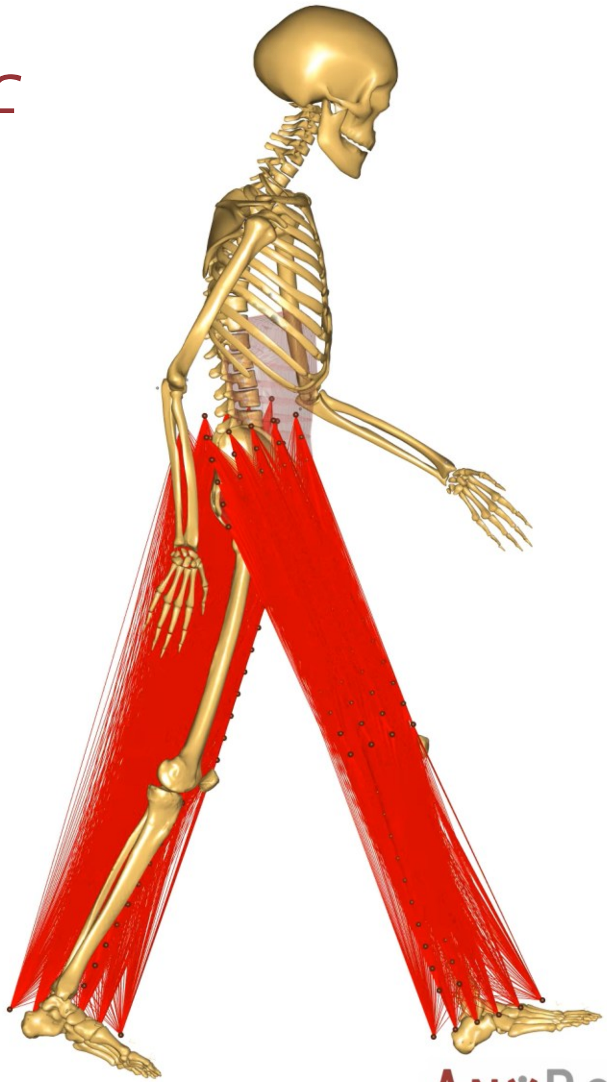
September 23, 2026

Topology Optimization of Exoskeletons



The webcast will begin shortly...

Outline

- Introduction to the AnyBody Modeling System
- Presentation
- Resources and upcoming AnyBody events
- Question and answer session

Presenter

Prof. John Rasmussen

Aalborg University

Denmark

Host

Divyaksh S. Chander

Sales Engineer

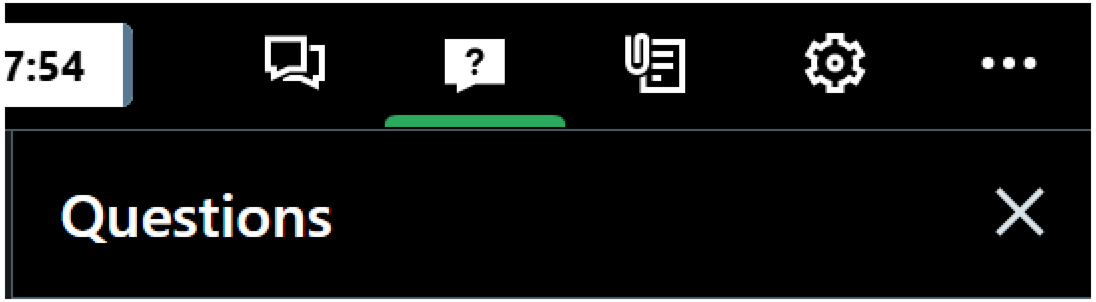
AnyBody Technology

dsc@anybodytech.com

Control Panel

The Control Panel appears on the **top-right** side of your screen.

Submit questions and comments via the Questions panel.



Questions will be addressed at the end of the presentation. If your question is not addressed, we will do so by email.

Musculoskeletal simulations

INPUT • Motion data

- Motion
- Forces

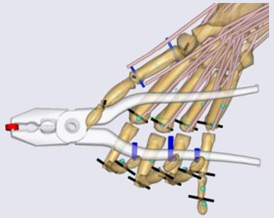
ANYBODY MODELING SYSTEM

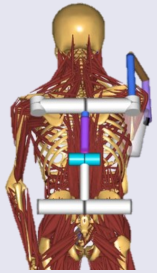
OUTPUT • Internal Body Loads

- Joint reaction forces
- Muscle forces
- Muscle activity
- Metabolic energy + fatigue

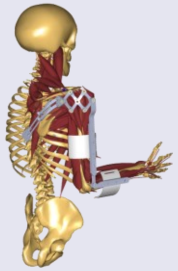
Motion analysis

Product design and optimization

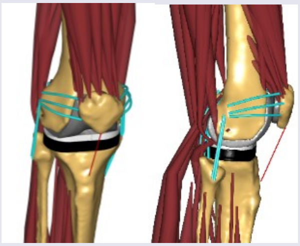




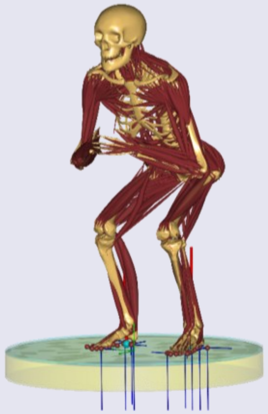
Ergonomics with/without exoskeletons



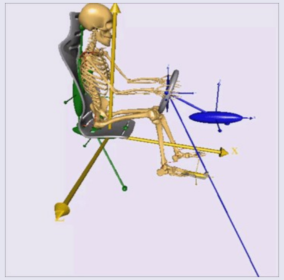
ANYBODY
MODELING SYSTEM



Orthopedics and Rehabilitation

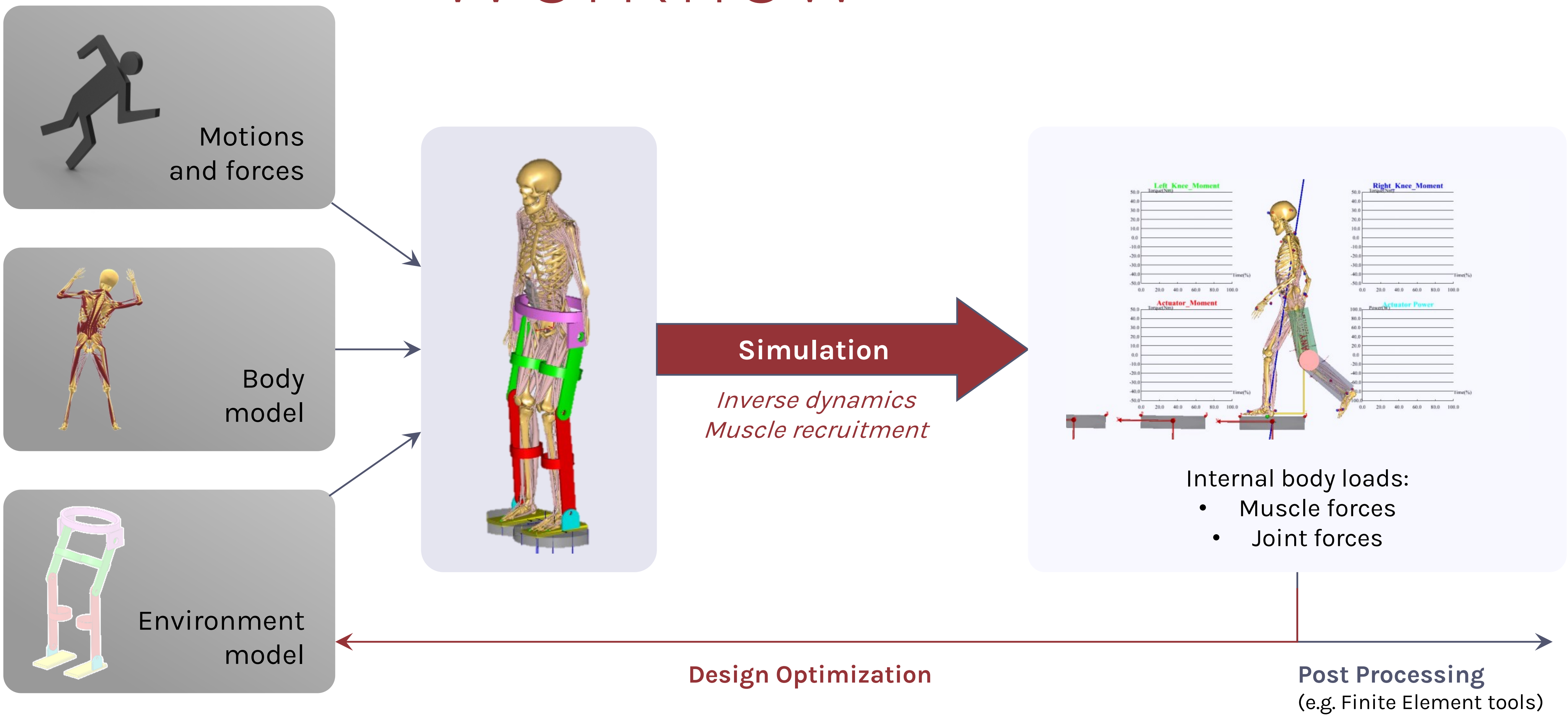


Sports

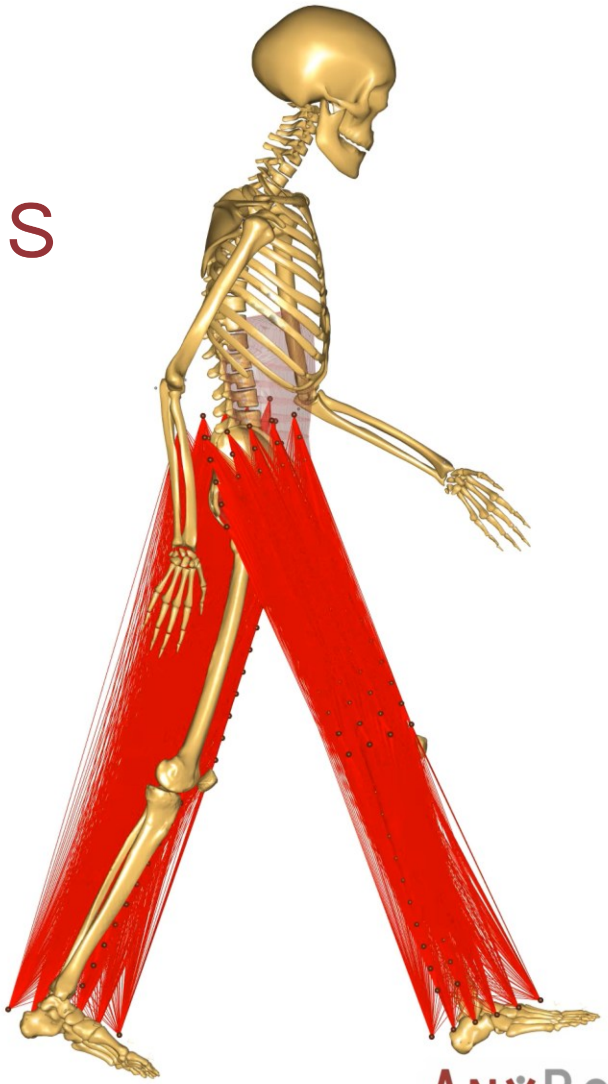


Automotive

Workflow


Motions
and forces
Body
model
Environment
model
Simulation
Inverse dynamics
Muscle recruitment
Left_Knee_Moment
Right_Knee_Moment
Actuator_Moment
Actuator Power
Internal body loads:
• Muscle forces
• Joint forces
Design Optimization
Post Processing
(e.g. Finite Element tools)

Topology Optimization of Exoskeletons



Topology Optimization of Exoskeletons

Computer Methods in Applied Mechanics and Engineering 89 (1991) 259–279
North-Holland

On CAD-integrated structural topology and design optimization

Niels Olhoff
Institute of Mechanical Engineering, Aalborg University, Denmark

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Mathematical Institute, The Technical University of Denmark, Denmark

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Received 30 August 1990
Revised manuscript received 11 February 1991

The Ground Structure

N. Olhoff et al., On CAD-integrated structural topology and design optimization

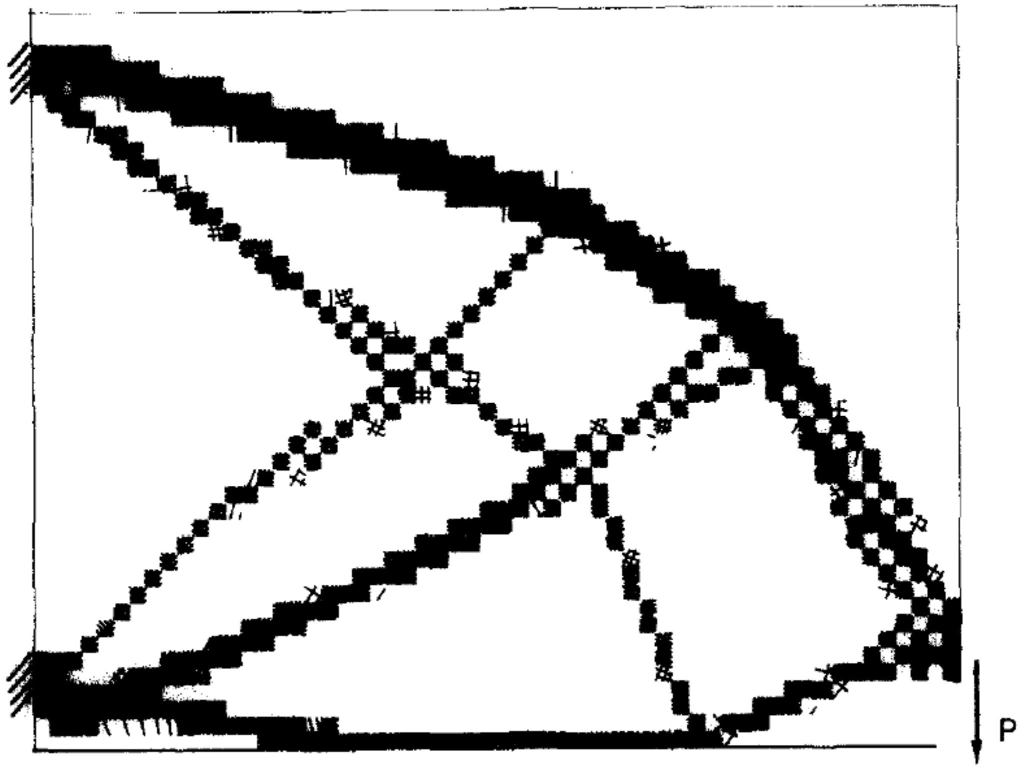

Fig. 4. Solution of topology optimization problem.

This is the
MBB Beam

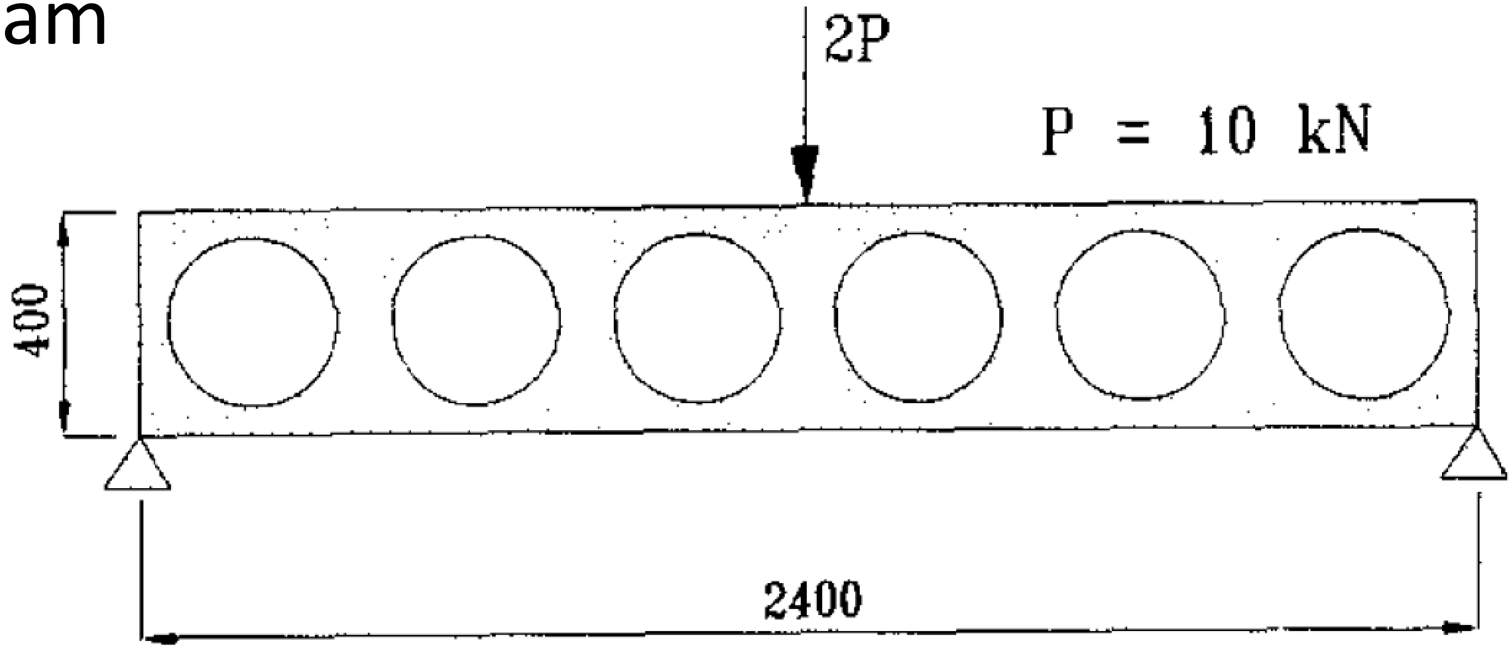

Fig. 12. Initial geometry with loads and boundary conditions.

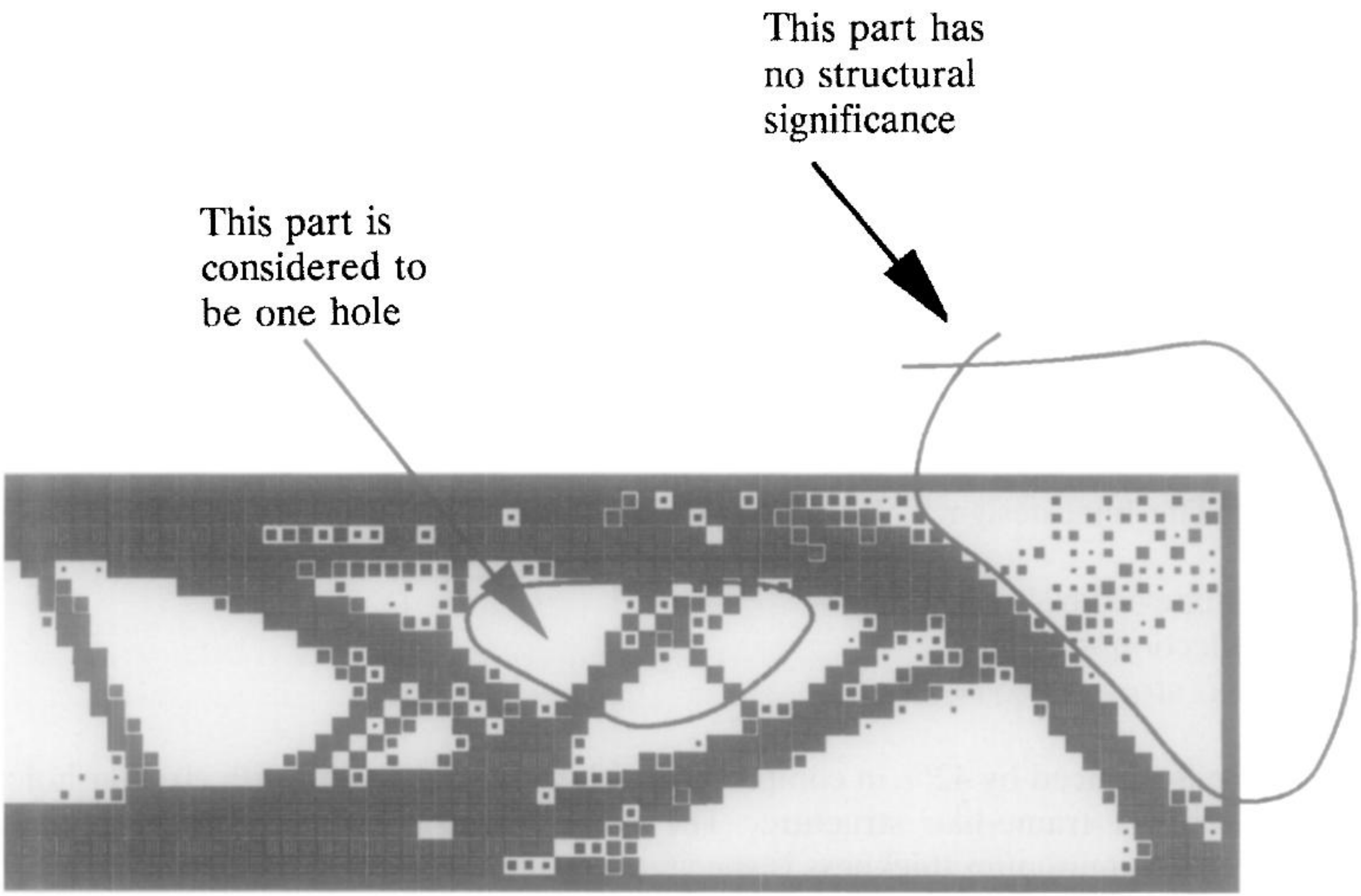

Fig. 16. Result of topology optimization.

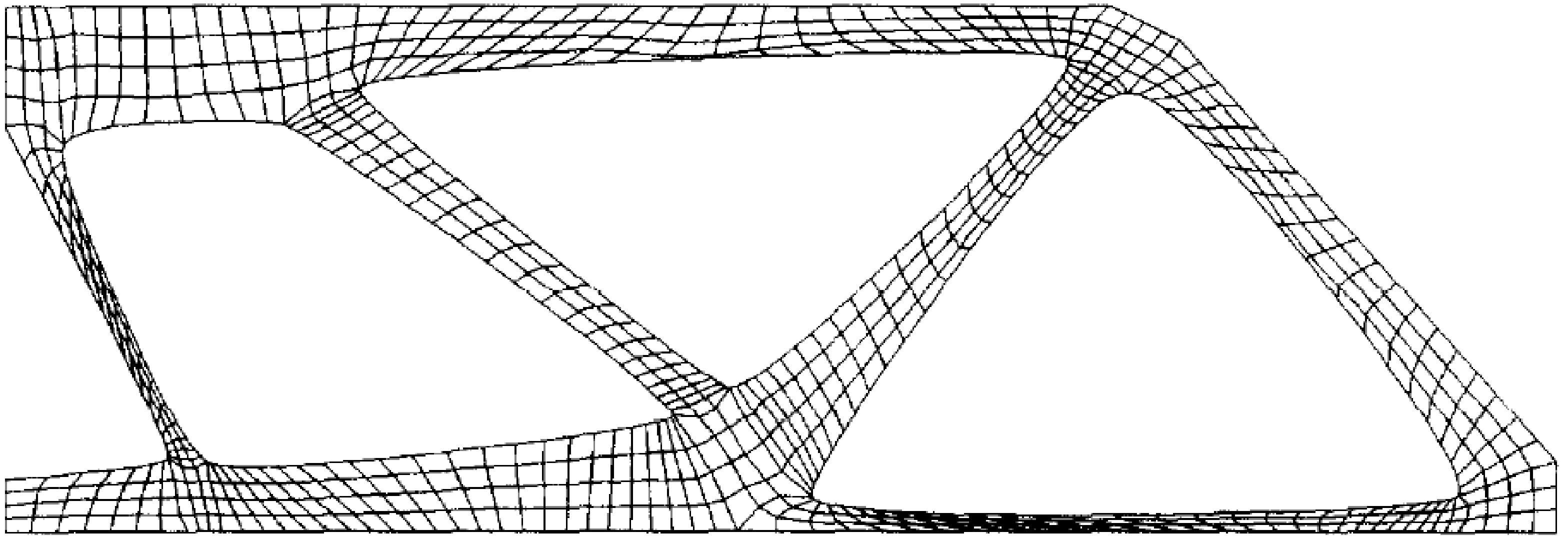

Fig. 18. Final finite element model.

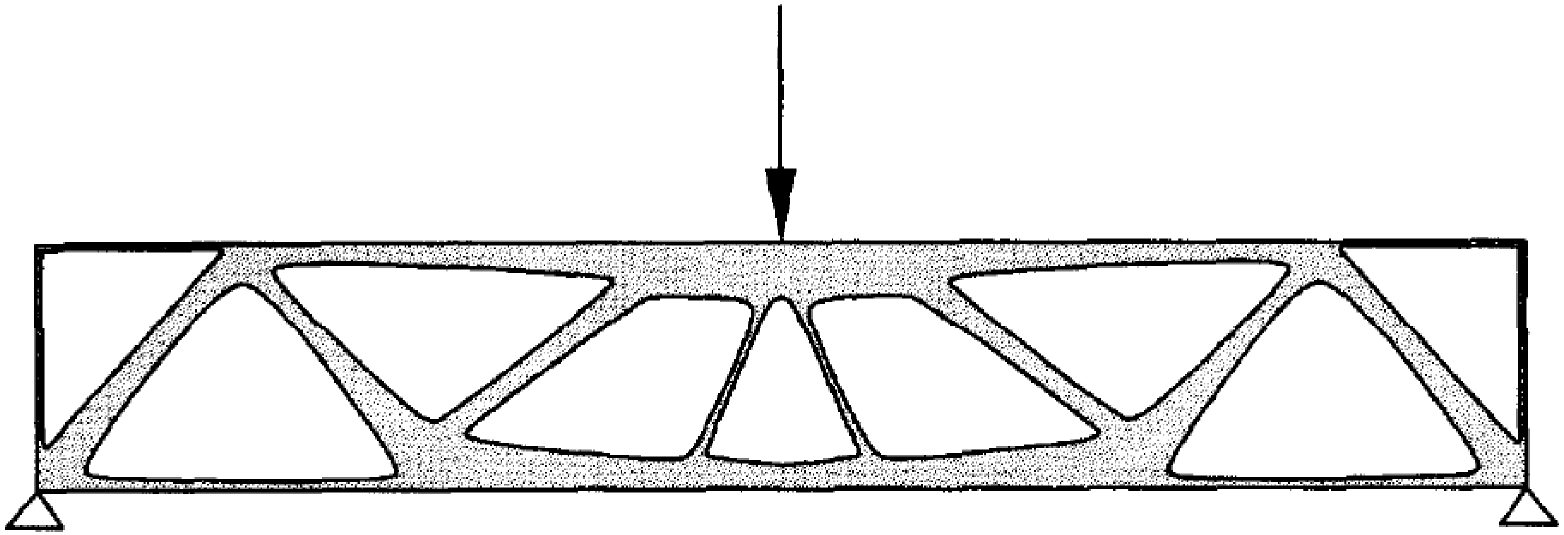

Fig. 19. Example of final geometry slightly modified by the designer. The upper right corner has been added again.

Når som helst
Siden 2026
Siden 2025
Siden 2022
Tilpasset interval...

Sorter efter relevans
Sorter efter dato

Alle typer
Oversigtsartikler

inkluder patenter
inkluder henvisninger

Opret underretning

[HTML] 3D printing of topologically optimized wing spar with continuous carbon fiber reinforced composites

Y Huang, X Tian, W Li, S He, P Zhao, H Hu… - Composites Part B …, 2024 - Elsevier

… In this section, a continuous carbon reinforced UAV wing spar and an **MBB beam** were calculated to verify the developed method, as shown in Fig. 5, Fig. 6, respectively. …

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Hurtig læsning

Multiscale concurrent design and 3D printing of continuous fiber reinforced thermoplastic composites with optimized fiber trajectory and topological structure

Y Huang, X Tian, Z Zheng, D Li, AV Malakhov… - Composite …, 2022 - Elsevier

… In this section, the continuous fiber reinforced **MBB beam** and cantilever beam by multiscale concurrent design with optimized fiber trajectory and topological structure are fabricated by …

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[HTML] Multiscale topology optimization and 3D printing of continuous carbon fiber reinforced composites lattice structure

Y Huang, S He, X Tian, W Li, Z Mei, P Liu… - Composites Part B …, 2025 - Elsevier

… topological **MBB beam** with … **MBB beam** with optimized unit cells and fixed unit cells are 40 h and 44 h, respectively, which are longer than the 38 h required for the tradition **MBB beam**. …

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Hurtig læsning

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S Khalilvandi Behrouzyar, A Kendibilir… - Engineering with …, 2025 - Springer

… The optimization process applied to both L-beam and **MBB-Beam** structures results in … For the **MBB-Beam**, optimization process induces geometric modifications that yield a stress …

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Hurtig læsning - d-nb.info

Investigation on Taubin smoothing performance of additively manufactured structures: case study of the **MBB beam** using laser powder bed fusion

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Can we transfer this idea to biomechanics and exoskeleton design?

The Ground Structure

Generating design ideas from all possible solutions

Questions?

What would a ground structure look like for an exoskeleton?

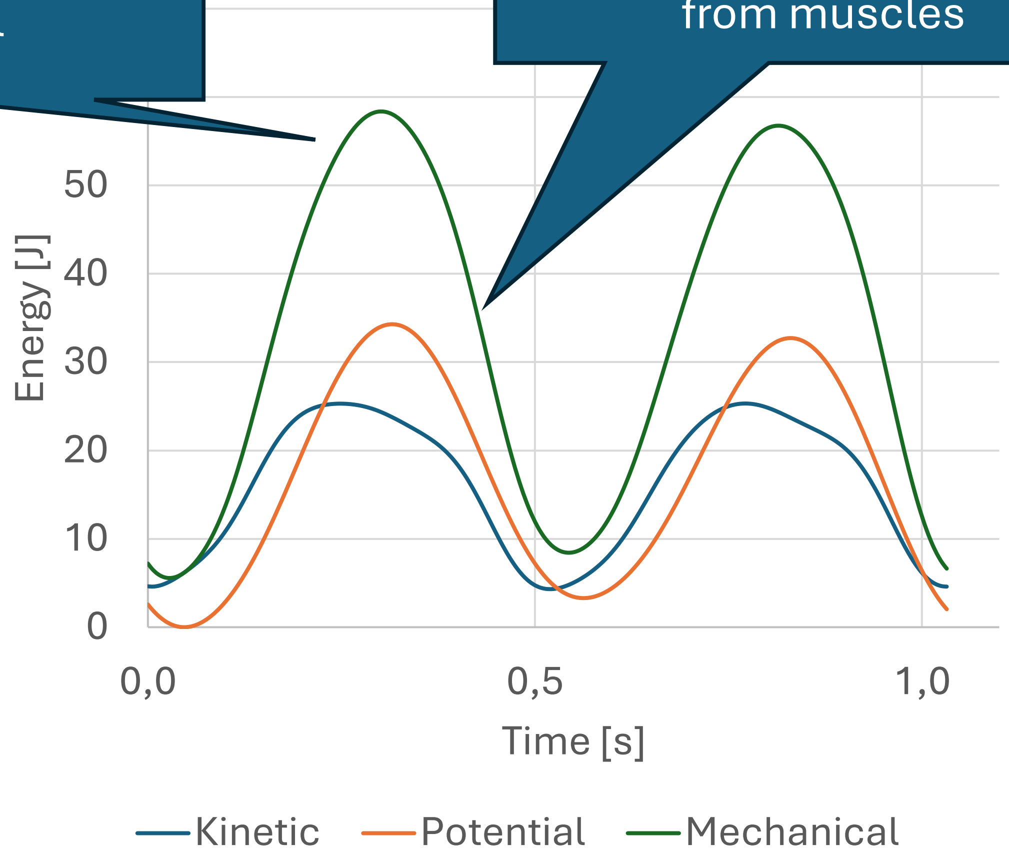
Which design criterion would we be trying to optimize?

Energy variation over the gait cycle

A walking human is energy-wise an isolated system

Almost, but not completely, symmetrical

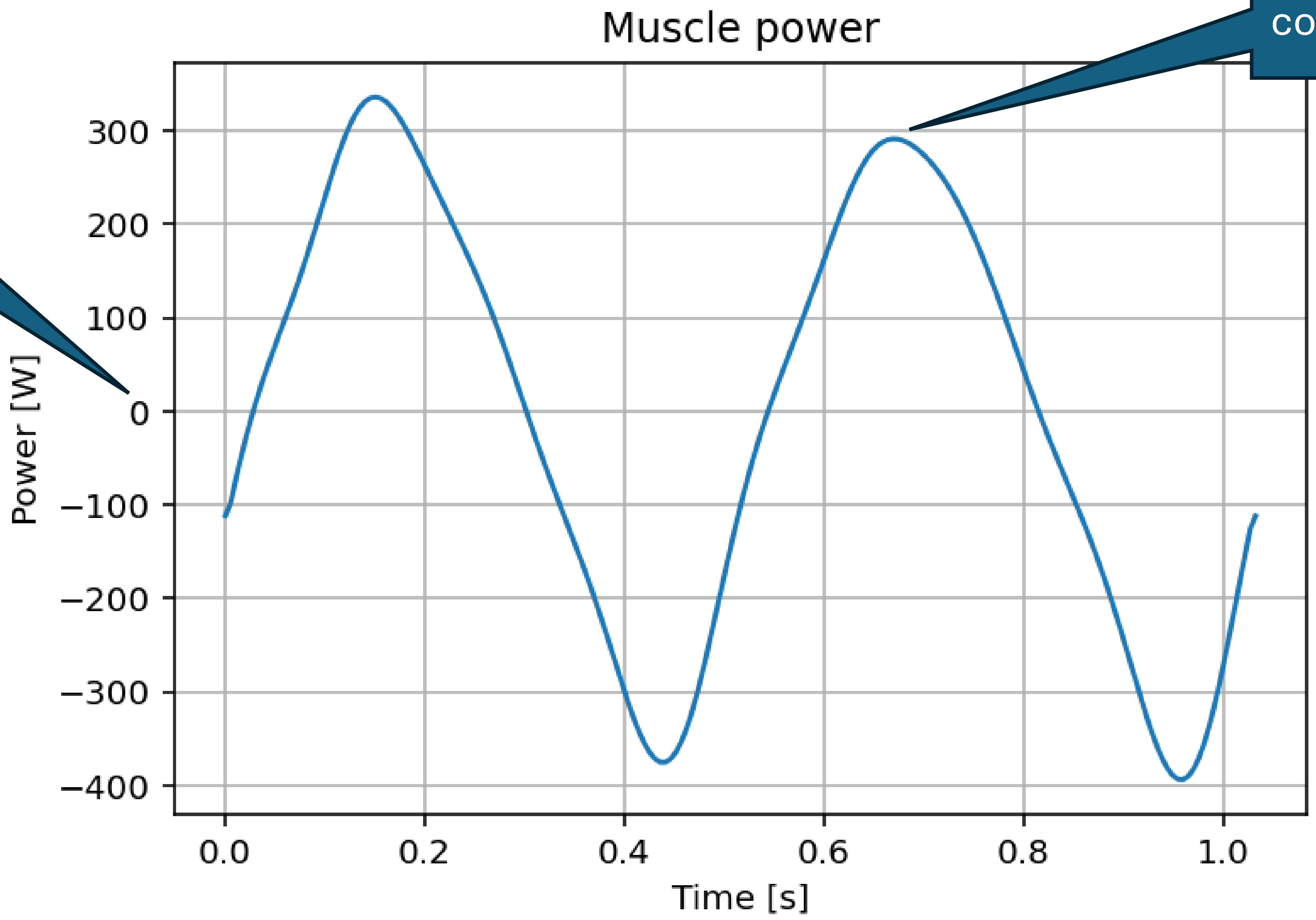
The necessary power to change energy can only come from muscles



If there were no change of energy, then ambulation would be effortless!

Total work is 0

Peaks are not completely symmetrical

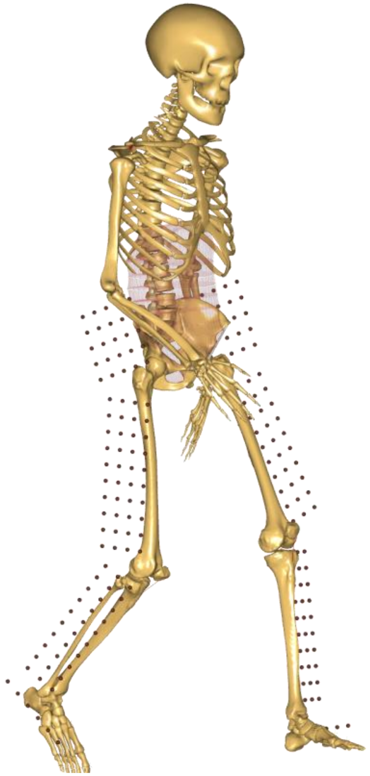


Key Idea:

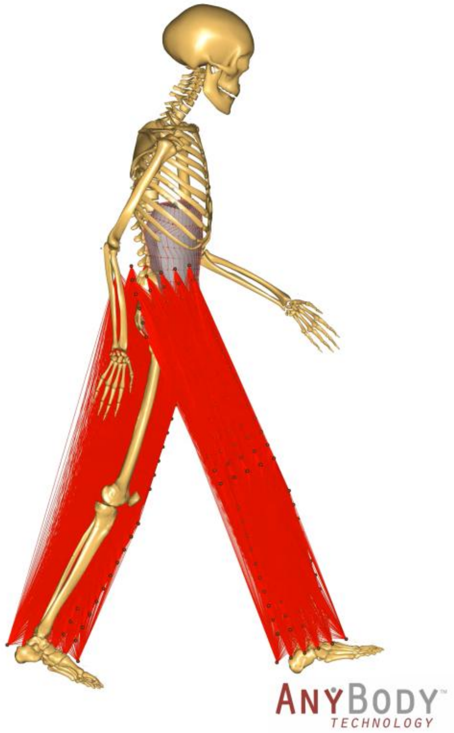
We add mechanical elements to the system such that the energy variation over the gait cycle is minimized.

Topology Optimization in Biomechanics

262 possible attachment points



The ground structure: 11350 possible springs

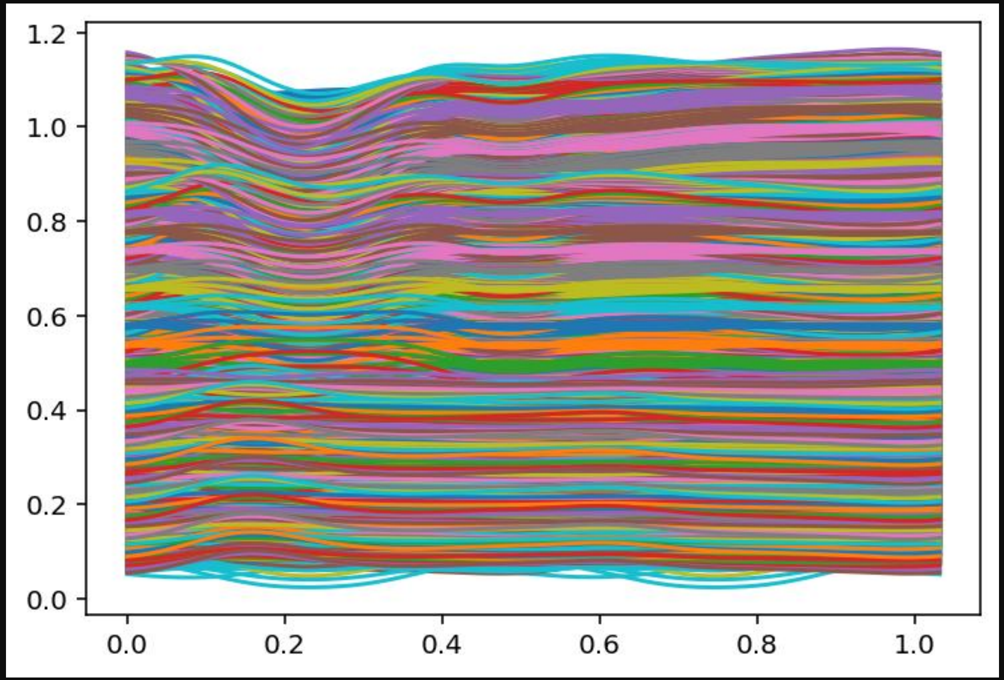


After kinematic analysis, we know the length variation of all the springs over the gait cycle

Now we must figure out:

- Which of the 11350 springs should we keep?
- Which spring properties (stiffness and slack length) should they have?

For this, we define an optimization problem.



We imagine each line is a linear spring

Assuming linear elasticity, the elastic energy of spring j in each time step can be computed analytically:

$$E_j(x) = \frac{1}{2} k_j (x_j - x_j^0)^2$$

Slack length

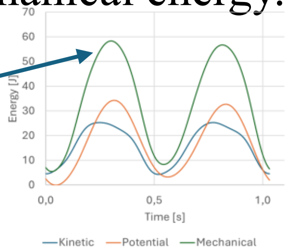
Spring stiffness

Spring length

For each time step, i, the elastic energy of all springs is summed and added to the mechanical energy.

We want this to be as constant as possible. We express this as variance.

$$E_i = \sum_{j=1}^{n} E_j(x_{ij}) + V_i$$



where V_i is the mechanical energy of the entire body in time step i, and x_{ij} is the length of spring j in time step i.

Optimization problem

Minimize the variance of total energy over the gait cycle:

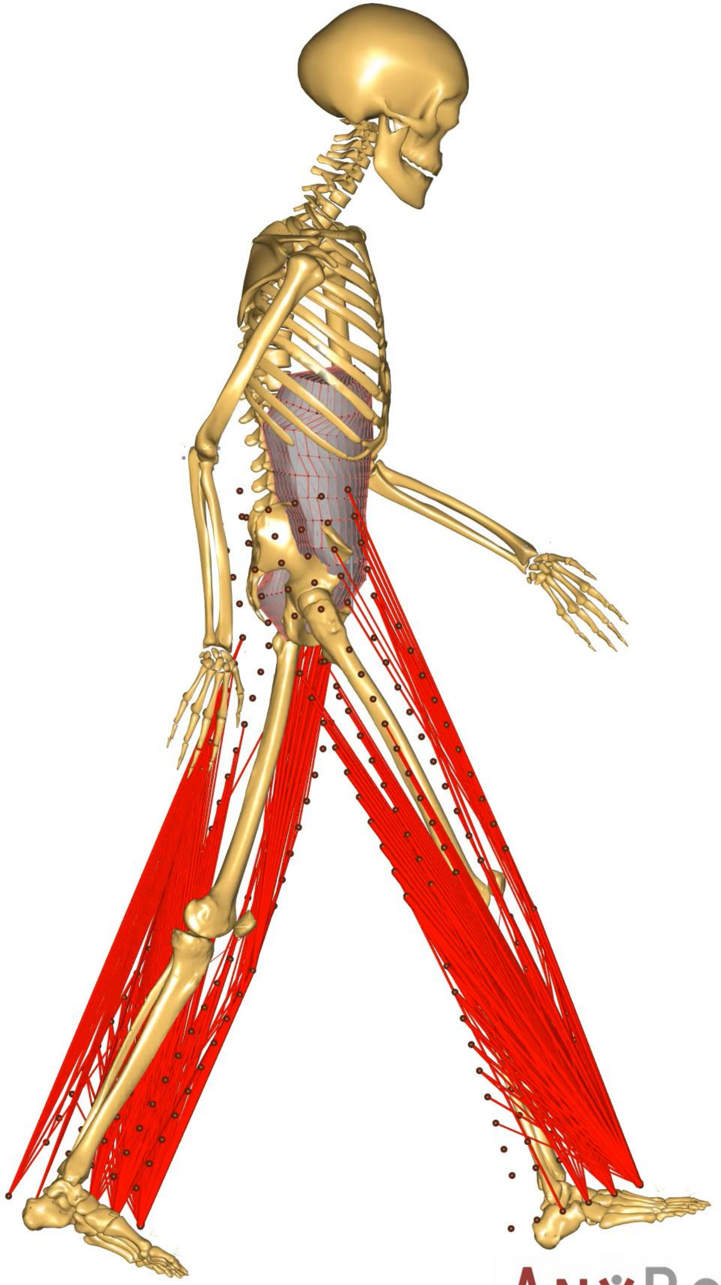
$$G\left(k_j, x_j^0\right) = \sum_{i=1}^{m} (E_i - \bar{E})^2$$

where $\bar{E}$ is the mean of the posture energies

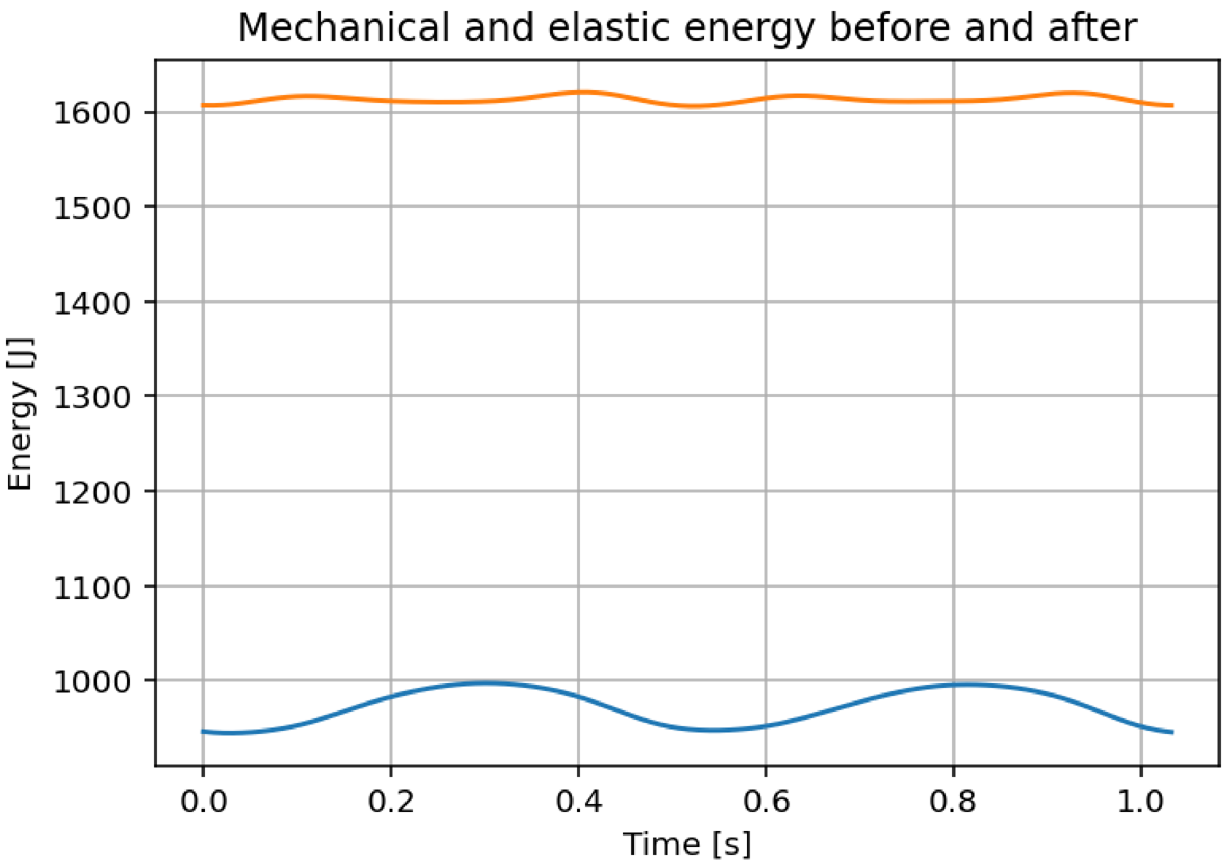
11350 springs = 11350 spring stiffnesses + 11350 slack lengths = 22700 design variables.
Very large optimization problem, but the objective function is explicit, so it can be solved very efficiently.
We dump the spring length variations from AnyBody and import them into a Python program, and then we optimize.

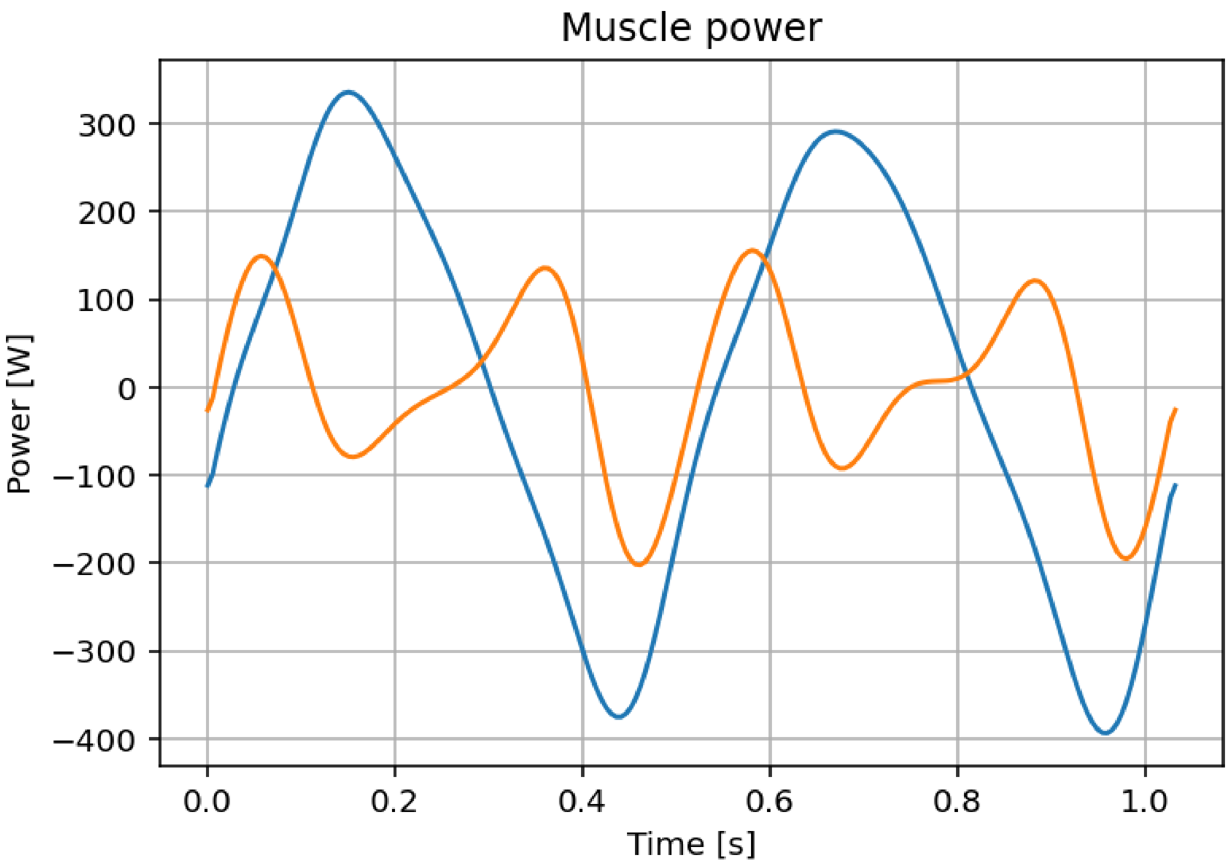
Interesting but impractical

- 360 individual springs remaining in the solution.
- Almost like pants made of an anisotropic fabric.
- Almost but not completely symmetrical.
- Is this practical for manufacture?
- 3D print on fabric?



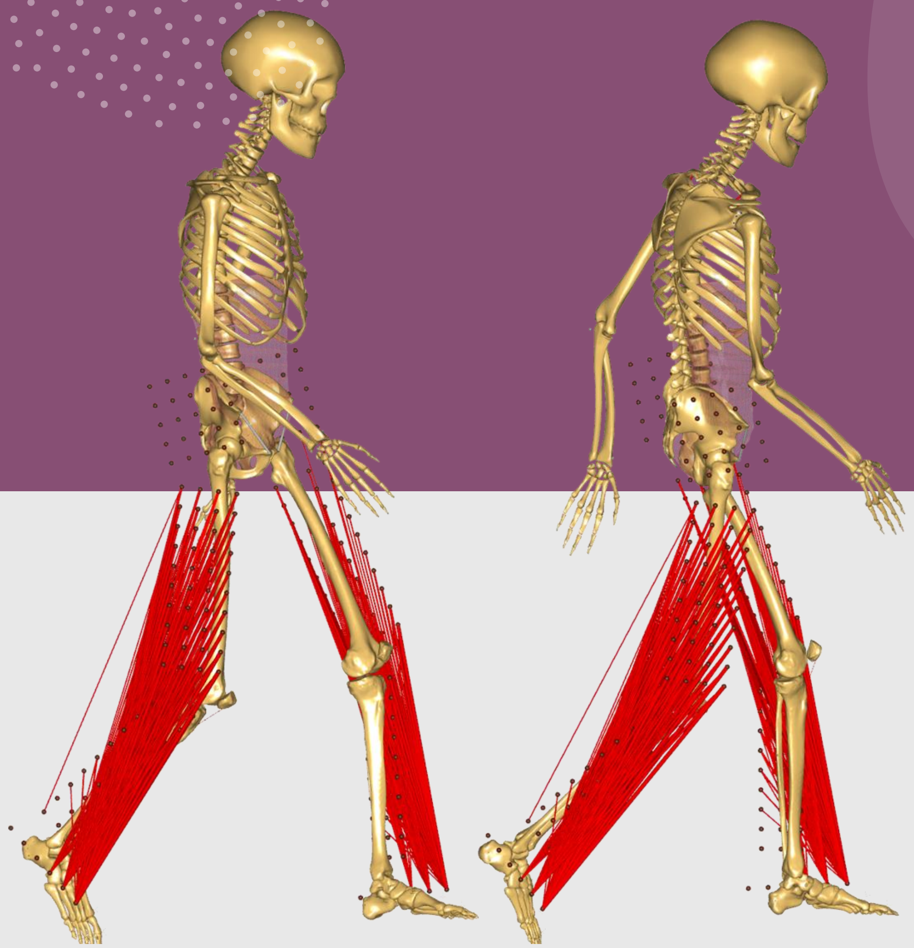
Biomechanical Effects





Can we simplify the solution?

- 360 springs is a lot
- We would like a simpler solution
- We cannot just randomly remove springs that we think are less important
- We must reformulate the optimization problem



Penalization of the objective function

Before:

$$G\left(k_j, x_j^0\right) = \sum_{i=1}^{m} (E_i - \bar{E})^2$$

where $\bar{E}$ is the mean of the posture energies.

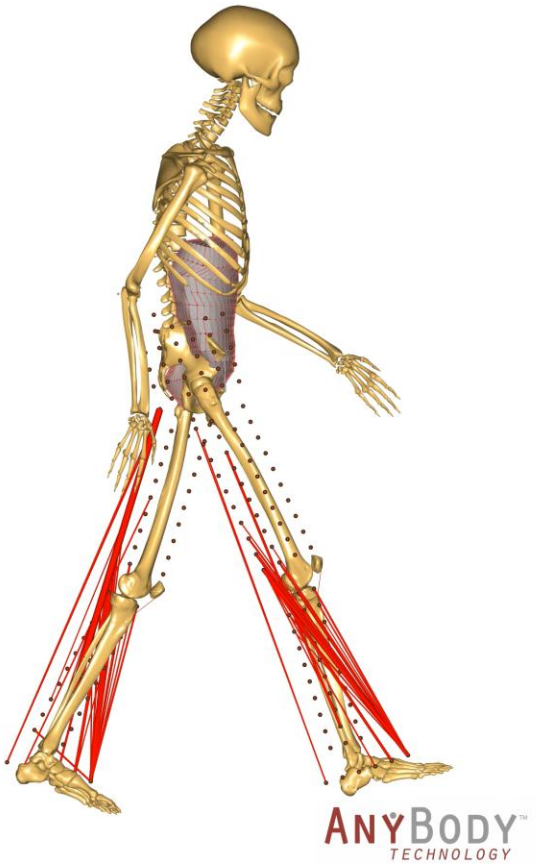
Now:

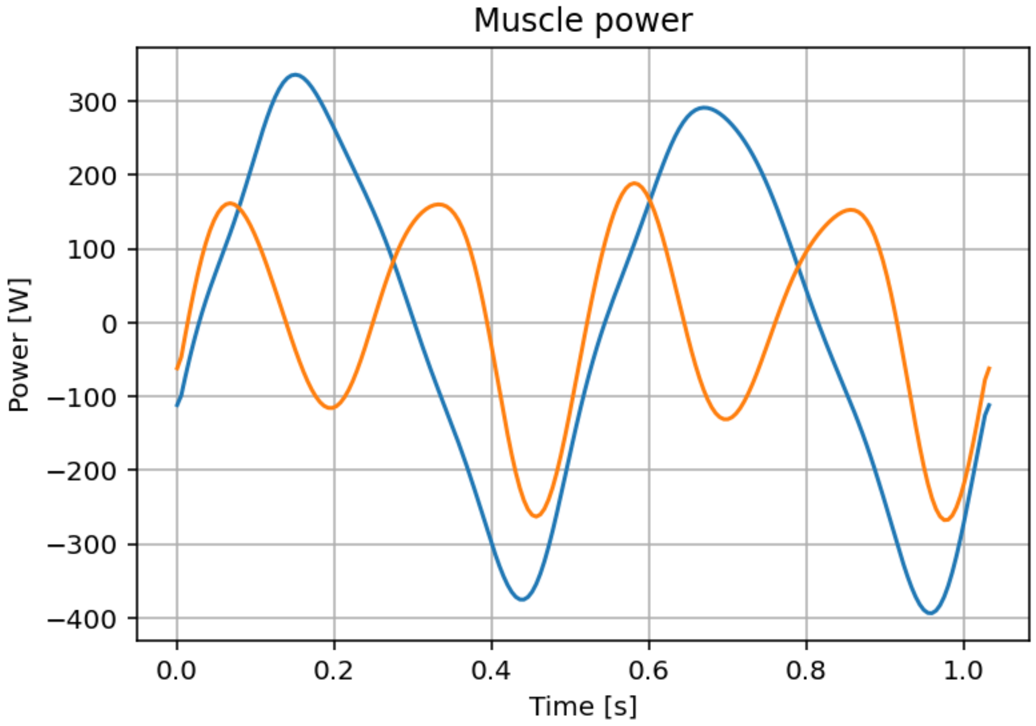
$$G\left(k_j, x_j^0\right) = \sum_{i=1}^{m} (E_i - \bar{E})^2 + \varepsilon \sum_{j=1}^{n} k_j$$

Reduce total amount of “spring”

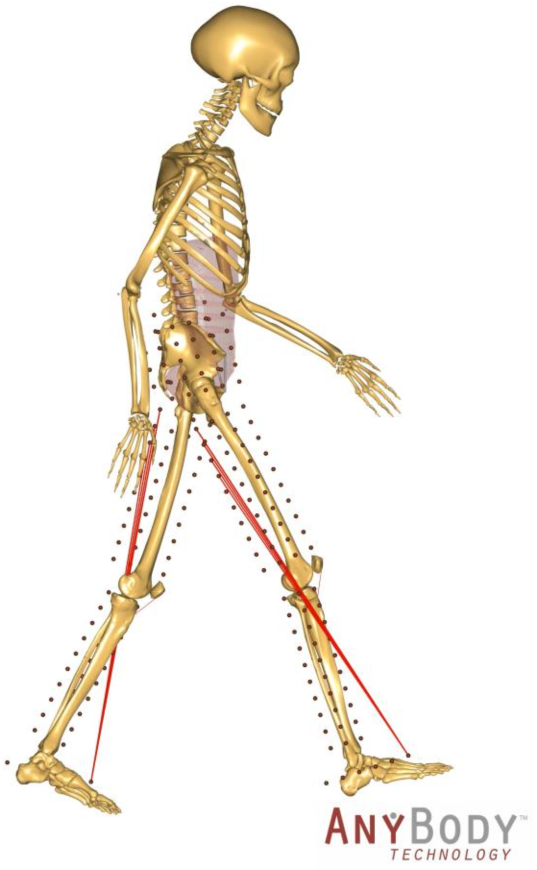
Penalization parameter

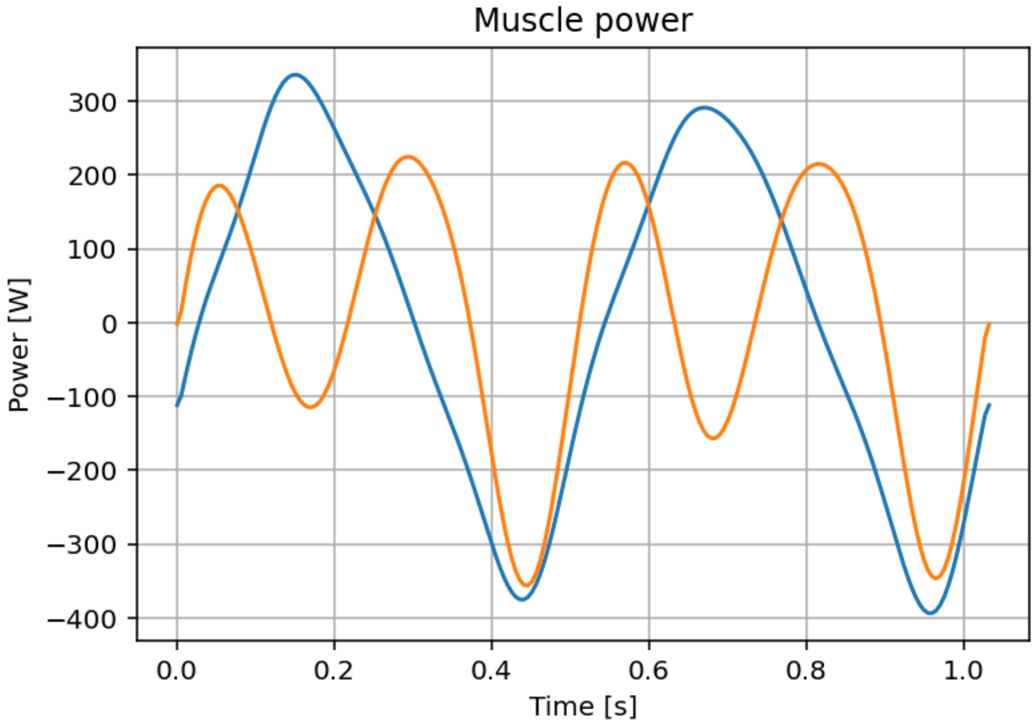
Solution with 47 springs



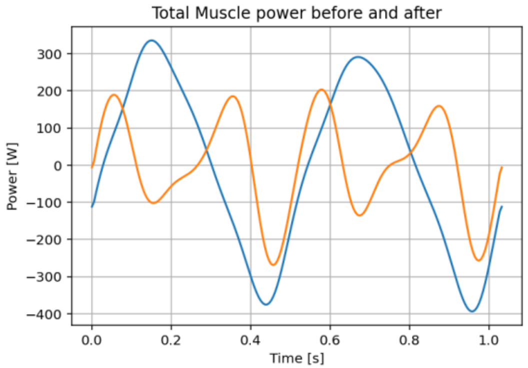


Solution with 8 springs

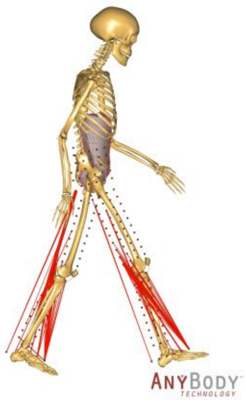




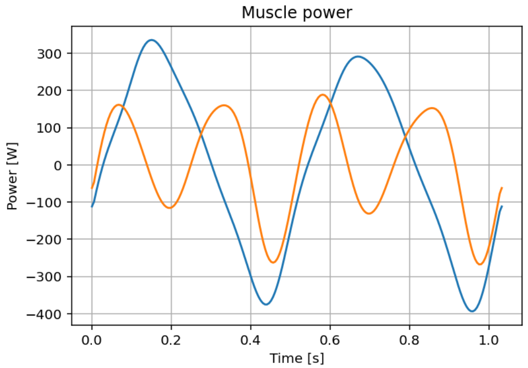
266 springs



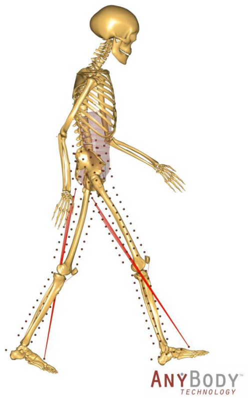
Energy span = 19.46 J



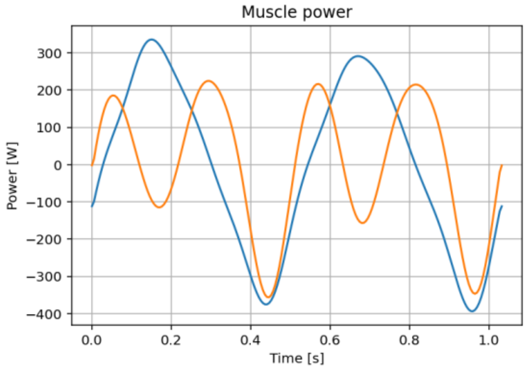
47 springs



Energy span = 20.82 J



8 springs



Energy span = 30.12 J

Discussion

Could there be better solutions?

- More points in the grids
- Larger grids
- Via points (multiple-point springs)

Enforce symmetry

- Should probably be done
- Left for a later iteration

Tights-type ground structure?

- Wrap springs around the leg surface to emulate running tights.
- Retained springs could be printed on the fabric.

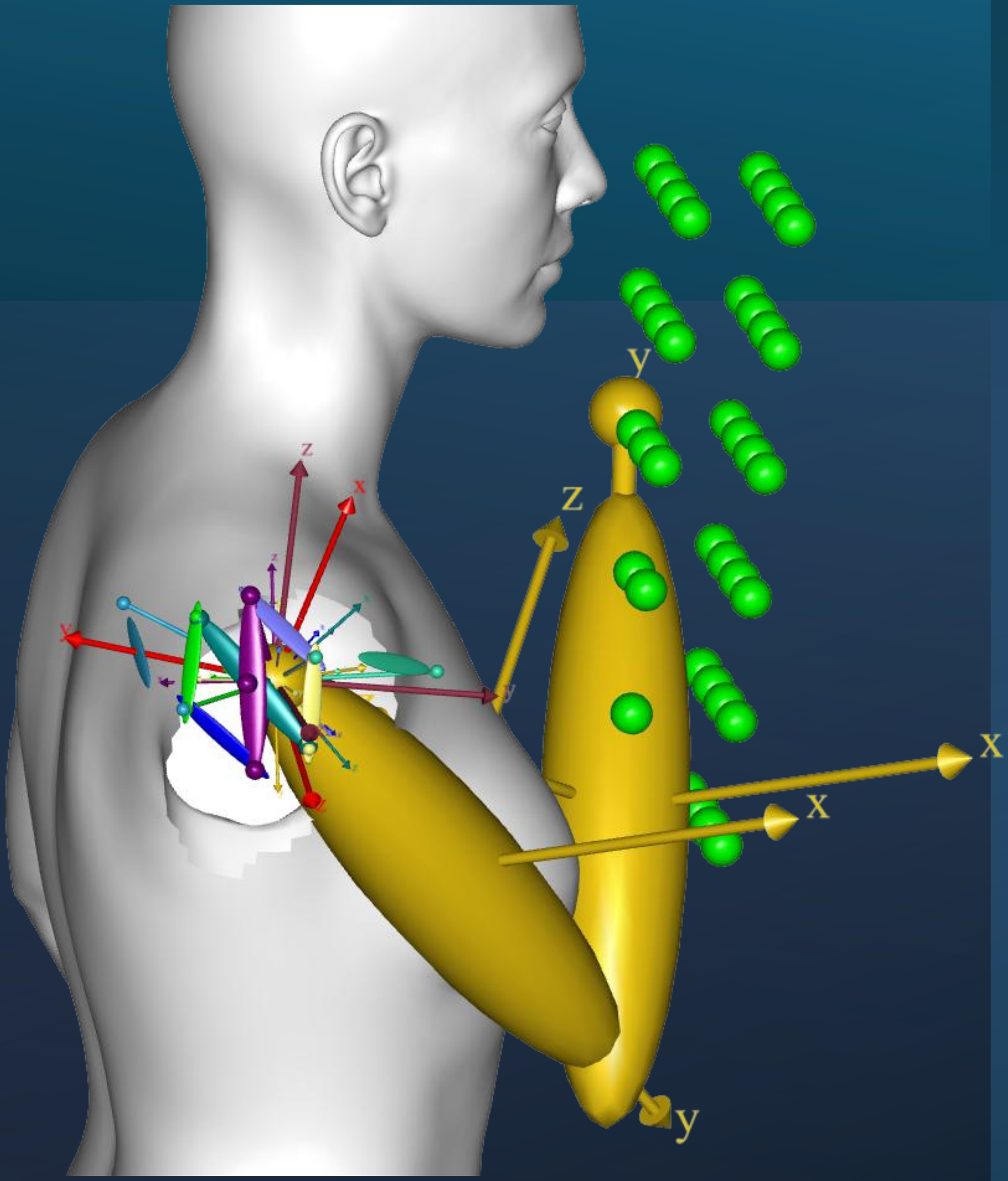
Running shoes-type ground structure

- Recently, marathon records have been broken with shoes that have tailored stiffness.

AI-generated image

Functional garments

- Ground structure = many crisscrossing elastic bands in the fabric
- Remaining rubber bands after optimization are only the useful ones.
- Possible manufacturing by printing methods directly on the fabric.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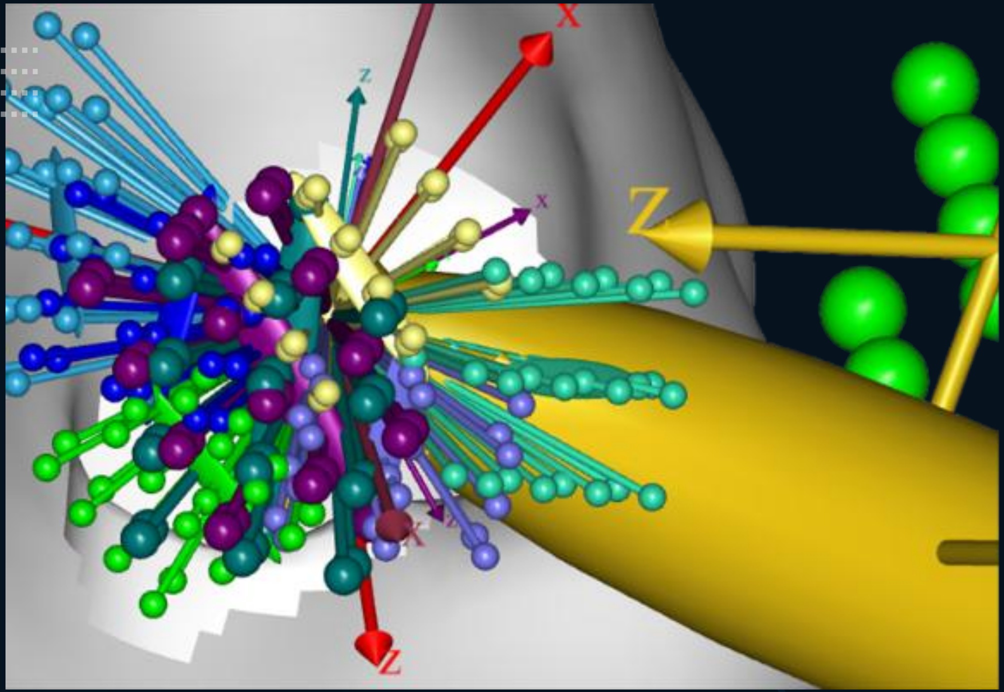
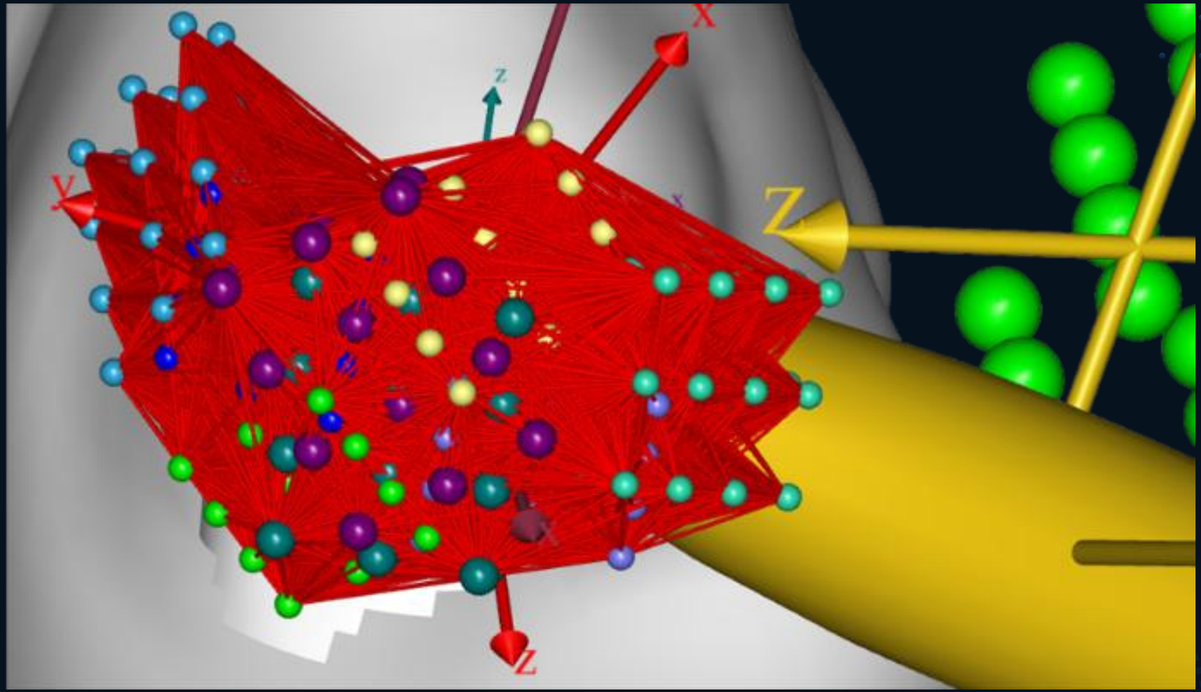
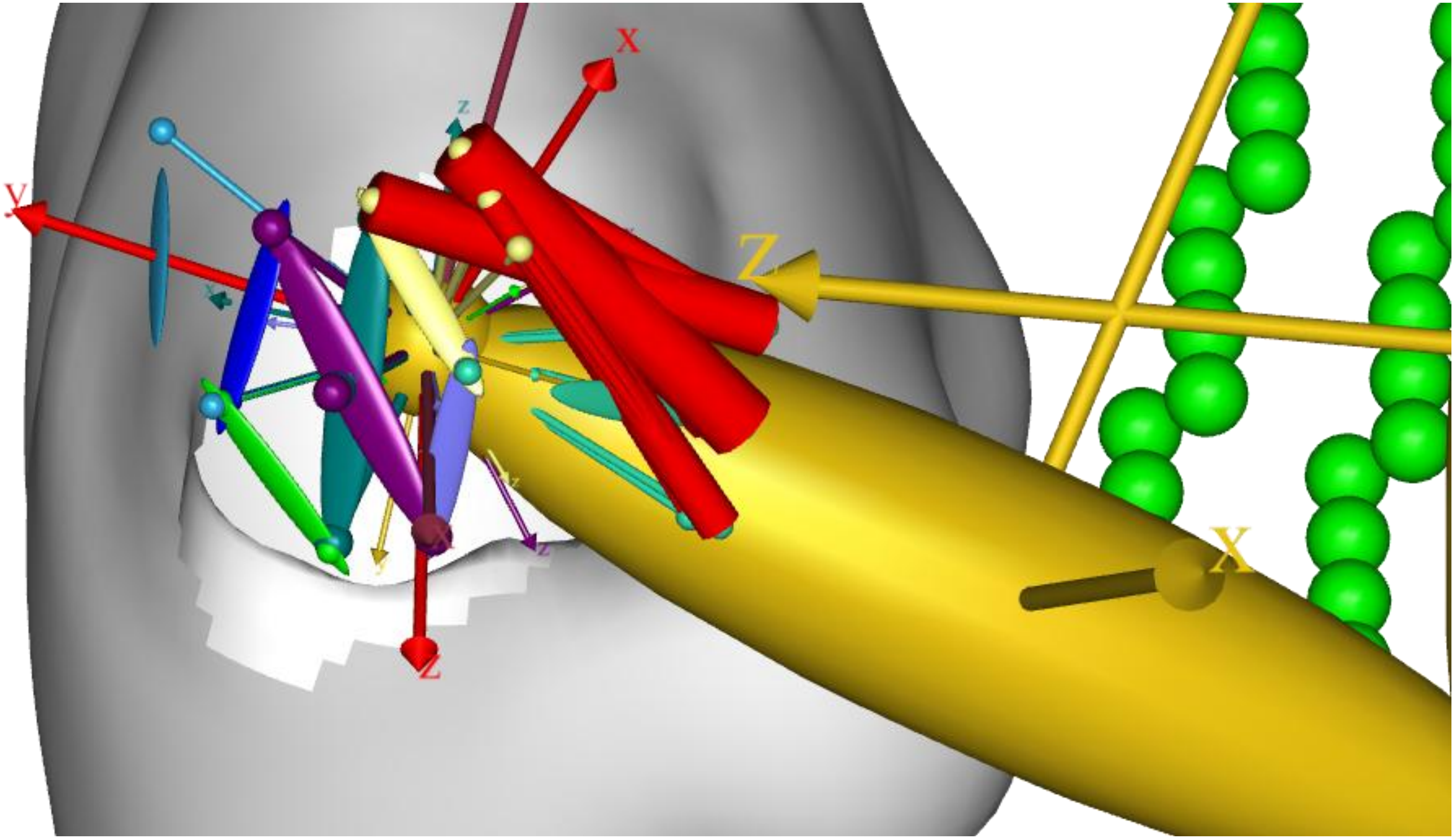




Similar example for the shoulder

- CXD shoulder orthosis
- 13,248 possible springs
- Springs with too large strain eliminated
- 8,339 springs left
- 16,678 variables in the topology optimization problem
- https://liftyahealth.com/

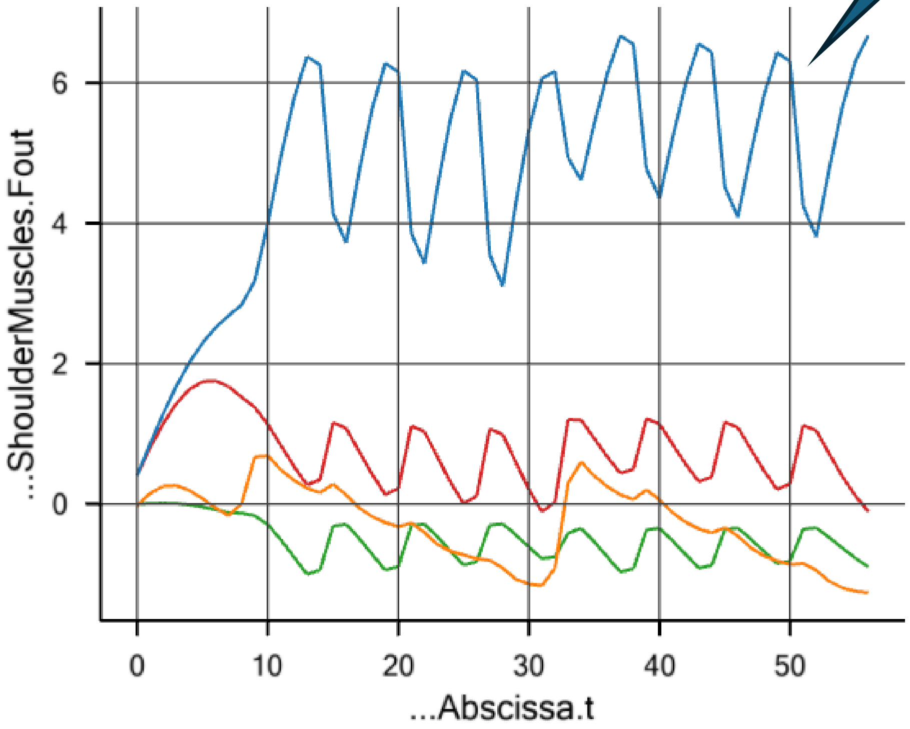
Result of topology optimization



Effect of the spring

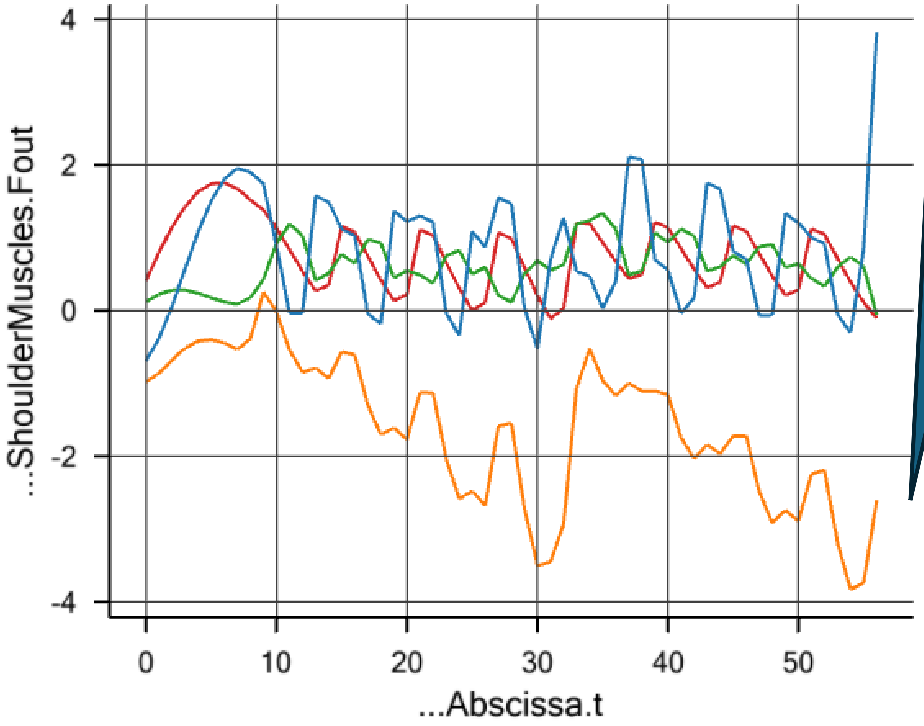
Shoulder flexion

Shoulder and elbow moments without springs

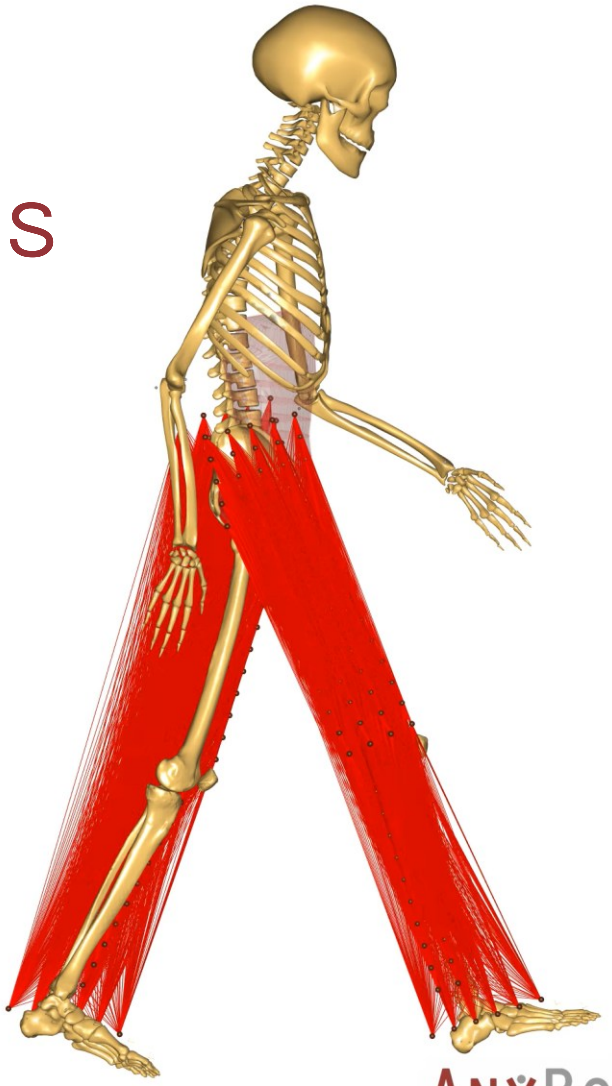


With springs

Internal rotation



Topology Optimization of Exoskeletons



Resources

- **www.anybodytech.com**
  - Events, Webcast library, Publication list, …
- **www.anyscript.org**
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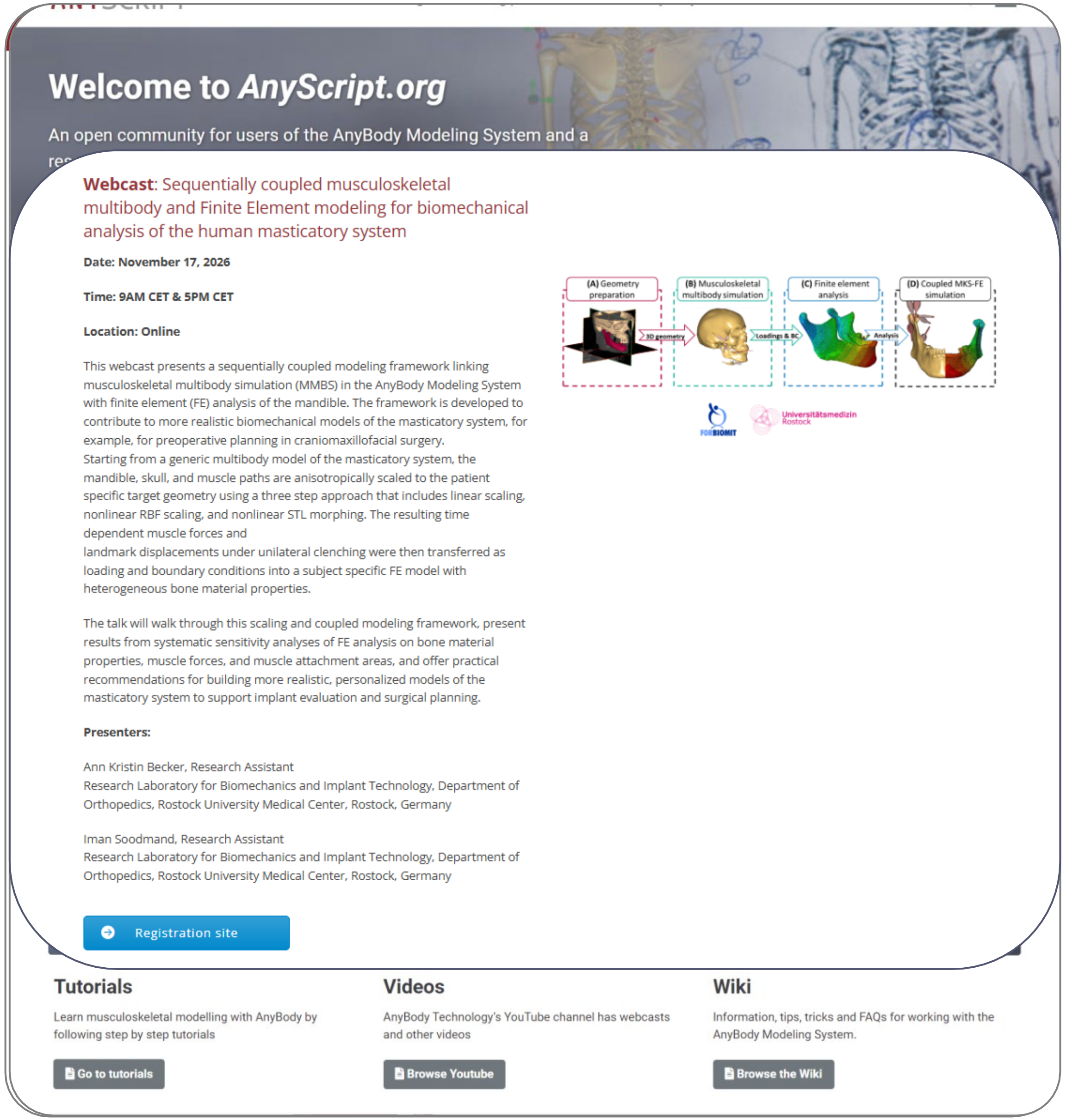
- **Events**
  - Webcast: Sequentially coupled MSK multibody and FE modeling for the analysis of the human masticatory system
    - November 17, 2026; 09.00 am and 05.00 pm CET



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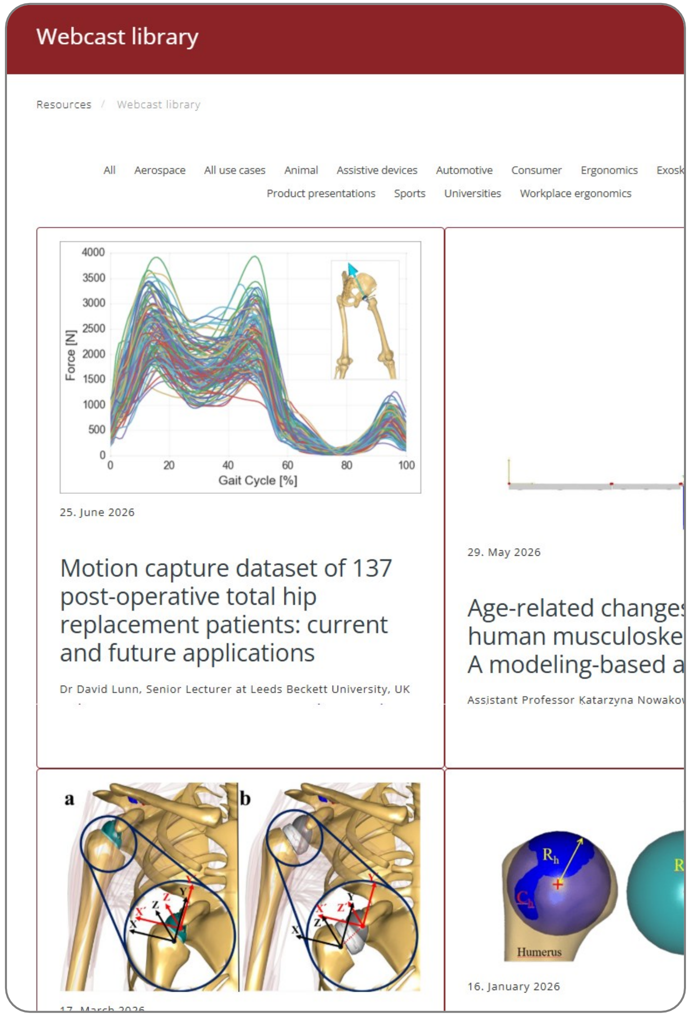

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