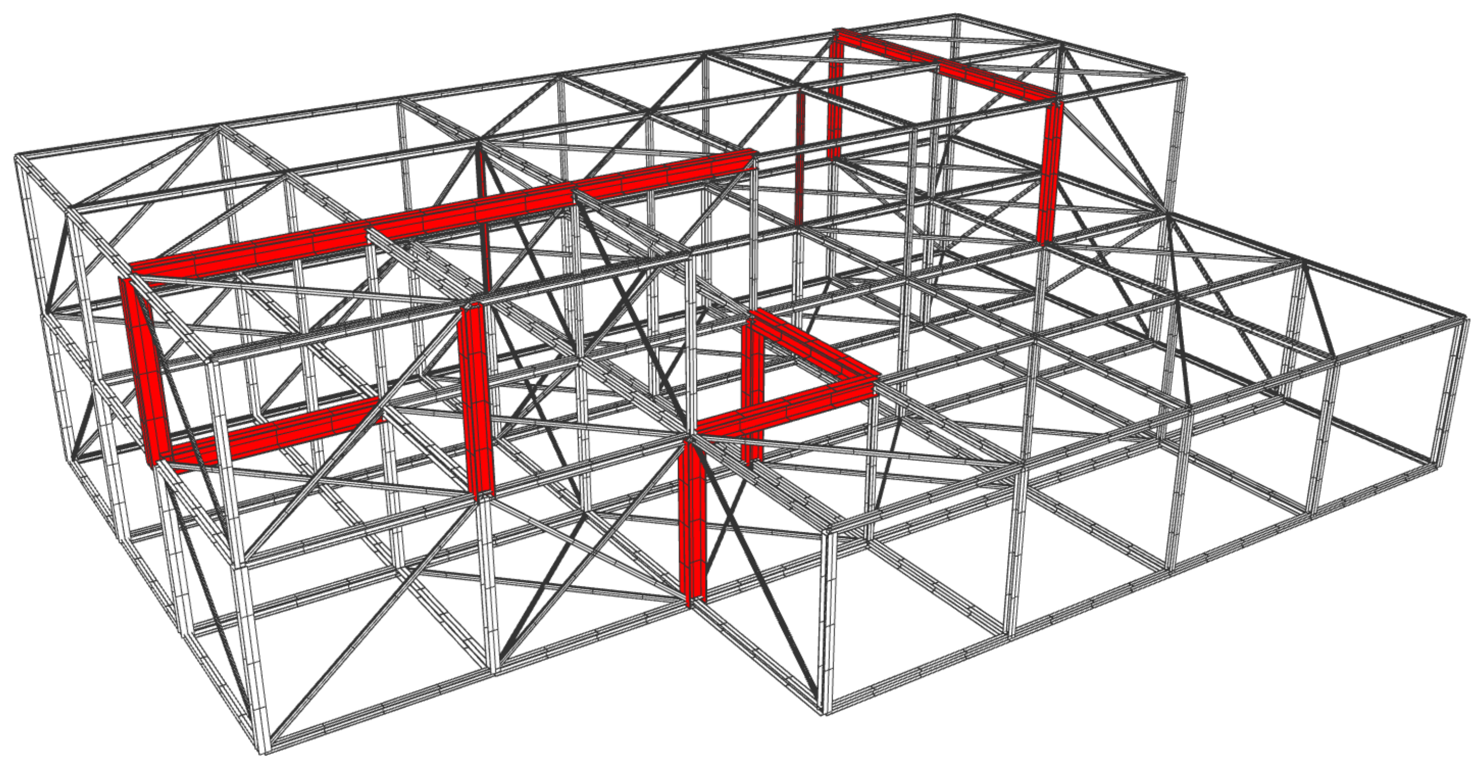
Demountable connections: 0
Mass: 16.847

Demountable connections



Demountable connections: 25
Mass: 16.847

Oversizing elements



Demountable connections: 0
Mass: 19.912

Life-cycles

1. Series of anticipated scenarios
   Future needs change as expected

2. Series of unanticipated scenarios
   Future needs change differently than expected

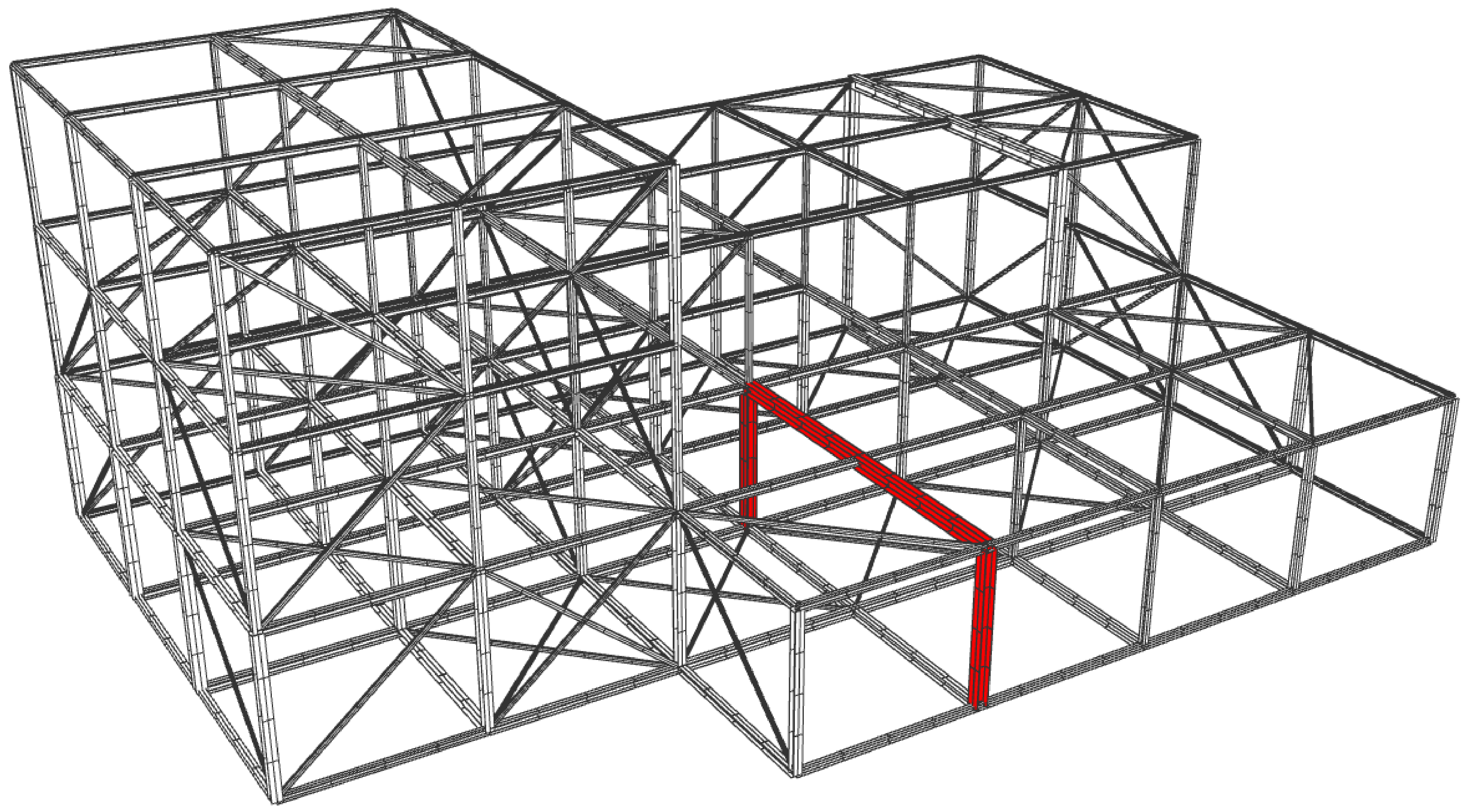
Life-cycle 1

Series of anticipated scenarios

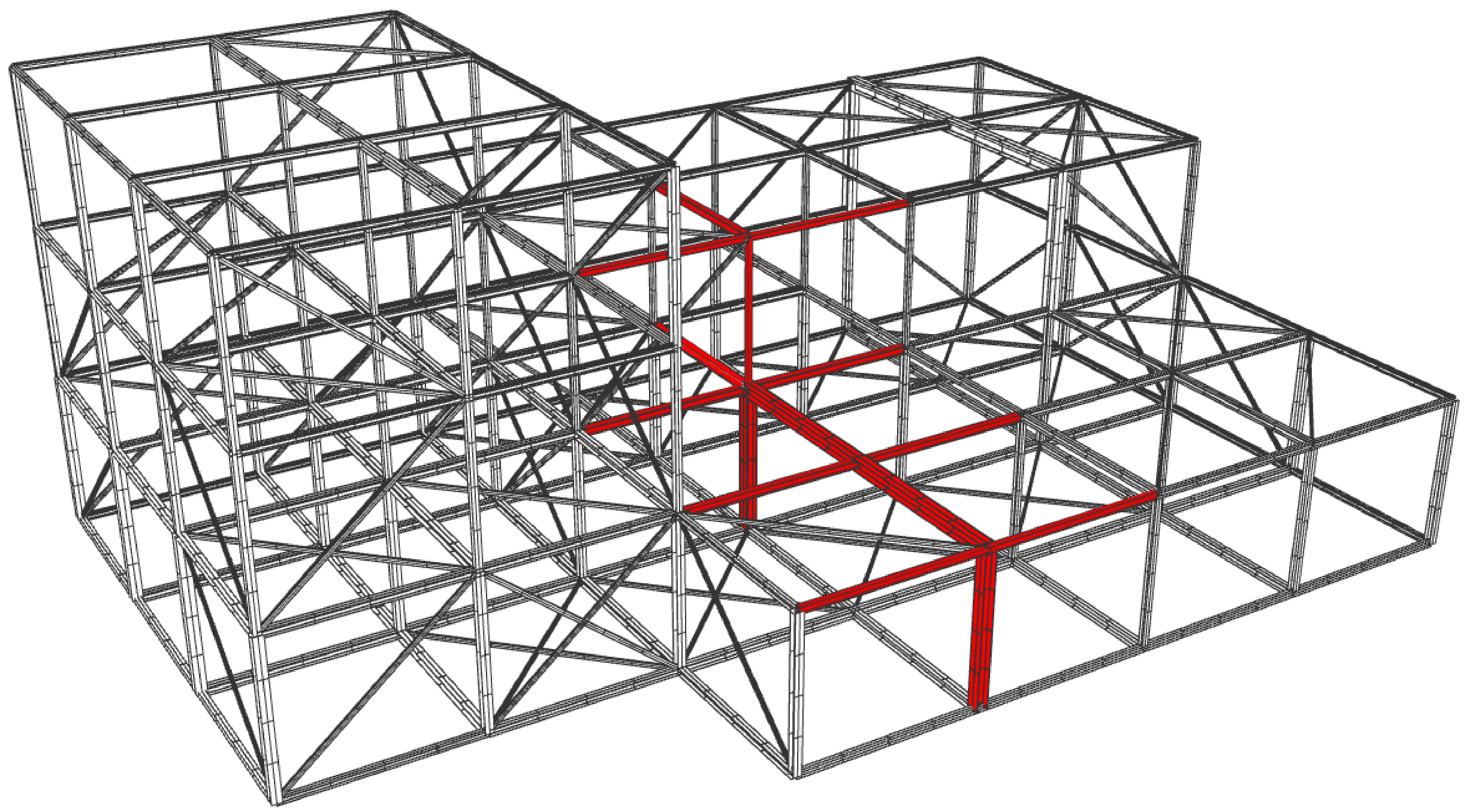
Over a building's lifespan multiple changes are made

Life-cycle 1

Changes due to replacing elements

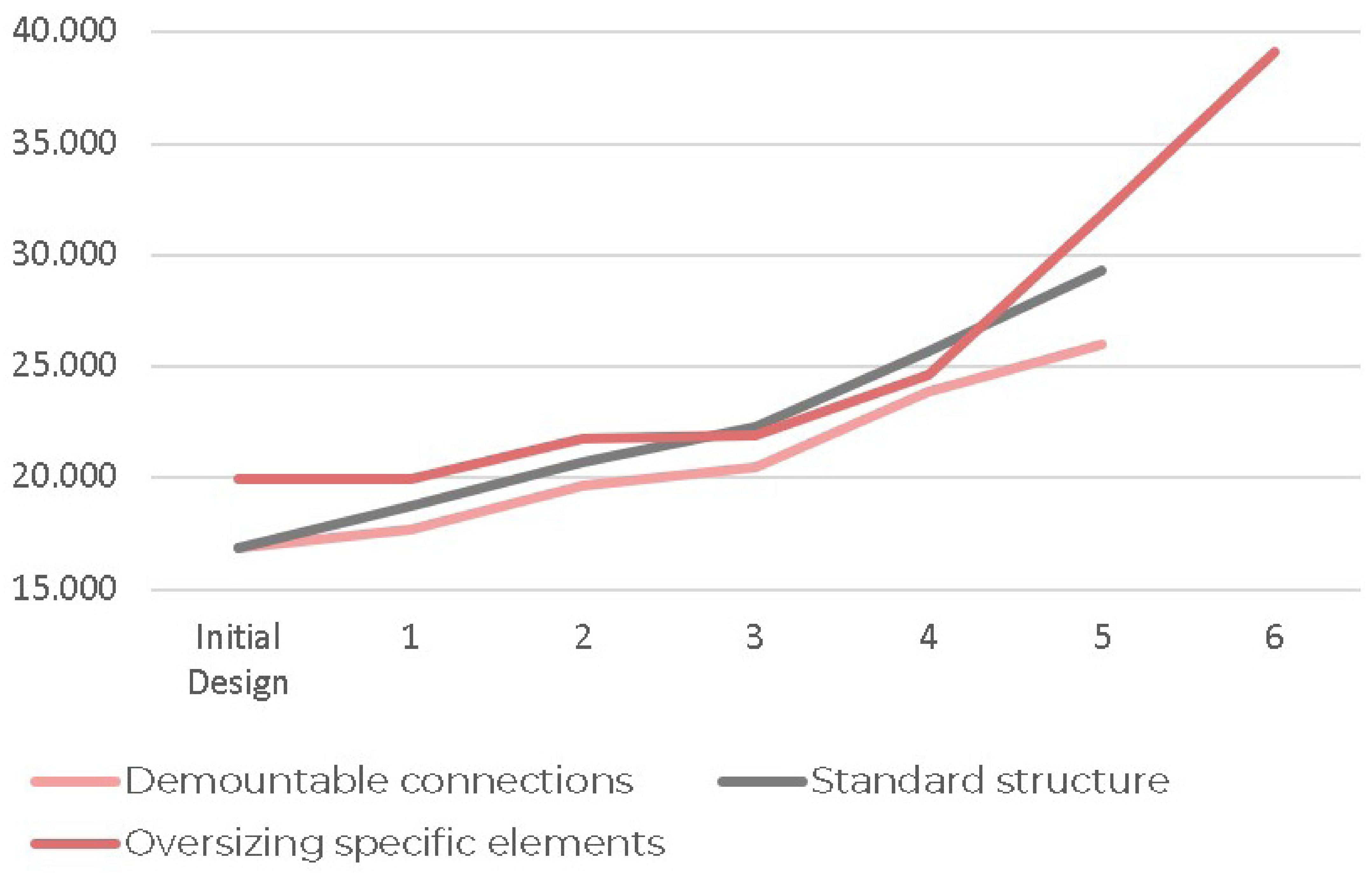


Extra changes due to logisitics



Life-cycle 1

Mass steel (kg)



Number of changes

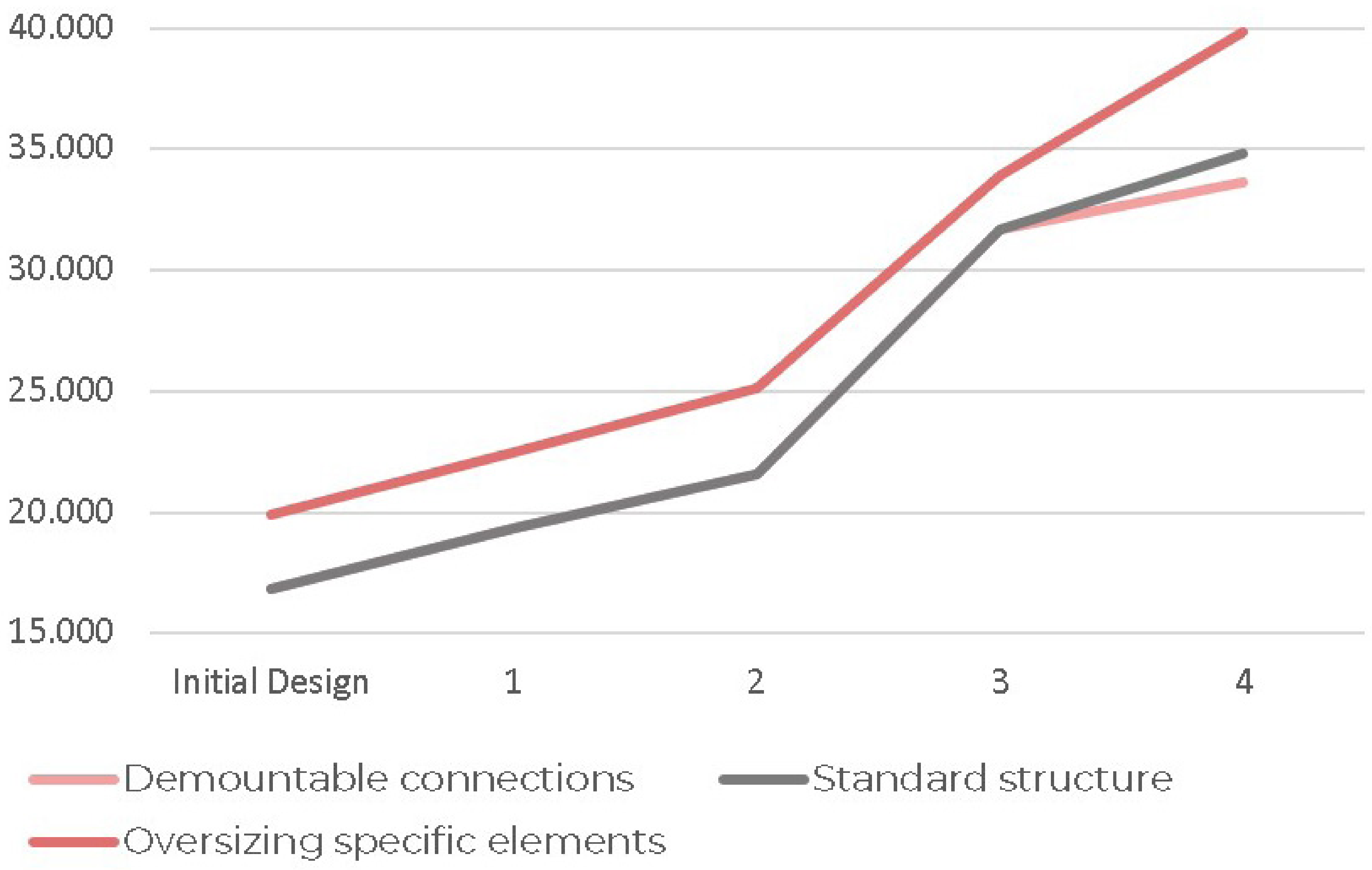
Life-cycle 2

Series of unanticipated scenarios

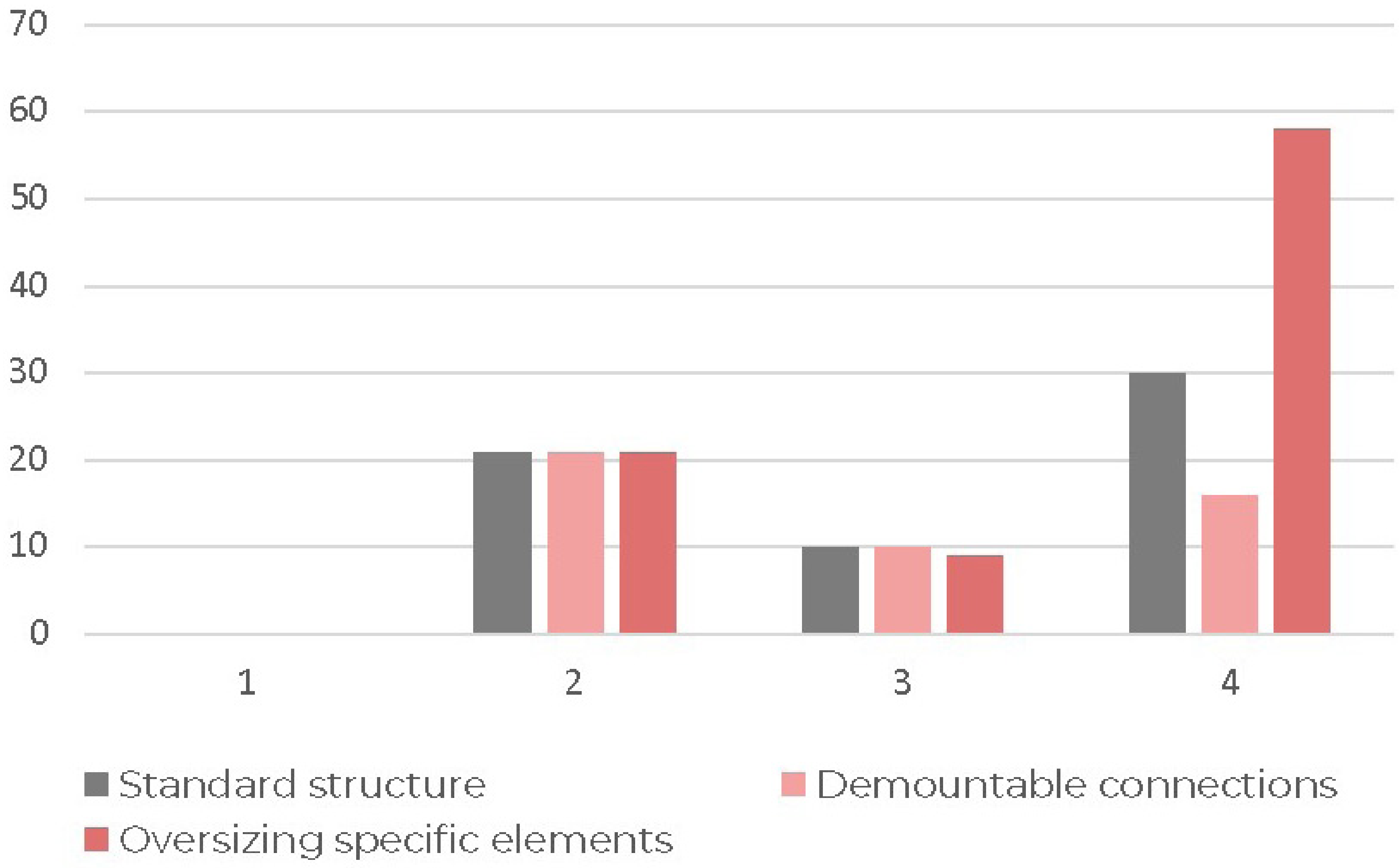
Difficult to determine likely scenarios

Life-cycle 2

Mass steel (kg)



Number of changes



Findings

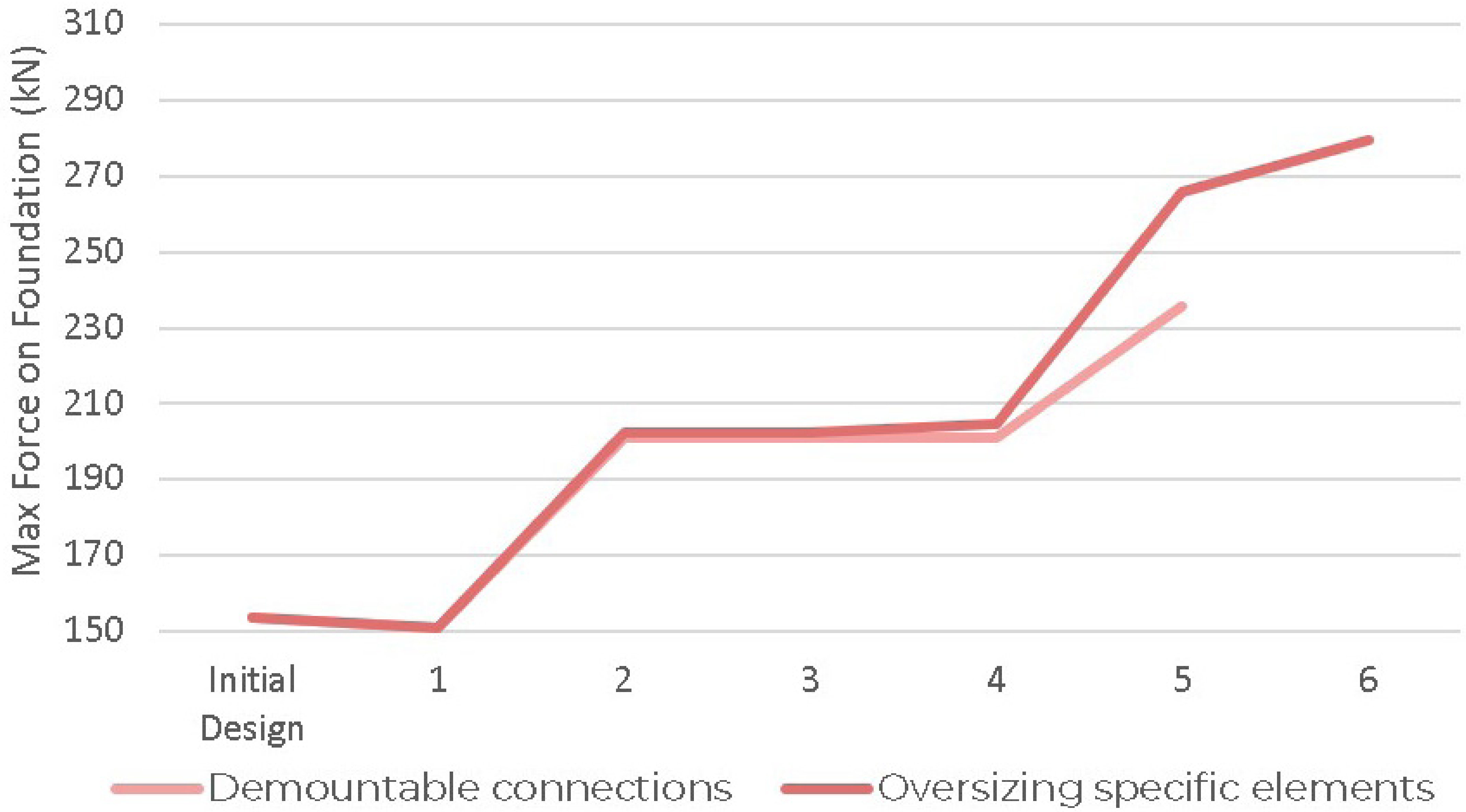
Workflow and methods could be applied to increase adaptability and decrease material use

Dependent on design case, chosen scenarios and future needs

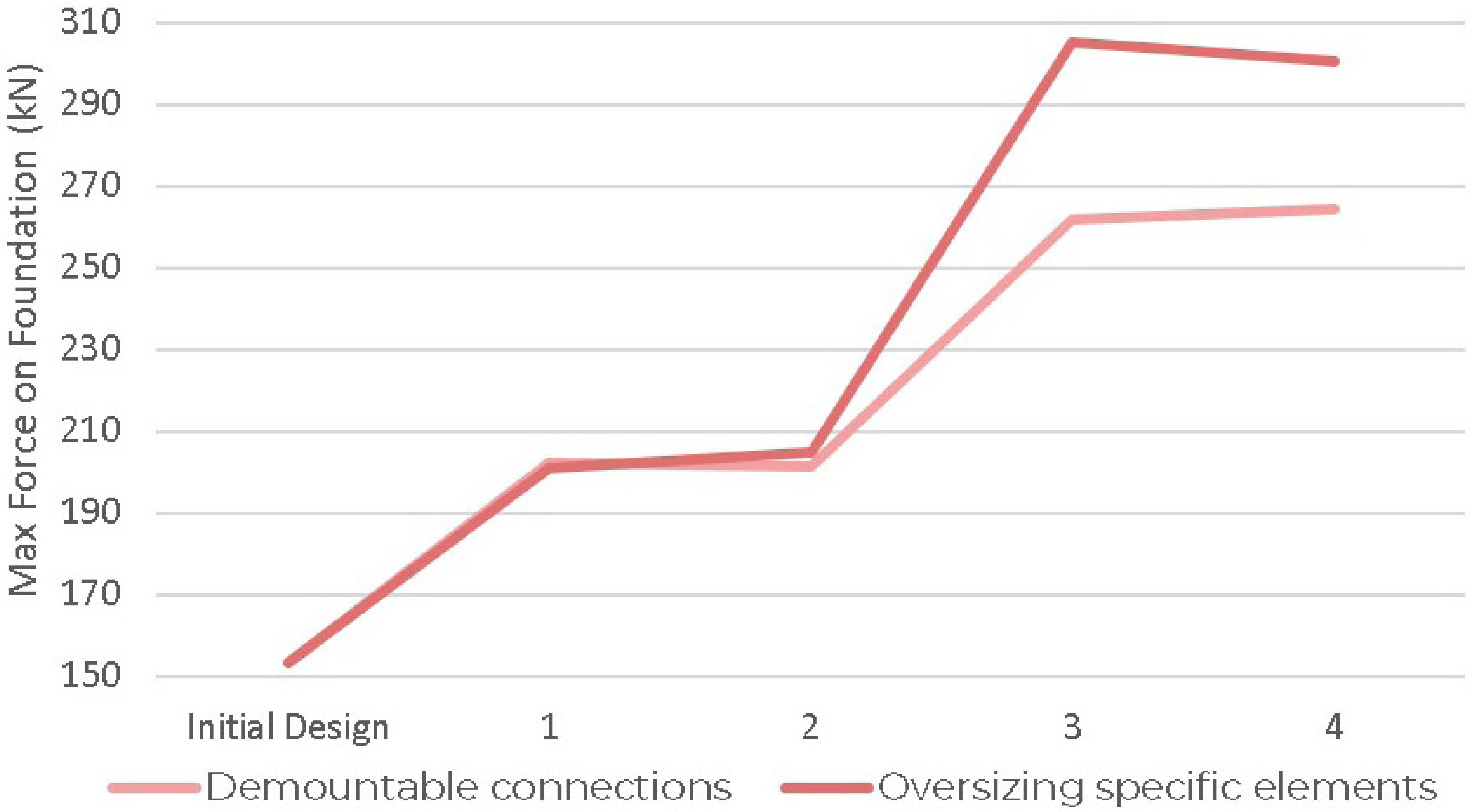
Overall demountable connections perform the best. But also complex process of replacing elements

Difficulties - Foundation

Anticipated scenarios



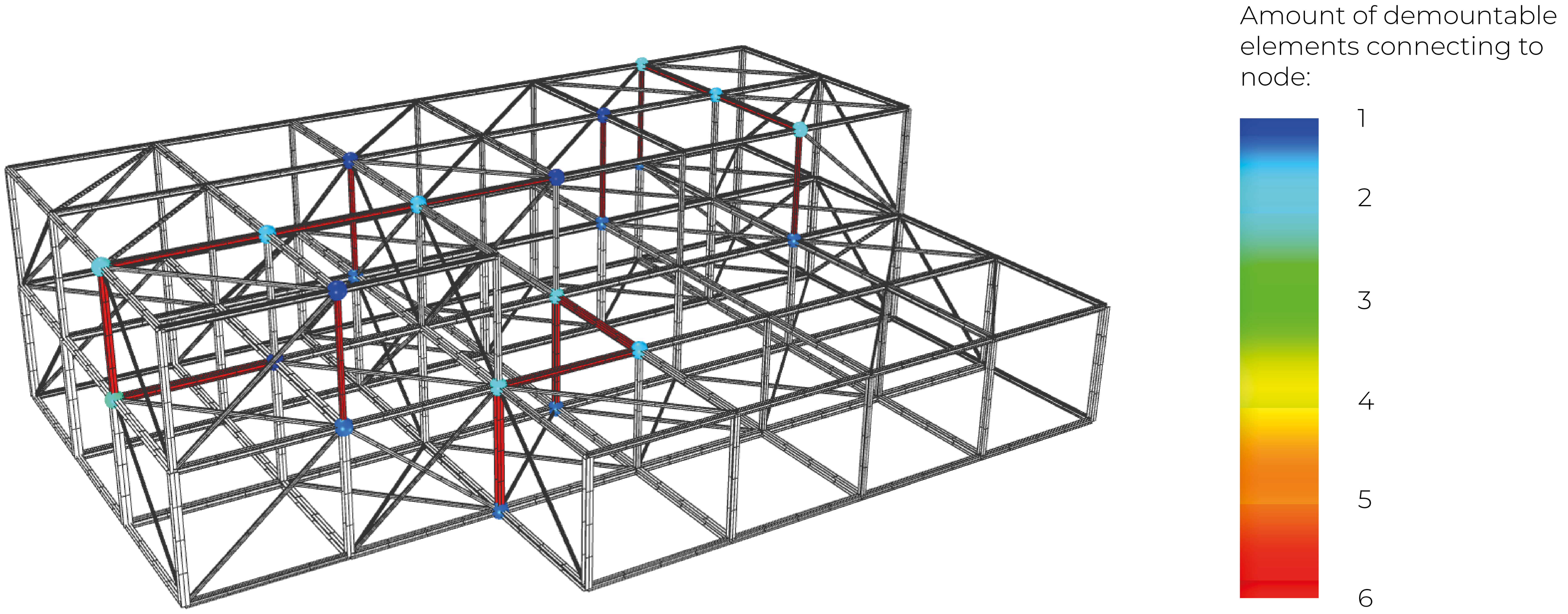
Unanticipated scenarios



Difficulties - Demountable connections

Many connection types already available

But not yet possible to replace any element individually



Difficulties - Demountable connections

For simple nodes standard bolted connections can be used

Do often include continuous elements

Image 8: Bolted Connections in Steel Structure(Rahman, 2020)

Difficulties - Demountable connections

Modular building connection

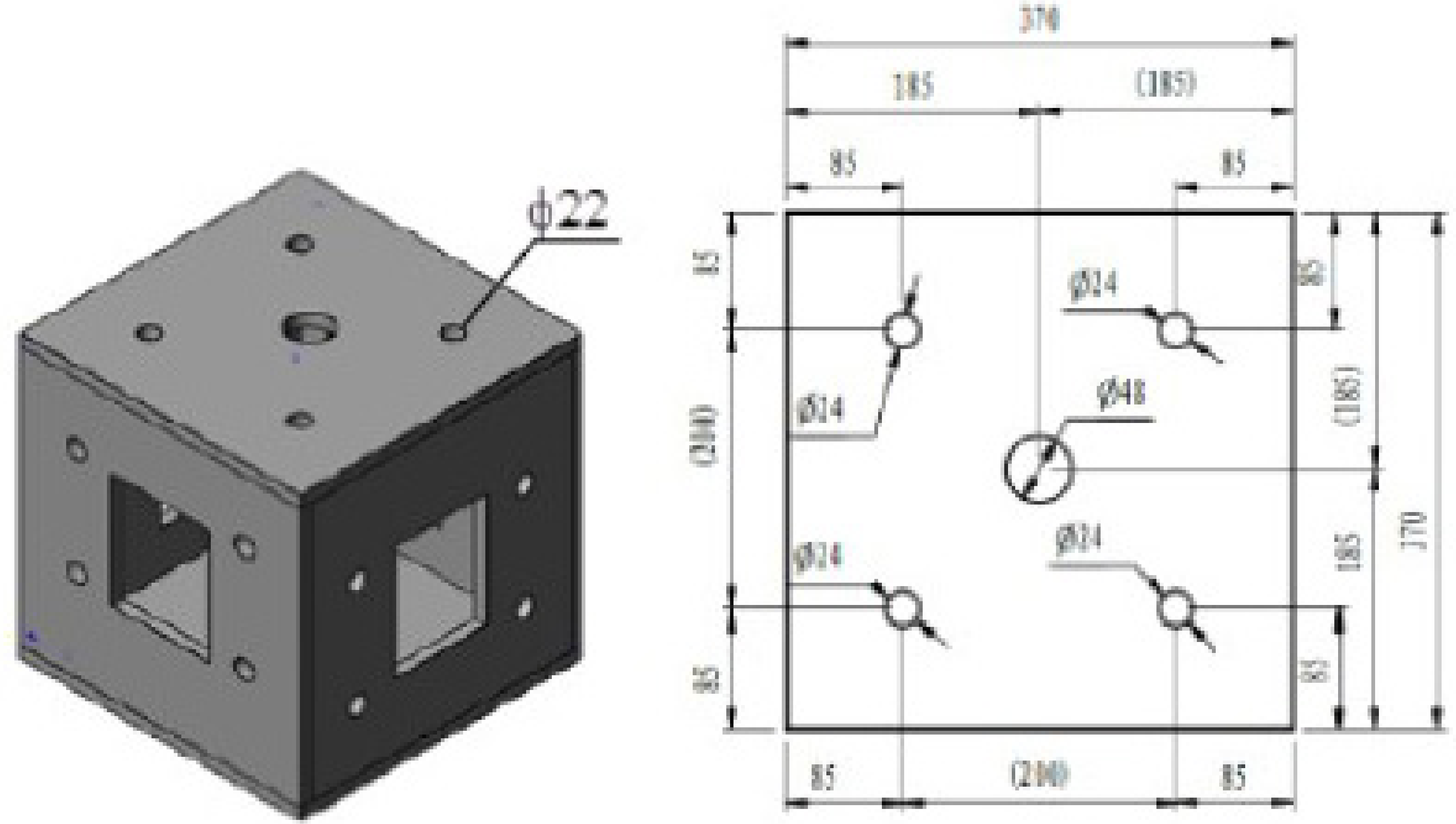


Image 9: Steel bracket (Rajanayagam et al., 2021)

Costs

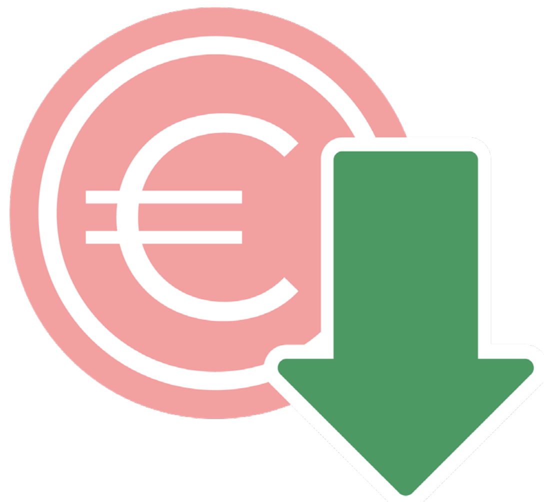
Material use

Dependent on scenarios

Adaptability

Over-sizing

Demountable connections



Complexity

Connections

Diversity elements

Process of replacing

Conclusion

Conclusions

Can be used to increase adaptability and decrease material use

Dependent on scenarios

Limited functionality, the workflow can de expanded upon in future research

Reflection

Not yet applicable in practice

Further research required into demountable connections and process of replacing elements

Thank you!

Sources

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