Optimizing the PETRA IV girder by using bio-inspired structures

Simone Andresen

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MEDSI PARIS 2018

MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION

AWI ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

DESY.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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Outline

1 Introduction

2 Support study

3 Topology optimization

4 Bionic lattice structures

5 Conclusion

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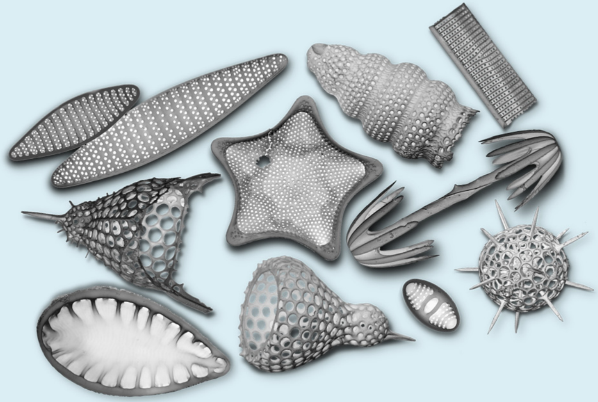
Introduction



Alfred-Wegener-Institute

- Leading position in polar & marine science
- ~1000 employees
- Intensifies its activities in technology transfer

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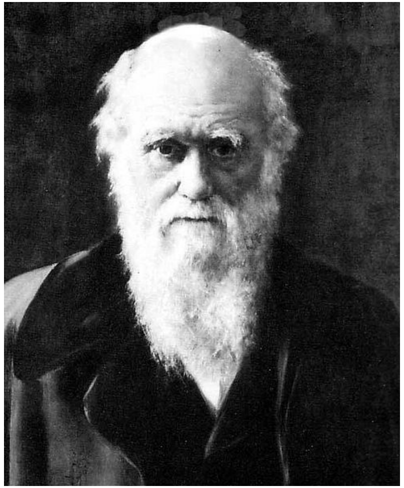
What is biomimetics?

- "bios" (life) + "mimesis" (to imitate)
- Solutions in nature are optimized
- Natural selection discards unnecessary things
  - Darwin (1895): "On the Origin of Species"
    - "Survival of the fittest"



Charles Darwin (1)

➢ Learning from nature to develop solutions for technical problems

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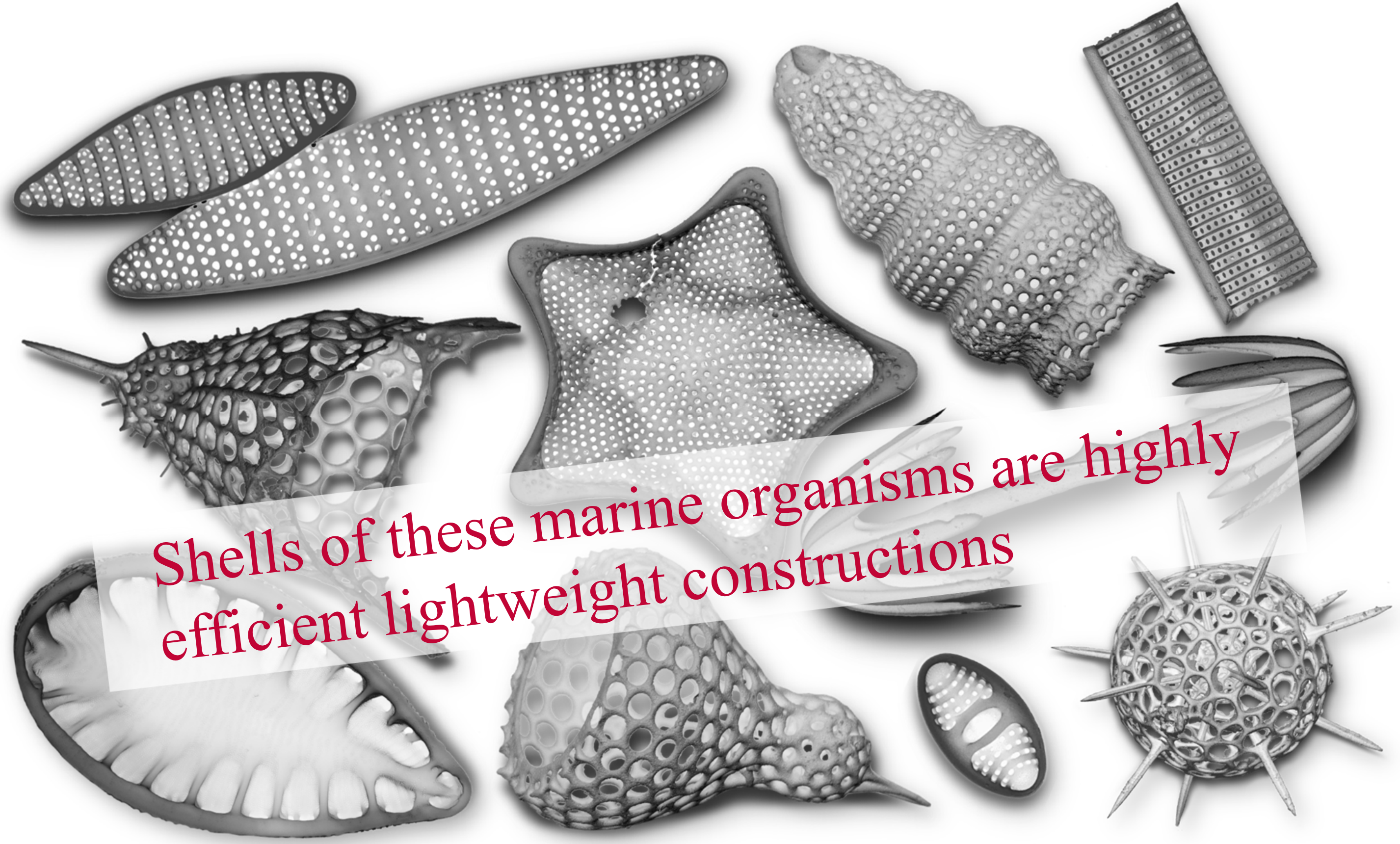
Why marine organisms as biological examples?



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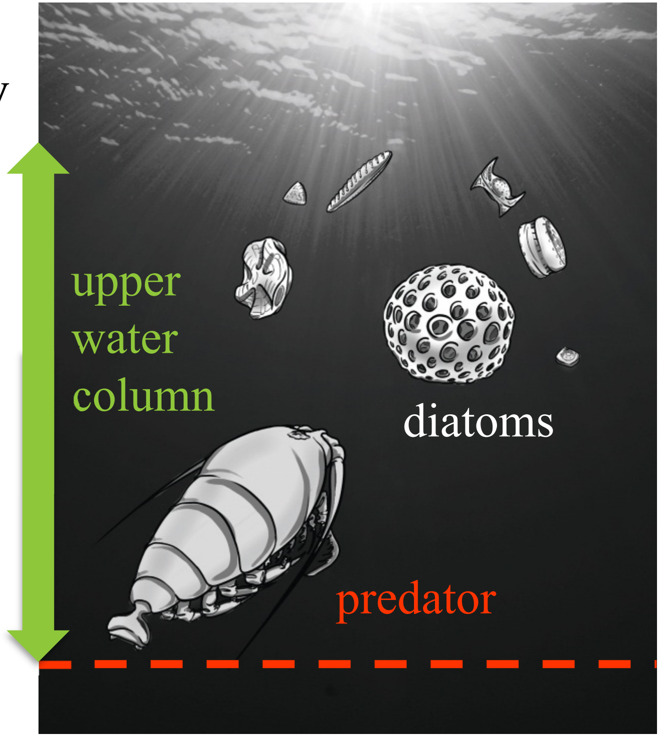
Why marine organisms as biological examples?

- 100,000 different species of diatoms with an enormous variety of shell structures are known
- Characteristics of the shell structures:
  - Lightweight
  - Very high stiffness
  - Expected to have positive impact on vibration characteristics



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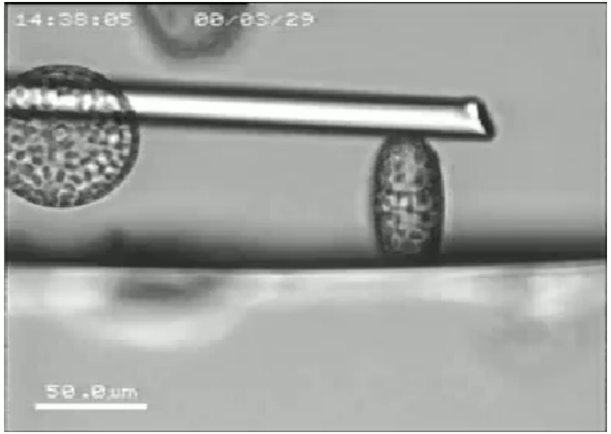
Why marine organisms as biological examples?

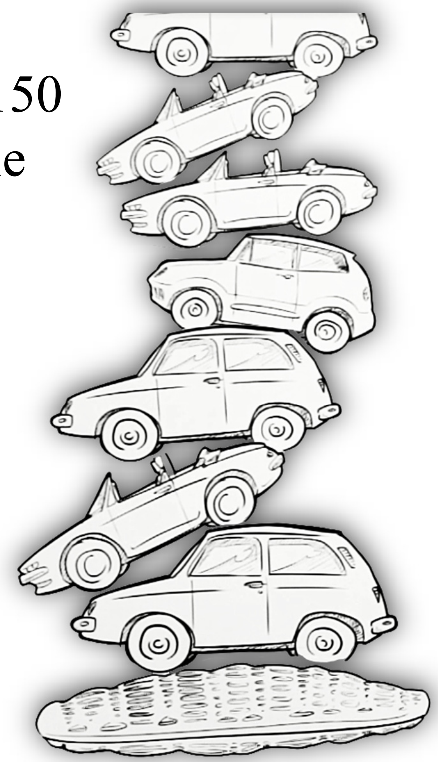
"Glass" shells (SiO_2) resist a pressure of approximately **700 t m^{-2}**.



(Hamm et al. 2003, Nature 421, 841-843)

That is equal to 150 cars on a manhole cover!

(2)



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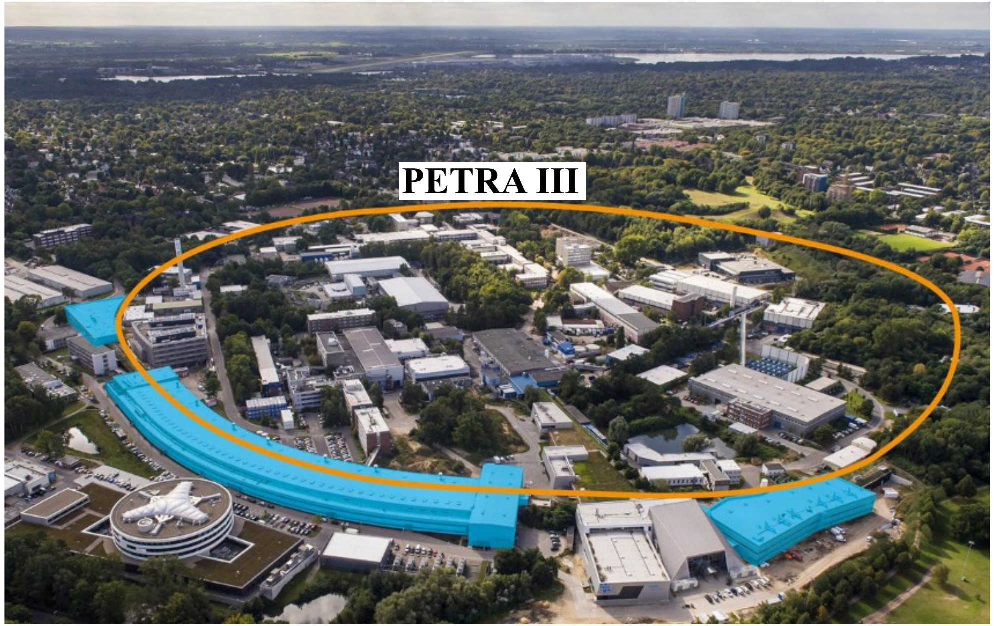
PETRA IV at DESY

PETRA III storage ring will be converted into an ultralow emittance synchrotron radiation source PETRA IV.



Project goals

- Systematic development of new girder designs considering several approaches using bio-inspired structures
- Goal: optimizing the PETRA IV girder
  - 1st natural frequency of more than 52 Hz
  - Maximal deflection (linear static): 0.5 mm
  - Maximal girder mass: 2,500 kg

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Support study

(3)

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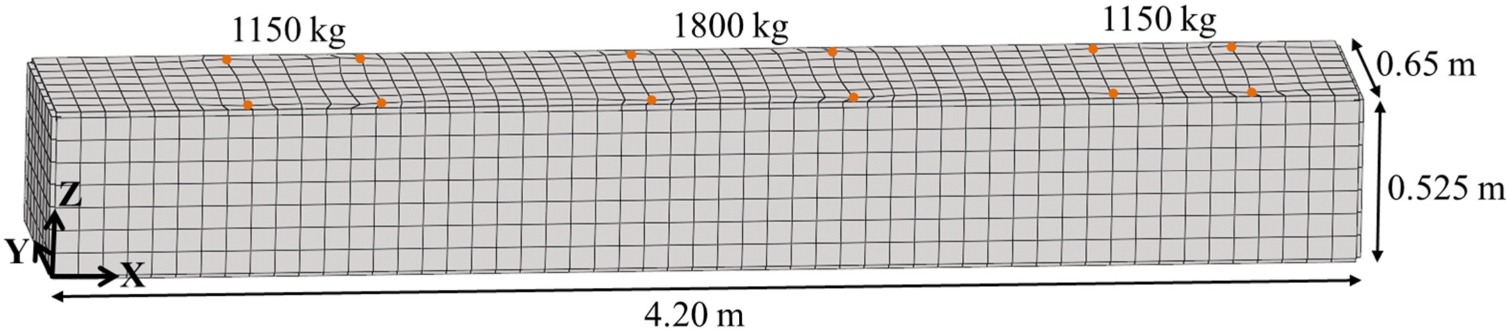
Model assembly

- Starting with PETRA III girder
- Girder abstracted as a hollow cuboid (material: steel)
- Shell elements
- Three heavy magnets considered as point masses
- Software: Rhinoceros (Grasshopper) combined with the Solver OptiStruct (Altair)
- Support points were varied in a parameter study



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Parameter study

Parameter that were varied:

Number of support points	Location of support points
3, 4, 5 and 6	Lower girder surface (Bessel points)
	Upper girder edges (close to the magnets)

Constraints at each support point: X=Y=Z=Rx=Ry=Rz=0

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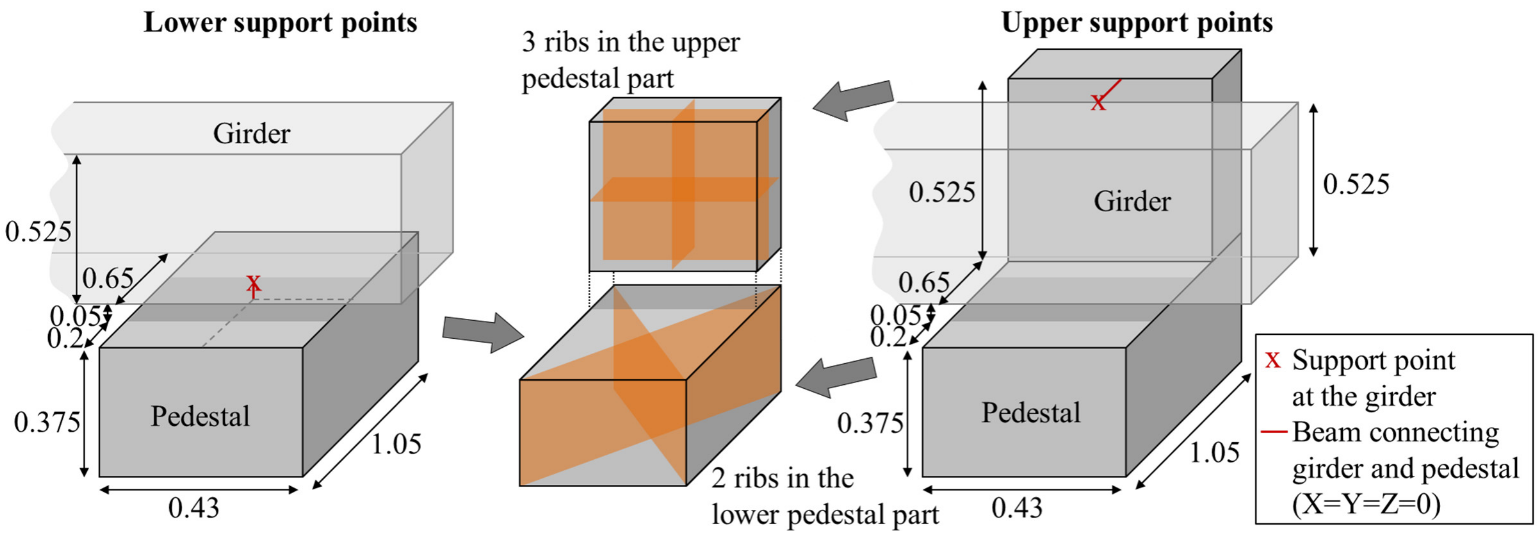
Considering the girder pedestals

Evaluating how the pedestals influence the natural frequency



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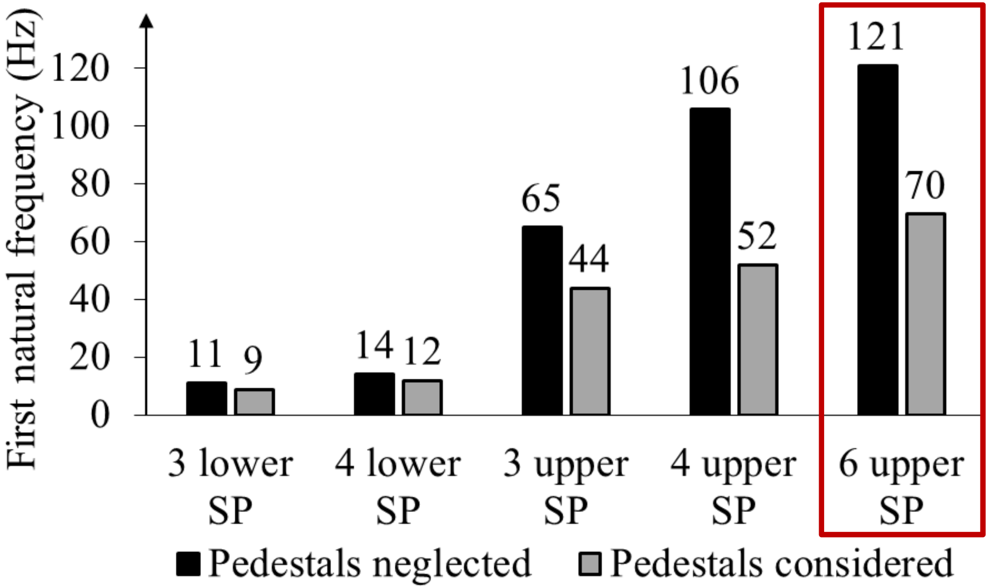
Results



- 6 support points close to the magnets (load) will be considered (keeping in mind that the support is modeled as quite stiff in the simulations)

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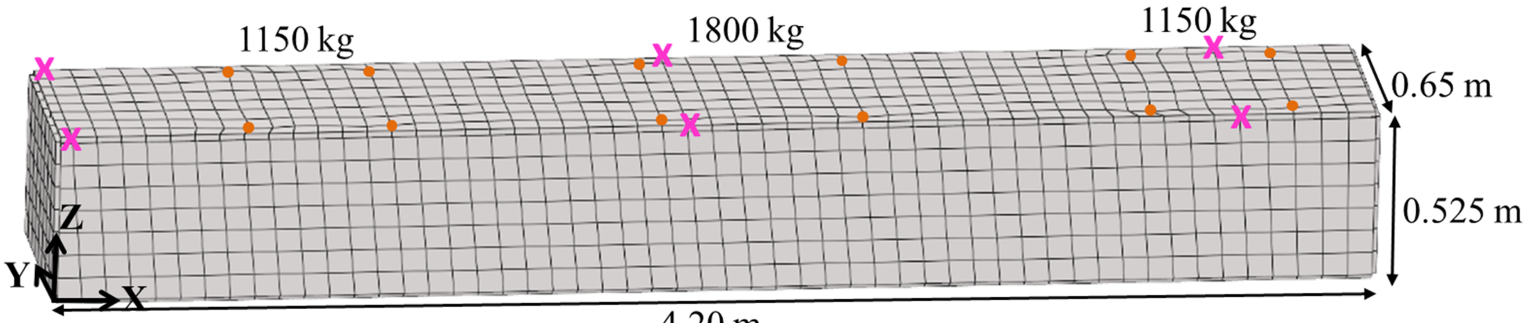
Results

- Best support point configuration:
  6 support points at the upper girder edges



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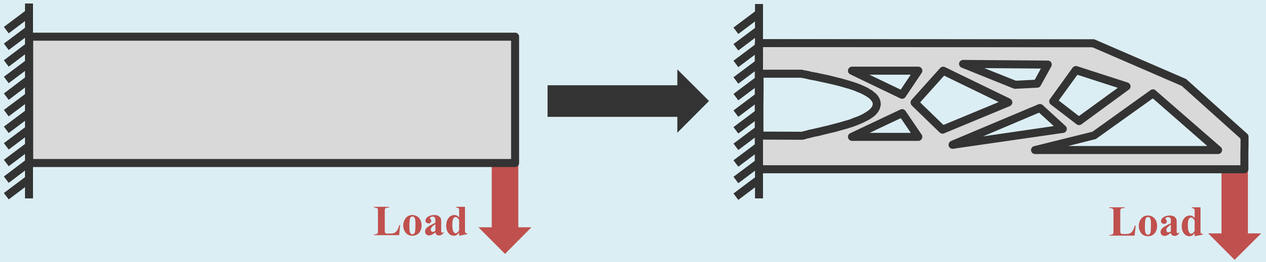
Topology optimization



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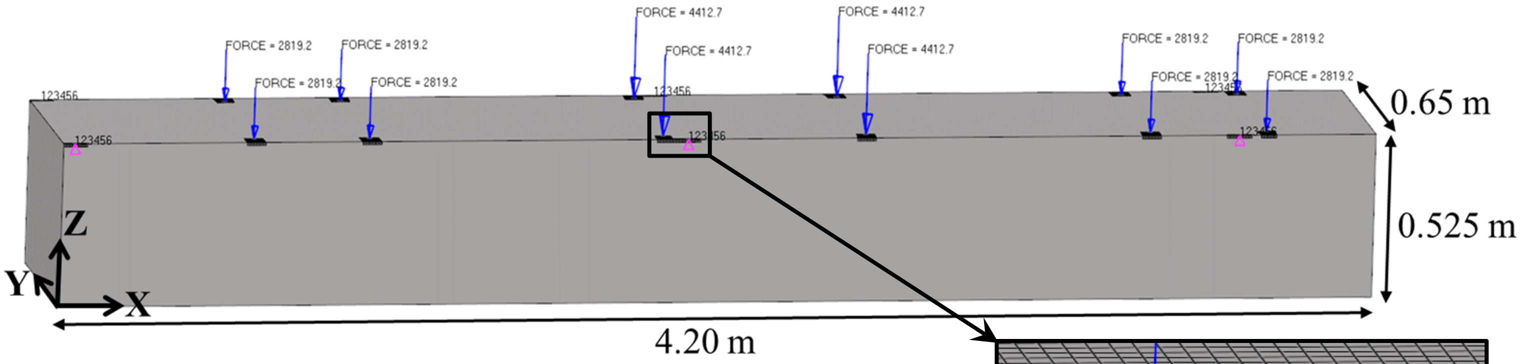
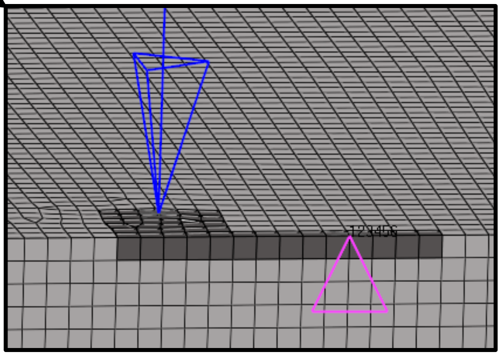
Model assembly





Fine 3D mesh

- Bright grey: design space,
  dark grey: non-design space
- Software: HyperWorks (Altair)
- Goal: Maximize stiffness
- Constraints: 1st natural frequency > 100 Hz
  Volume < 10 % of design space volume

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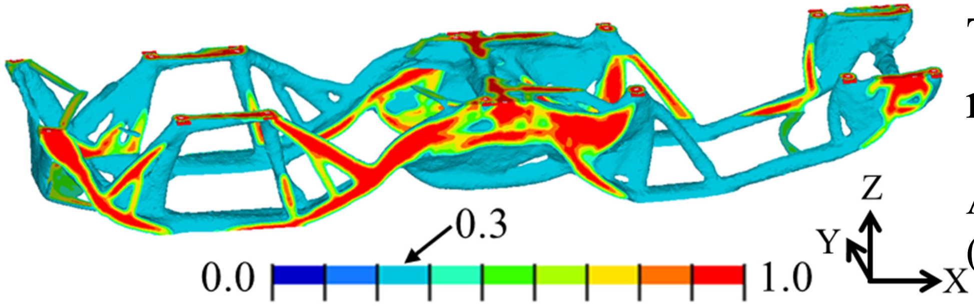
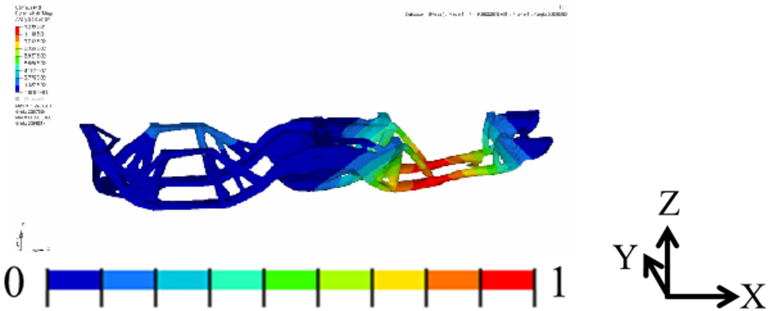
Results



Topology optimization result

Artificial element density (densities > 0.3 are displayed)

Properties of the resulting structure:
1st natural frequency: 91 Hz - mass: 863 kg - maximal static deflection: 0.03 mm



Modal analysis result

Normalized vibration amplitude of the 1st eigenmode

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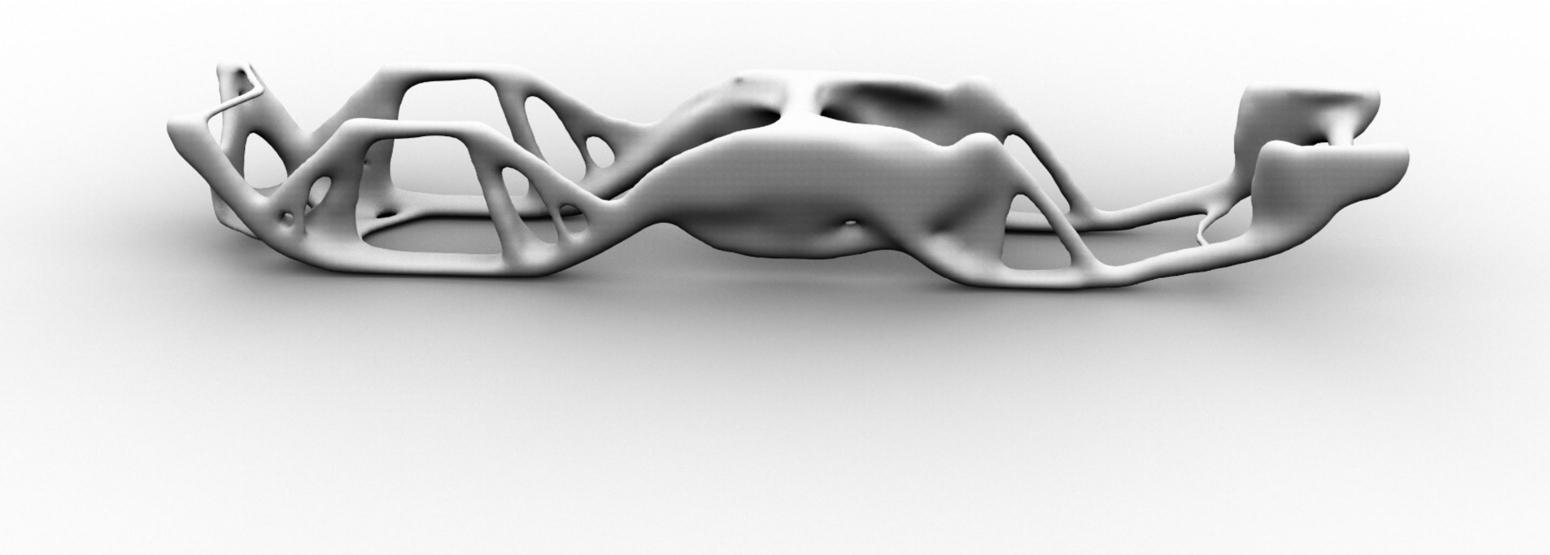
Further optimization

Smoothing the topology optimization result, deriving curves from it, projecting them on the outer girder walls as ribs and varying the rib thicknesses in parameter studies.



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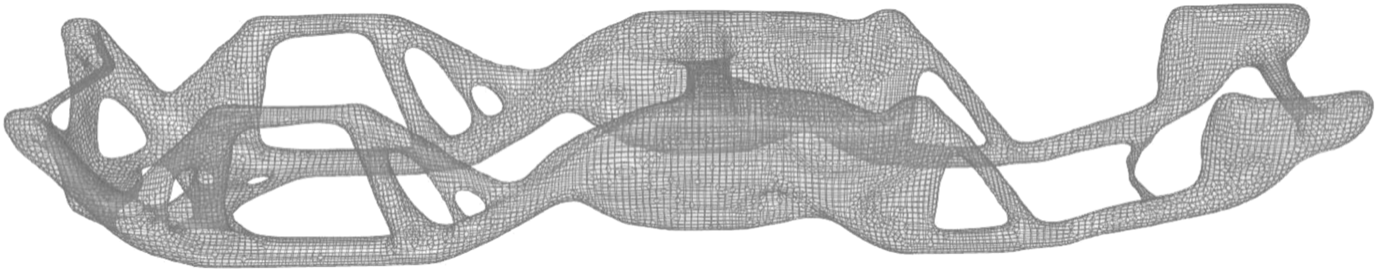

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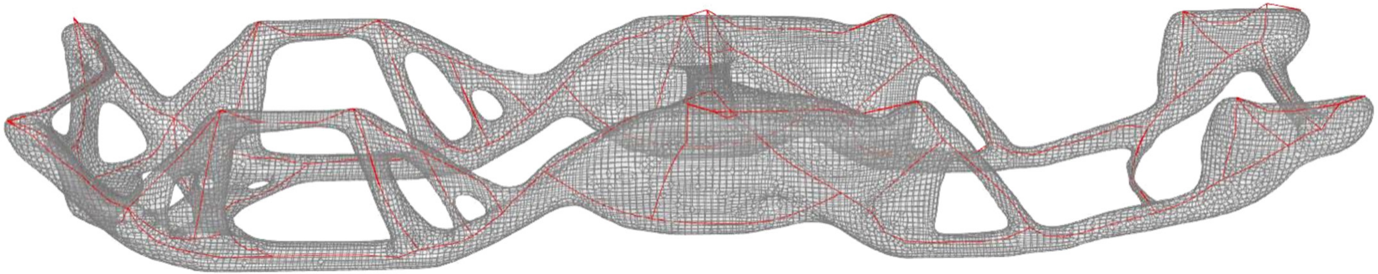

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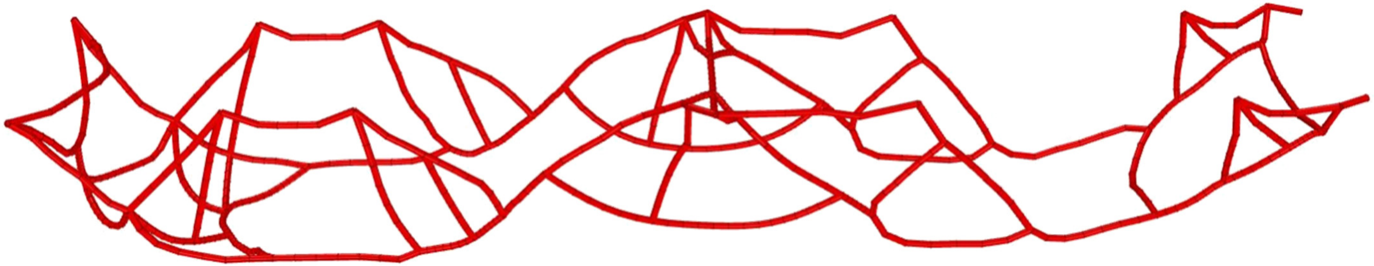

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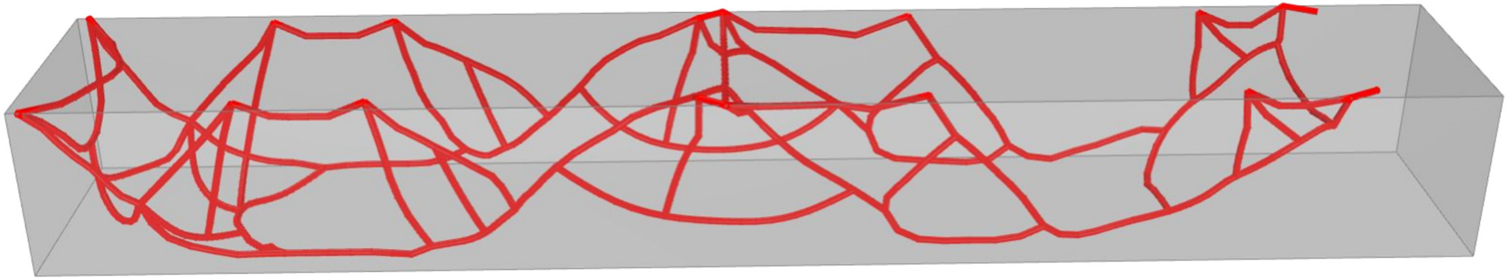

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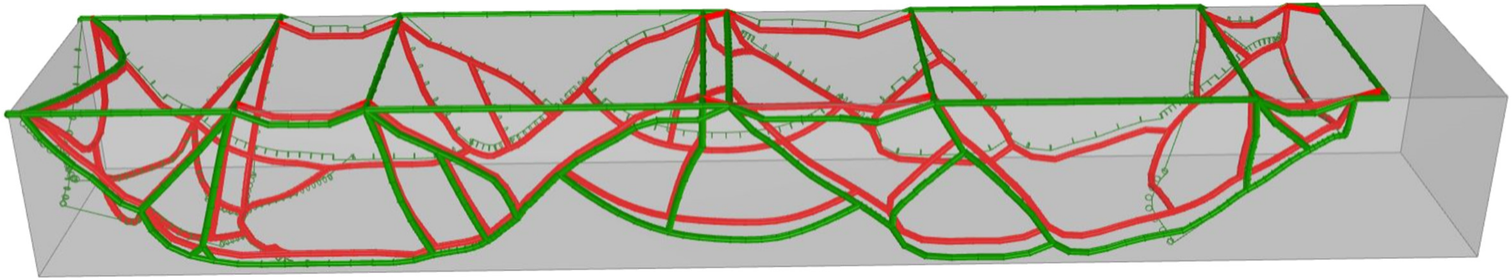

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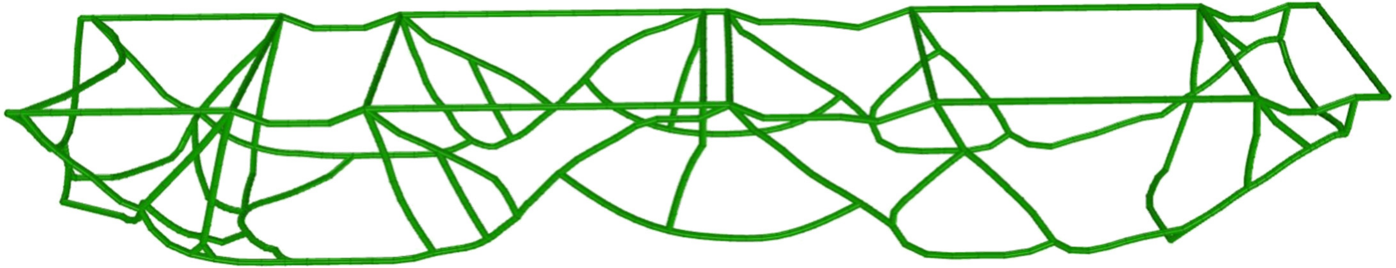

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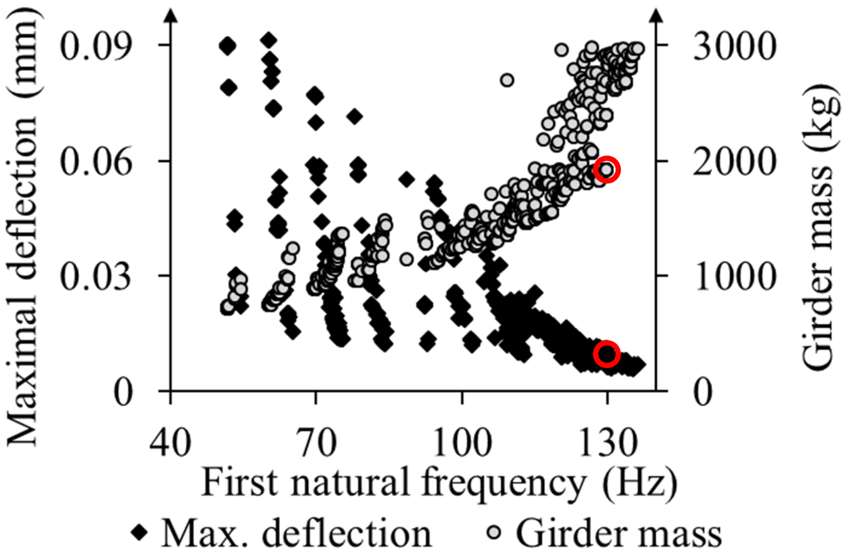
Further optimization: Results

Smoothing the topology optimization result, deriving curves from it, projecting them on the outer girder walls as ribs and varying the rib thicknesses in parameter studies.



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Further optimization: Results

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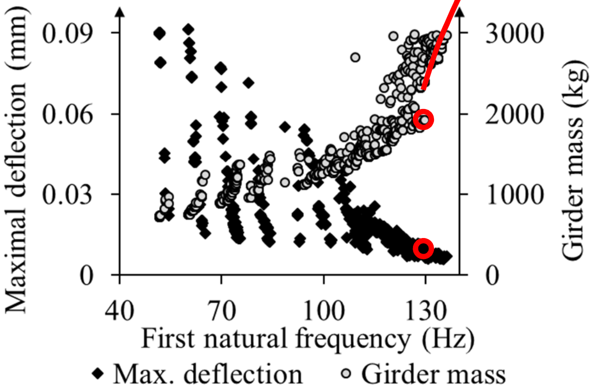
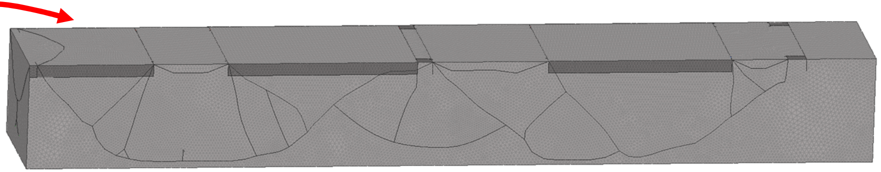
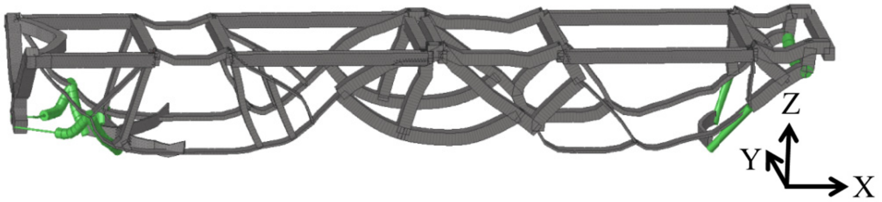




1st natural frequency: 130 Hz
mass: 1,920 kg – max. deflection: 0.01 mm

Outer girder walls hidden:



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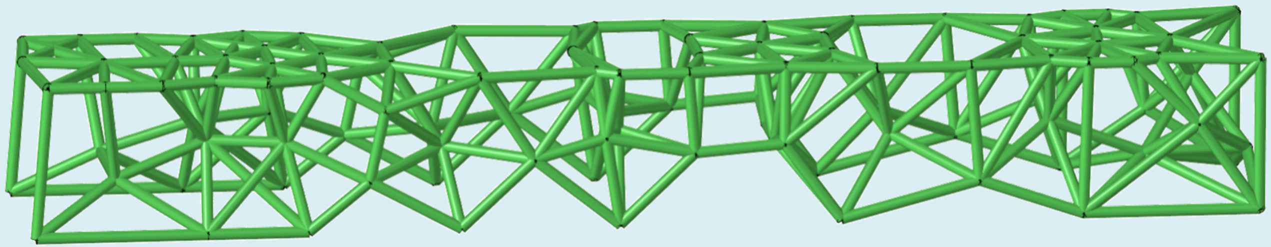
Bionic lattice structures



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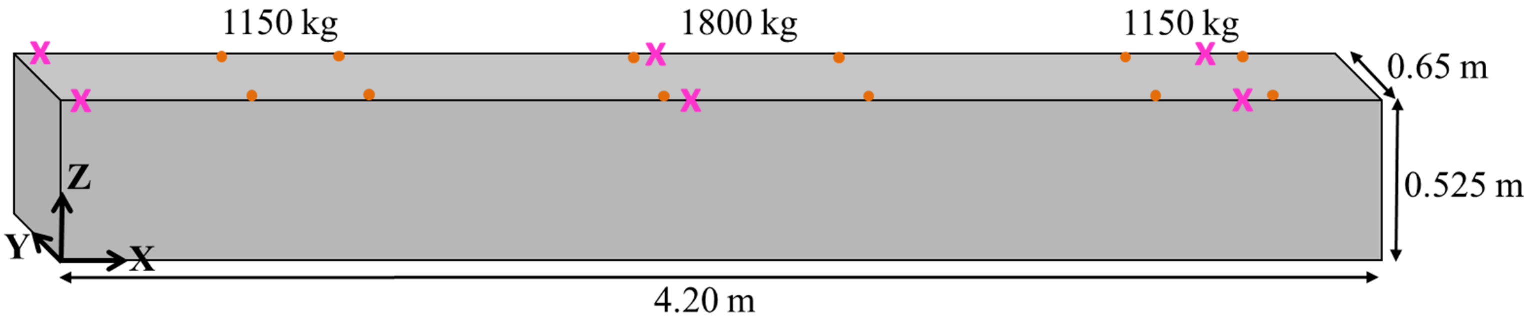
Model assembly

- Construction of lattices inside the hollow girder



- Boundary conditions, material properties and loads were analogous to the previous studies.
- Lattice parameters were varied to develop different structures and find the best parameter combination.

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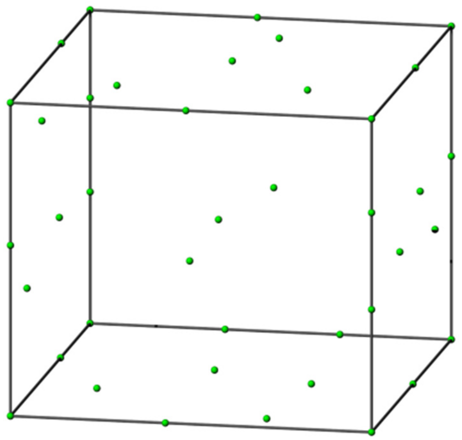
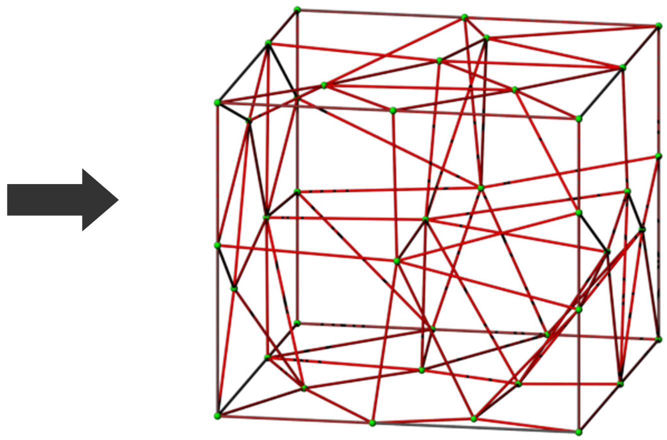
Generating bionic lattice structures

Lattice structures were built by connecting neighboring points.



Point distribution inside a volume



Connecting each point with several neighboring points

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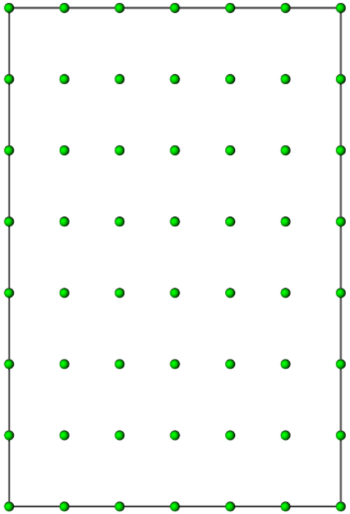
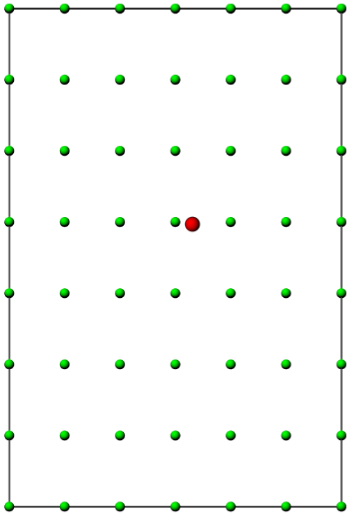
Generating bionic lattice structures

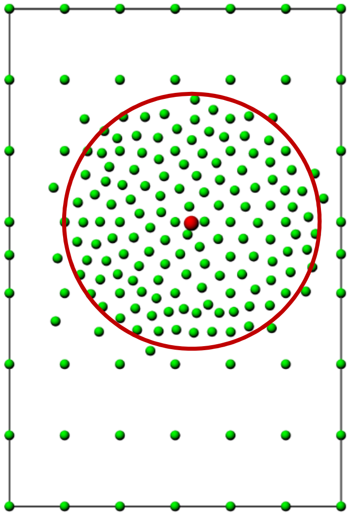
Lattice structures were influenced by attractors.



Point distribution (here: regular)



Defining an attractor (here: red point)



Point distribution density is changed close to the attractor

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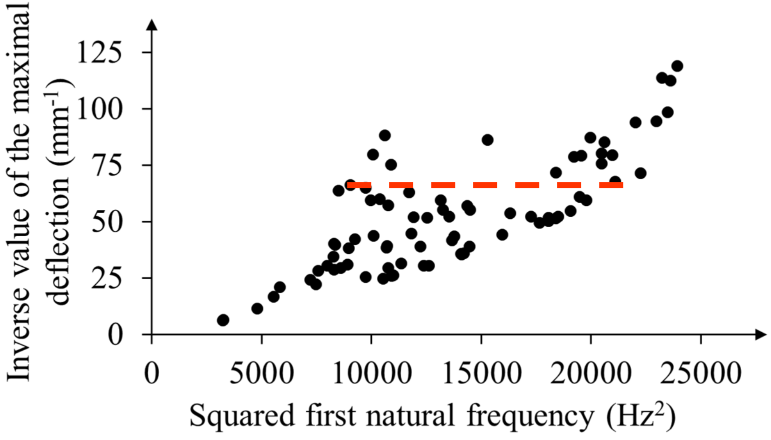
Results

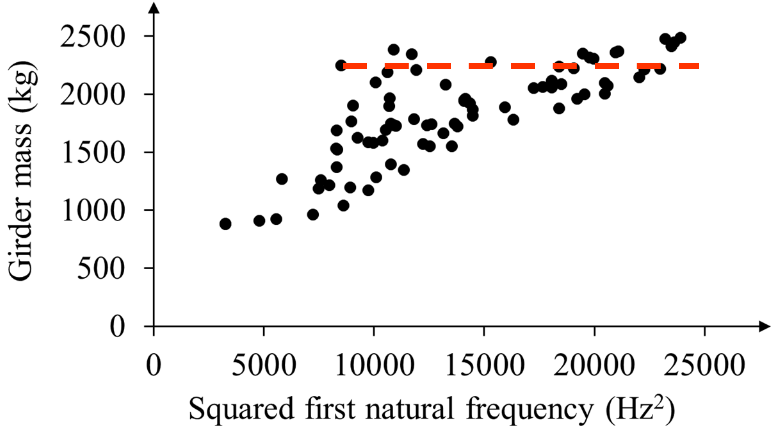
High potential of bionic lattice structures:

Natural frequency can be increased by leaving the stiffness and/or mass constant.

One mass oscillator (1 DOF):

$$f = \frac{1}{2\pi}\sqrt{\frac{c}{m}}$$





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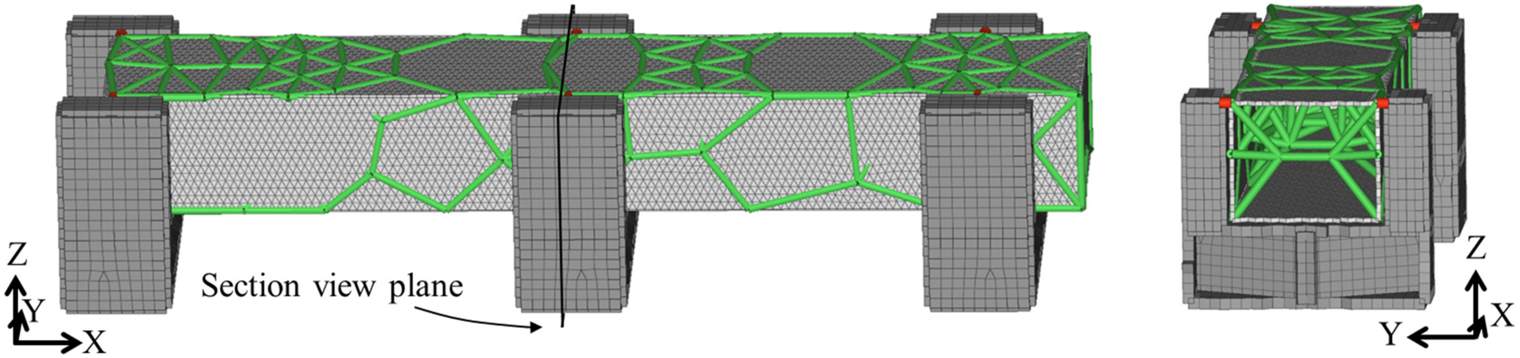
Results

Best girder structure (pedestals are included)

- 1st natural frequency: 70 Hz
- Girder mass: 2489 kg
- Maximal deflection (linear static): 0.02 mm



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Conclusion

(4)

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Conclusion

- Support point number and location have a huge impact on the girder properties.
- Pedestals should have a high stiffness.
- Topology optimizations in combination with further optimizations to find optimal rib thicknesses leads to promising girder designs.
- The use of bionic lattice structures also allows the development of girder designs with high natural frequencies and stiffness.

Images

(1) http://www.charles-darwin-jahr.at/index.php?m=viewarticle&ar=76 (06/22/2018)

(2) https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=2ahUKEwjhrcT7u-TbAhUJGuwKHY5GCegQjxx6BAgBEAI&url=https%3A%2F%2Fwww.bild.de%2Fratgeber%2Fevergreen%2Fverkehrsordnungswidrigkeit%2Falltagsfrage_gullideckel-48699678.bild.html&psig=AOvVaw0CmhRN6iVYW9WBXEEzcuN3&ust=1529660609455012 (06/21/2018)

(3) https://www.dreamstime.com/stock-illustration-cartoon-boy-asking-question-image52969173 (06/21/2018)

(4) http://posandnegaimpactsofsocnetsites.blogspot.com/2014/12/conclusion.html (06/19/2018)

Thank you very much for your attention

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