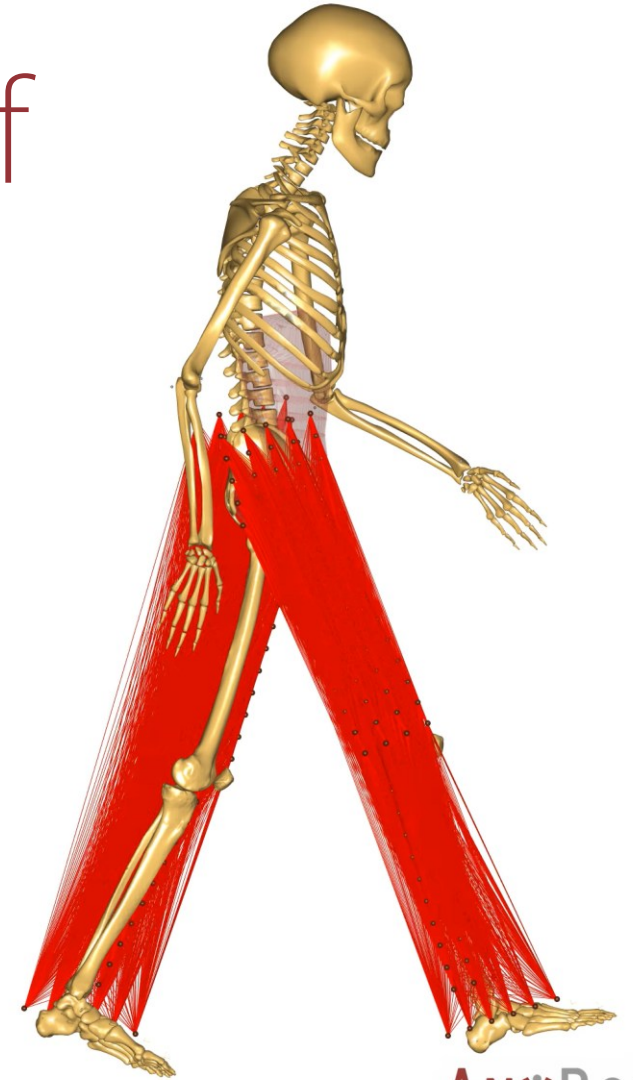


Topology Optimization of Exoskeletons

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.

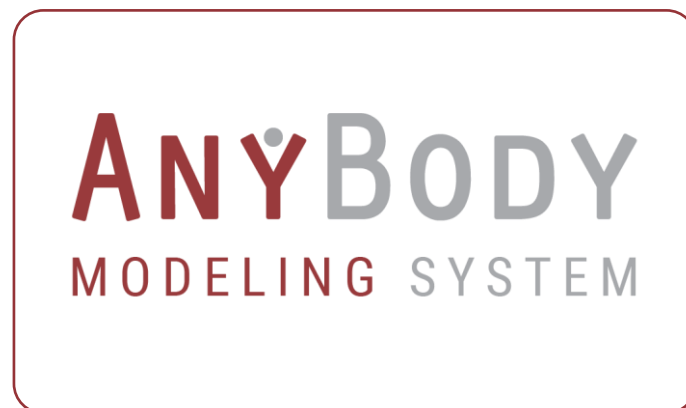
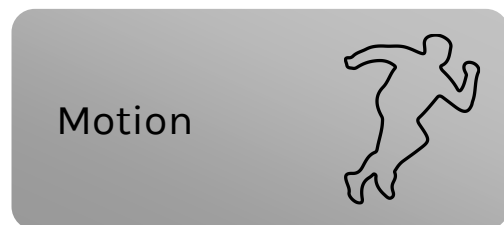
Submit questions and comments via the Questions panel.

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



OUTPUT • Internal Body Loads

Joint reaction forces

Muscle forces

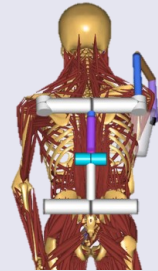
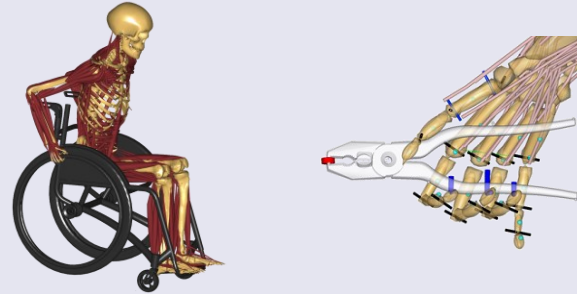
Muscle activity

Metabolic energy + fatigue

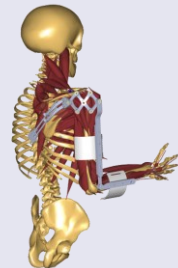


Motion
analysis

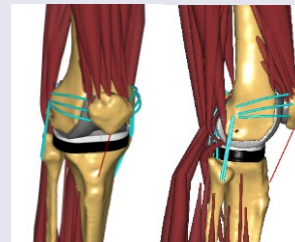
Product design
and optimization



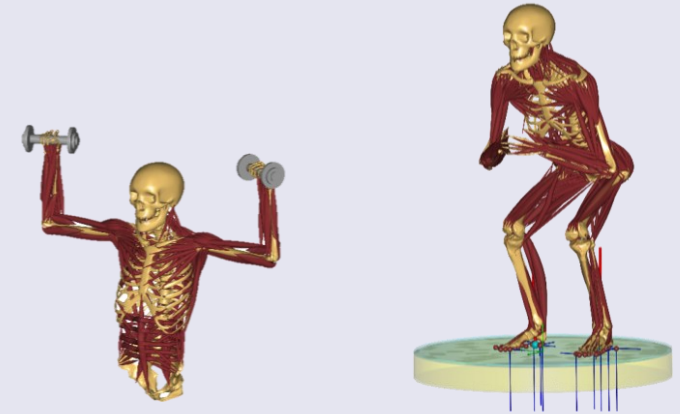
Ergonomics
with/without
exoskeletons



ANYBODY
MODELING SYSTEM



Orthopedics
and
Rehabilitation

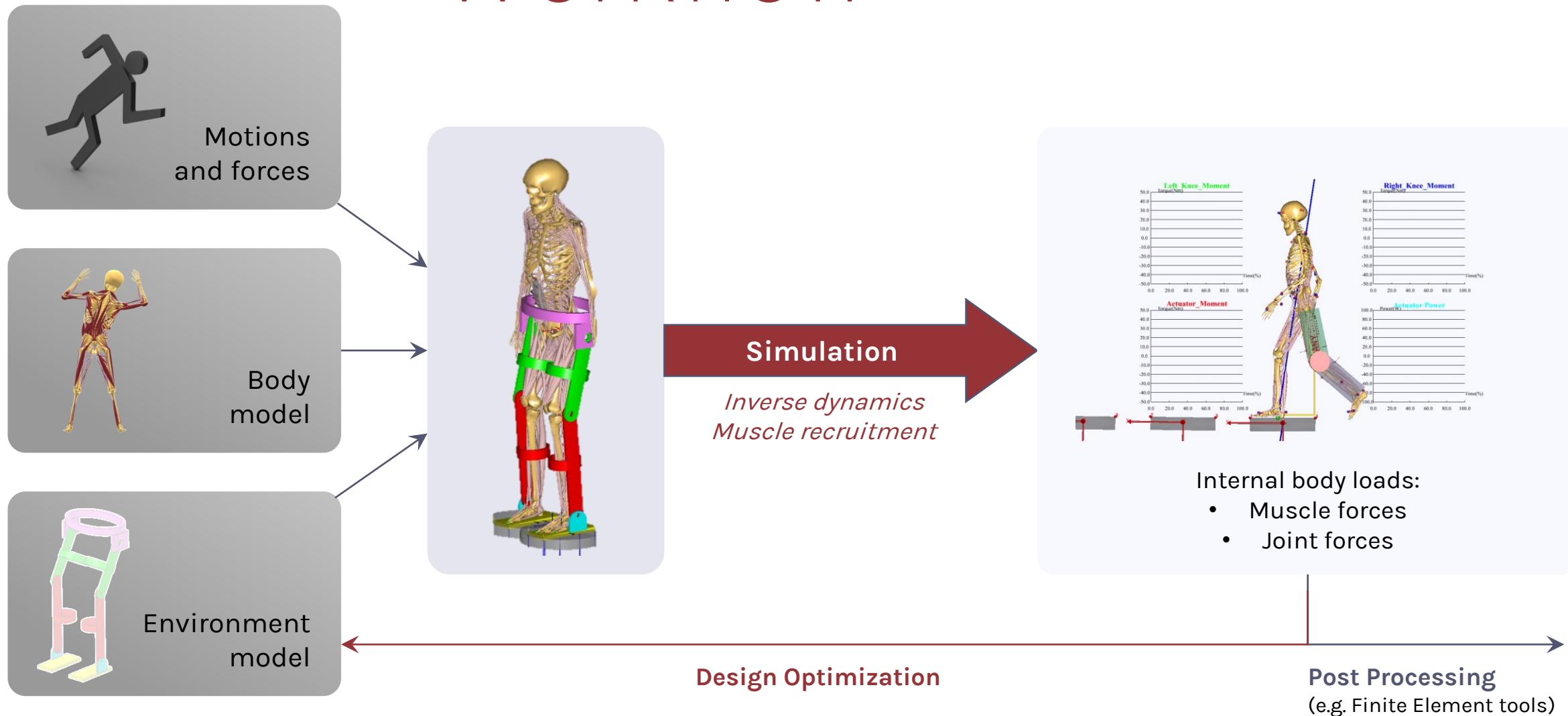


Sports

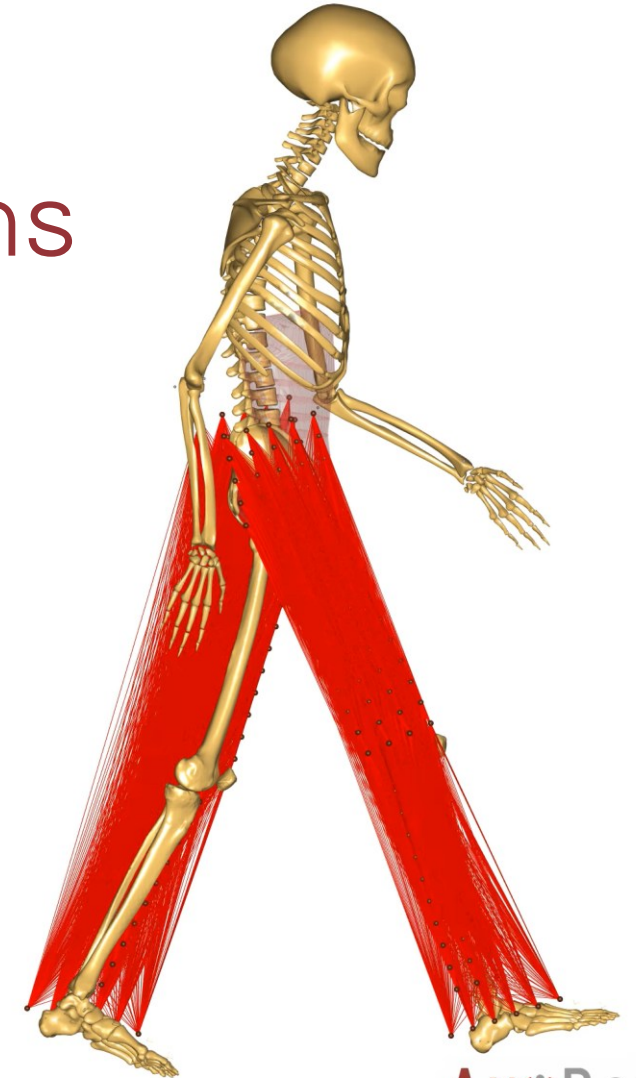


Automotive

Workflow



Topology Optimization of Exoskeletons



The background image is a 3D visualization of a topology optimization process. It features a grid of black lines on a gray surface. Scattered across this grid are numerous small, gray, L-shaped blocks. Each block has a black line drawn on its top surface, forming a path that follows the outer edge of the L-shape. The blocks are arranged in a way that suggests a complex, interconnected network or a series of paths, which is the result of a topology optimization algorithm. The text "Topology Optimization of Exoskeletons" is overlaid in the center of the image in a white, sans-serif font.

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

Martin P. Bendsøe

Mathematical Institute, The Technical University of Denmark, Denmark

John Rasmussen

Institute of Mechanical Engineering, Aalborg University, Denmark

Received 30 August 1990

Revised manuscript received 11 February 1991

The Ground Structure

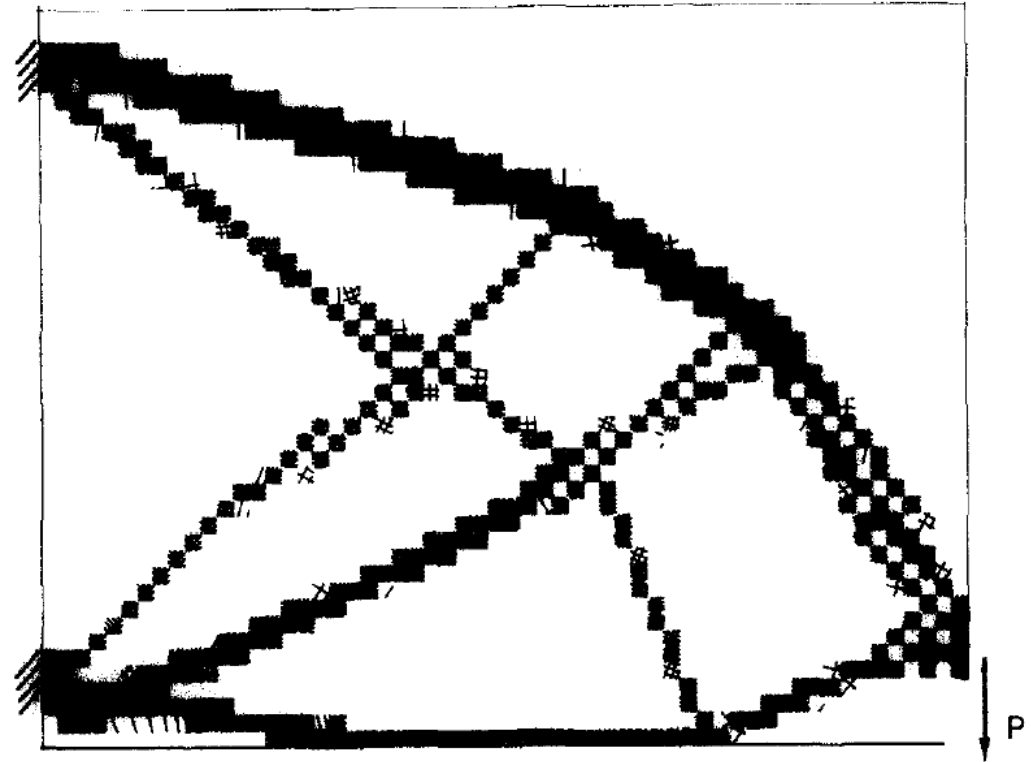


Fig. 4. Solution of topology optimization problem.

This is the
MBB Beam

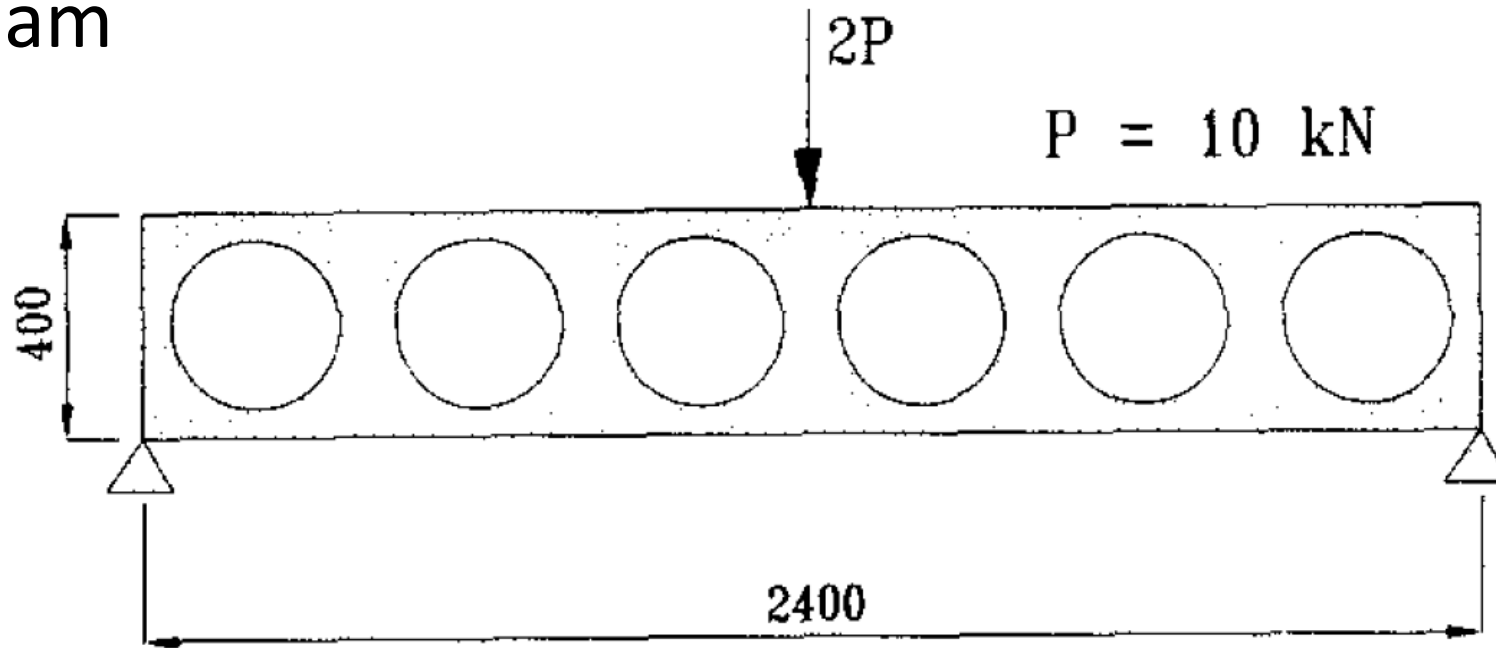


Fig. 12. Initial geometry with loads and boundary conditions.

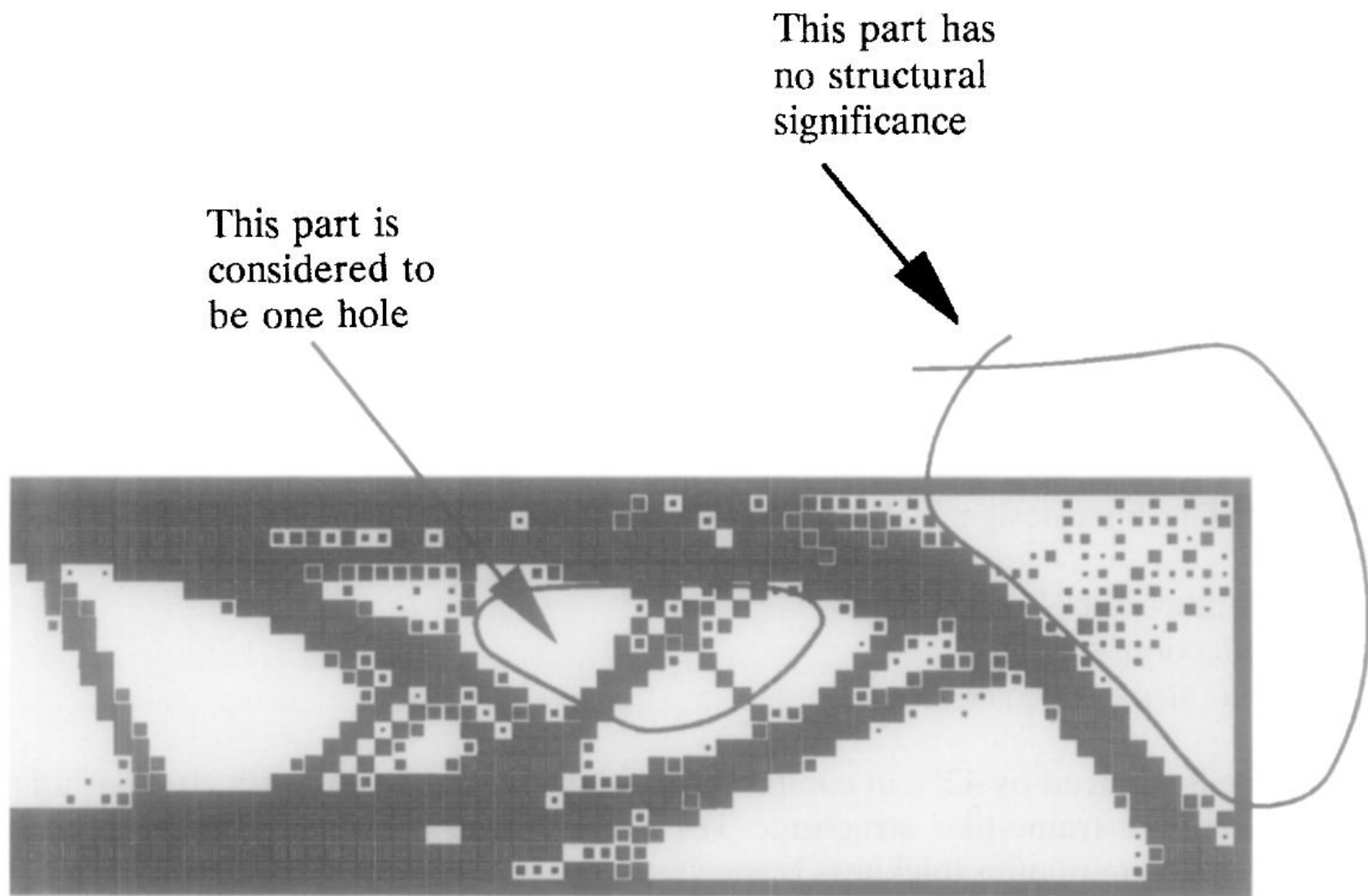


Fig. 16. Result of topology optimization.

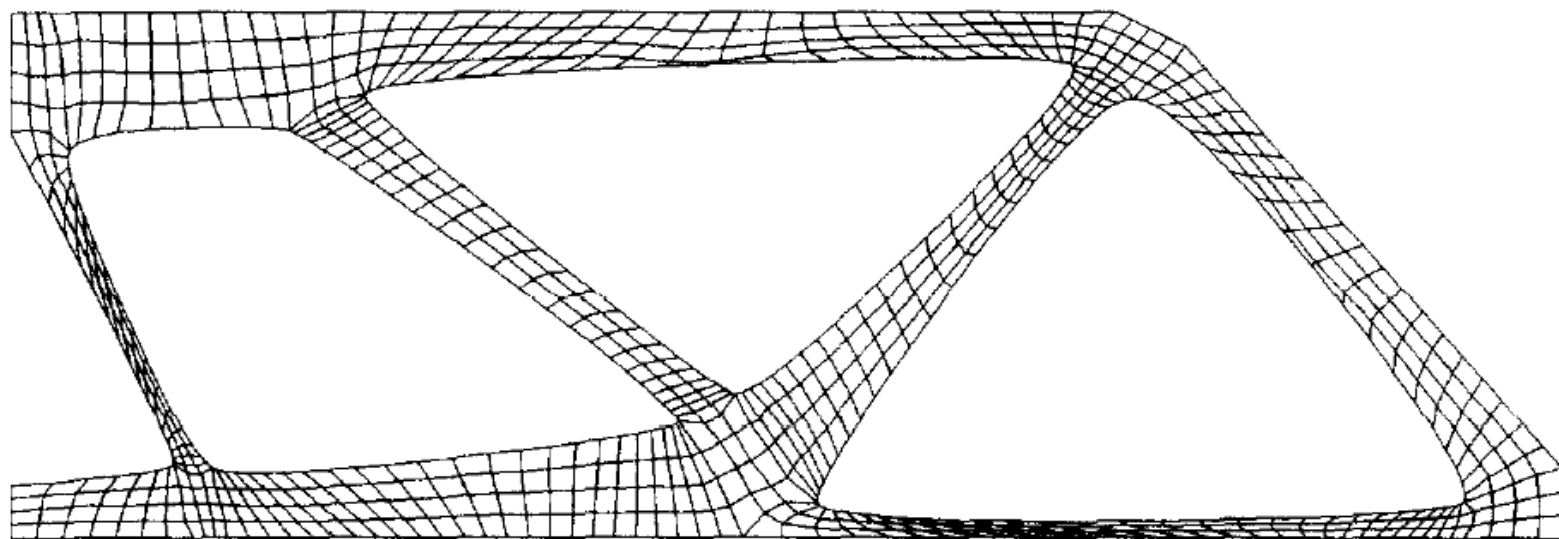


Fig. 18. Final finite element model.

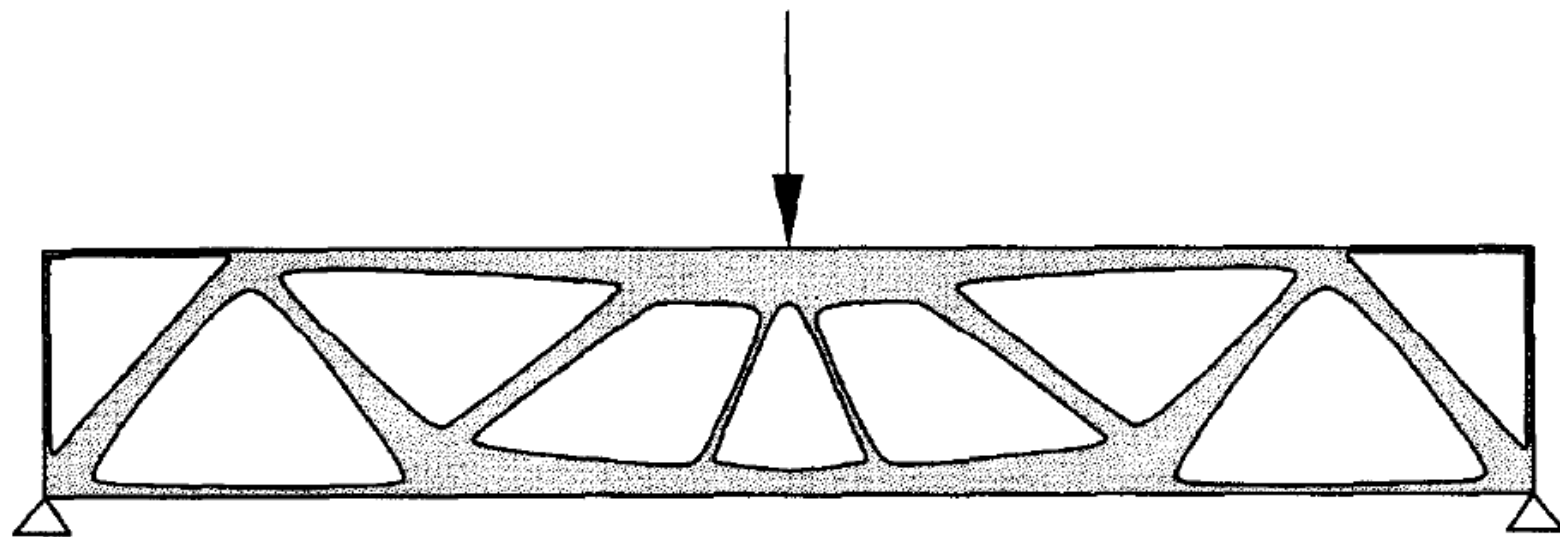


Fig. 19. Example of final geometry slightly modified by the designer. The upper right corner has been added again.

MBB beam - Google Scholar

scholar.google.dk/scholar?as_vis=1&q="MBB+beam"&hl=da&as_sdt=0,5

120%

Google Scholar

"MBB beam"

Artikler

Ca. 2.140 resultater (0,08 sek.)

Min profil

Min samling

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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[HTML] 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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Minimizing thermally induced residual stresses in metal additive manufacturing through peridynamics topology optimization

S Khalilvandi Behrouzfar, 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 ...

☆ Gem Citer Citeret af 10 Relaterede artikler Alle 10 versioner

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

[HTML] sciencedirect.com

♦ Hurtig læsning

[HTML] sciencedirect.com

♦ Hurtig læsning

[PDF] springer.com

♦ Hurtig læsning - d-nb.info

[PDF] springer.com

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

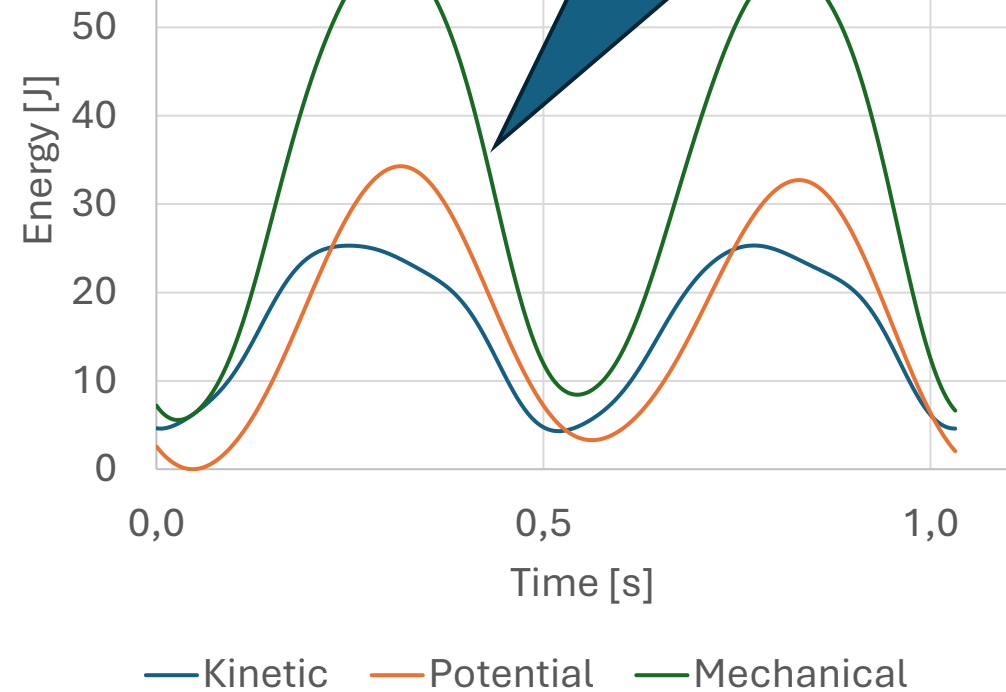
A walking human is energy-wise an isolated system



ANYBODY
TECHNOLOGY

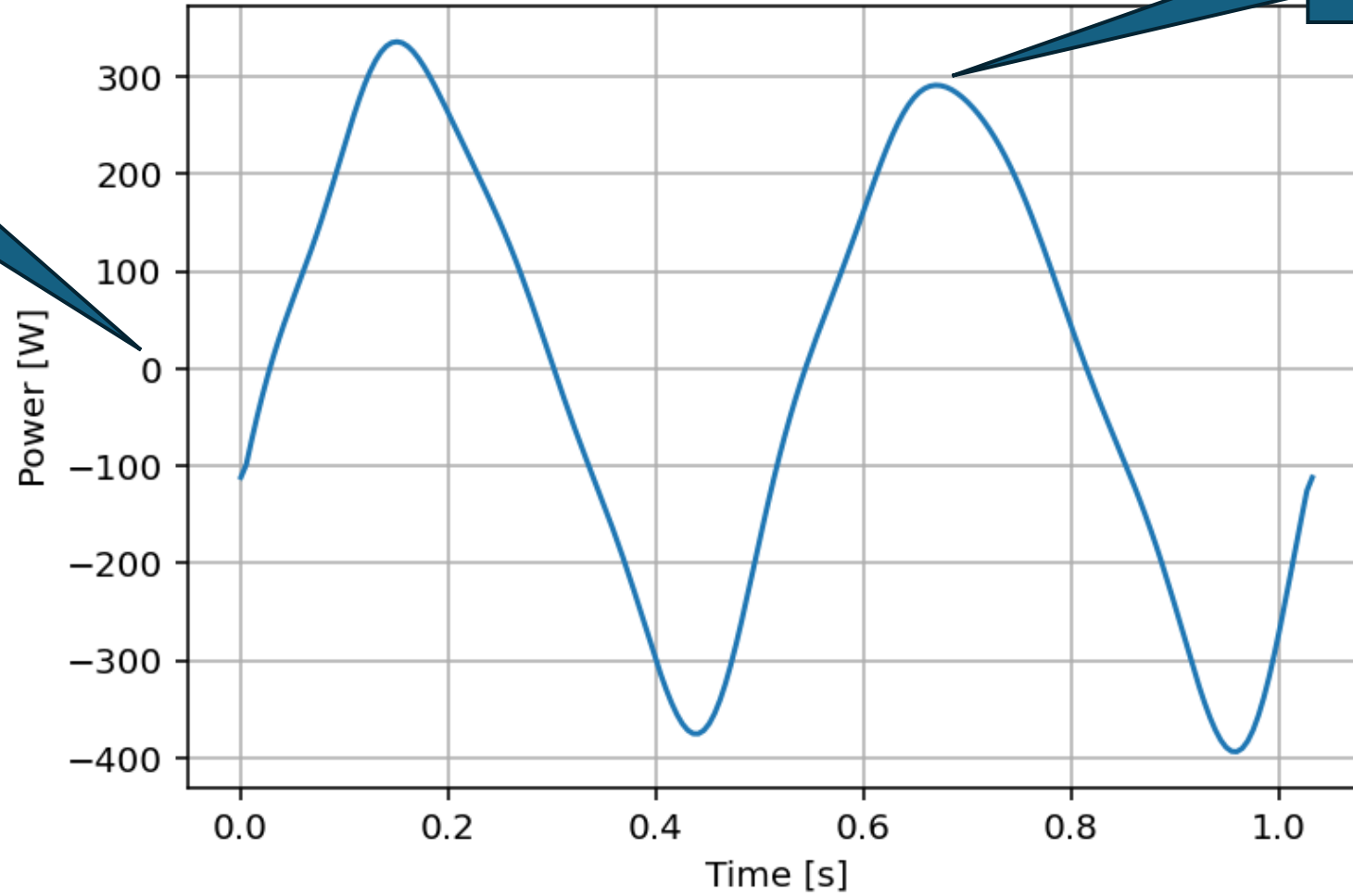
Almost, but not completely, symmetrical

The necessary power to change energy can only come from muscles



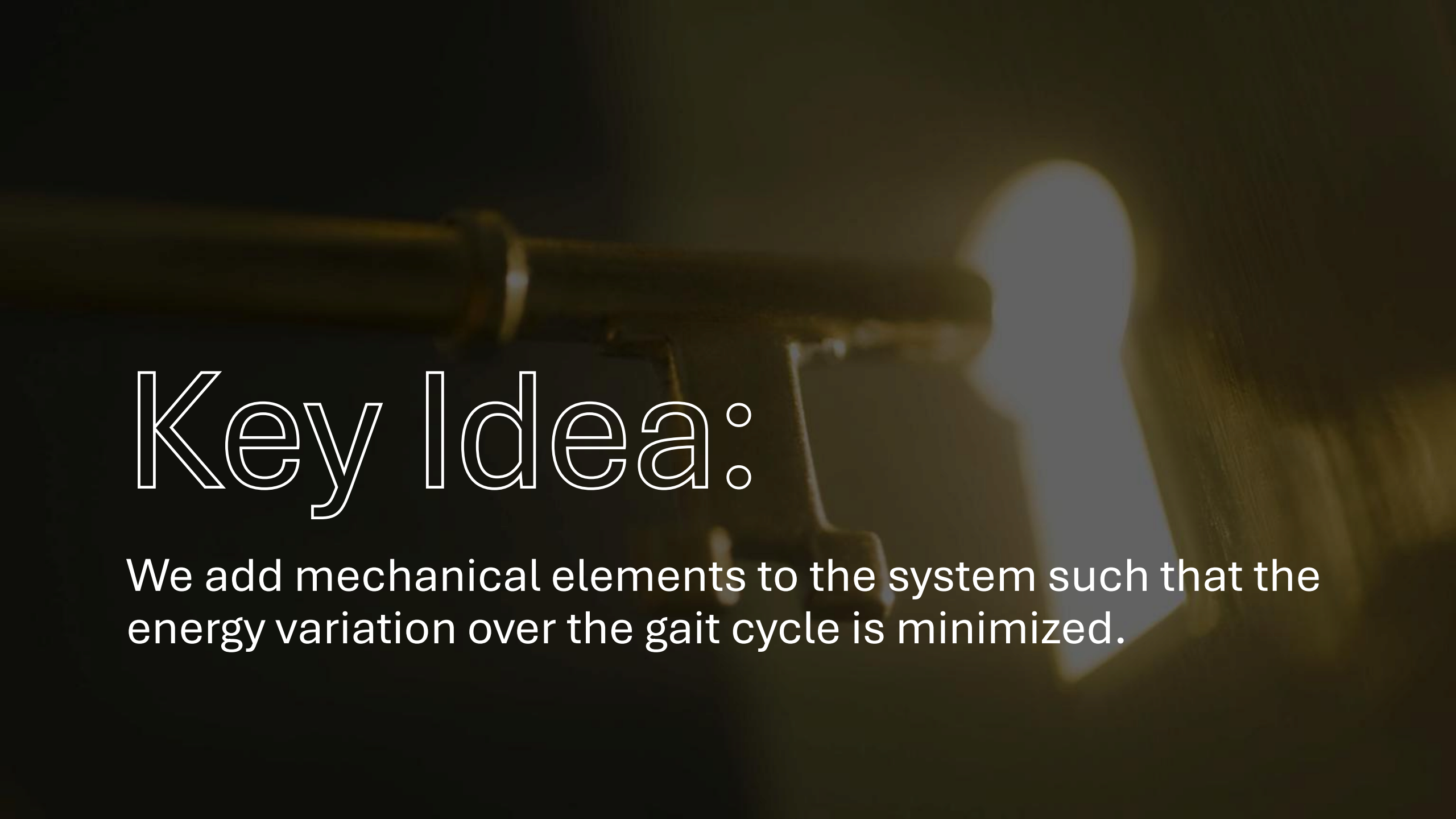
If there were no change of energy, then ambulation would be effortless!

Muscle power



Total work is 0

Peaks are not completely symmetrical

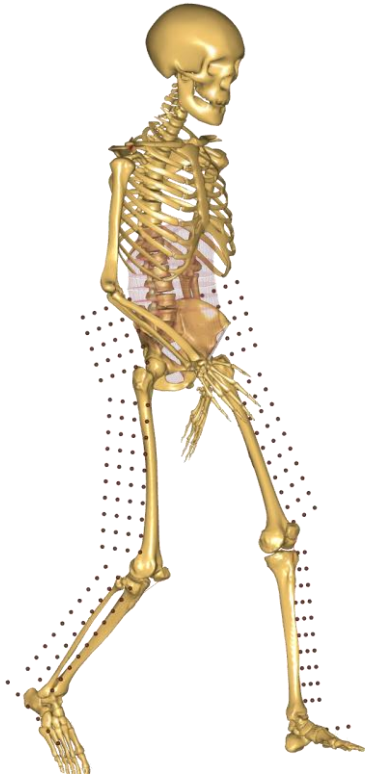


Key Idea:

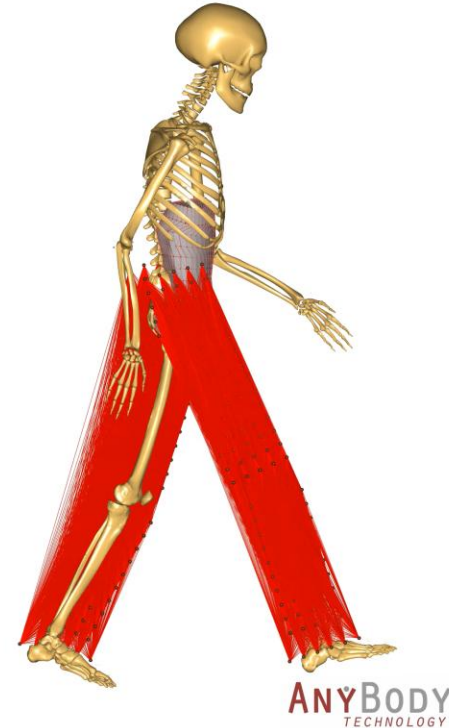
We add mechanical elements to the system such that the energy variation over the gait cycle is minimized.

Topology Optimization in Biomechanics

262 possible attachment points



The ground structure: 11350 possible springs

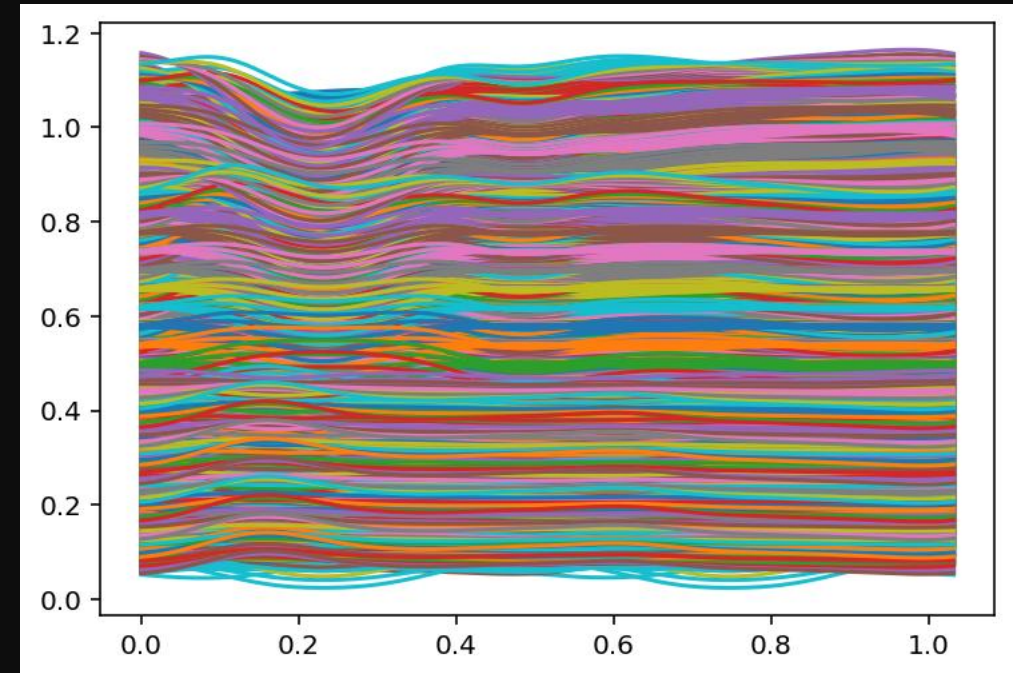


After kinematic analysis, we know the length variation of all the springs over the gait cycle

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:

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

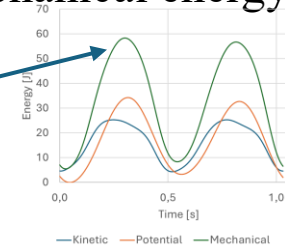
Diagram illustrating the components of the spring energy equation:

- $\frac{1}{2}$: Spring stiffness
- k_j : Spring length
- $(x_j - x_j^0)^2$: Slack 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:

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

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

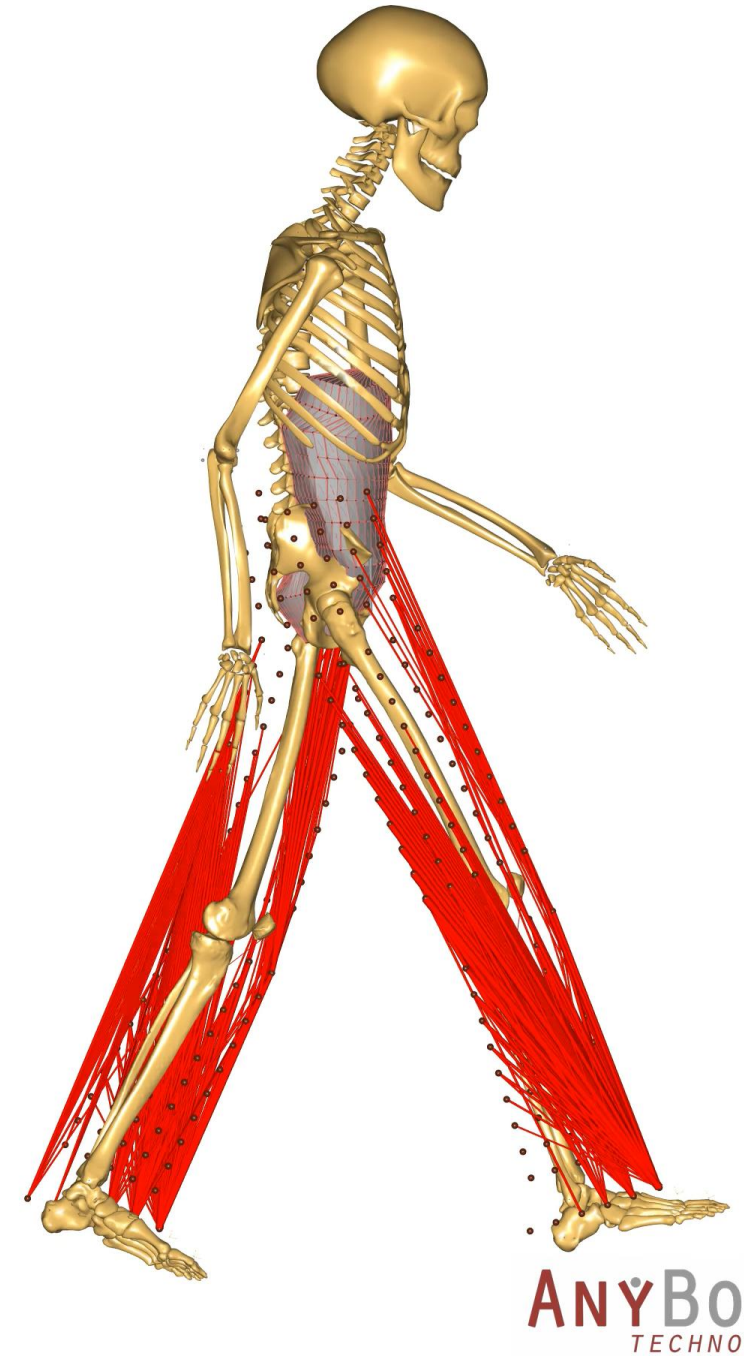
11350 springs = 11350 spring stiffnesses + 11350 slack lengths = 22700 design variables.

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.

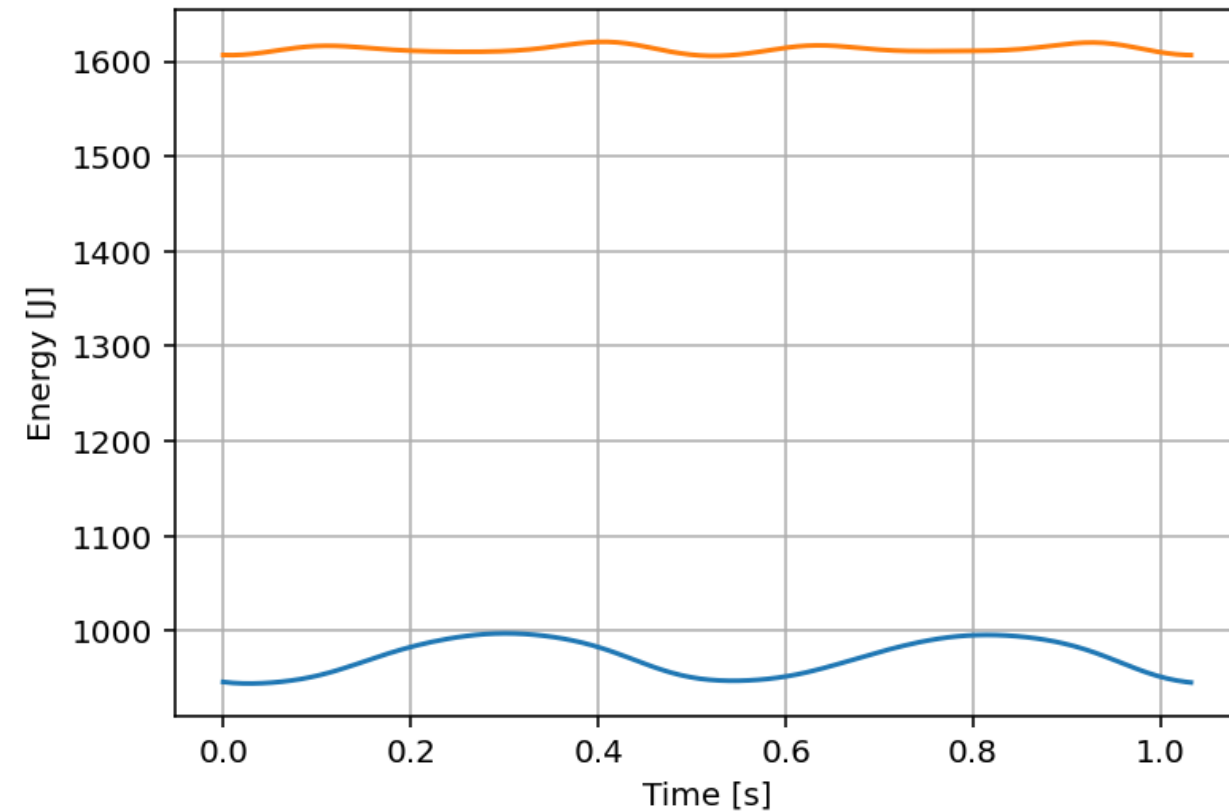
Interesting but impractical

- 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?
-

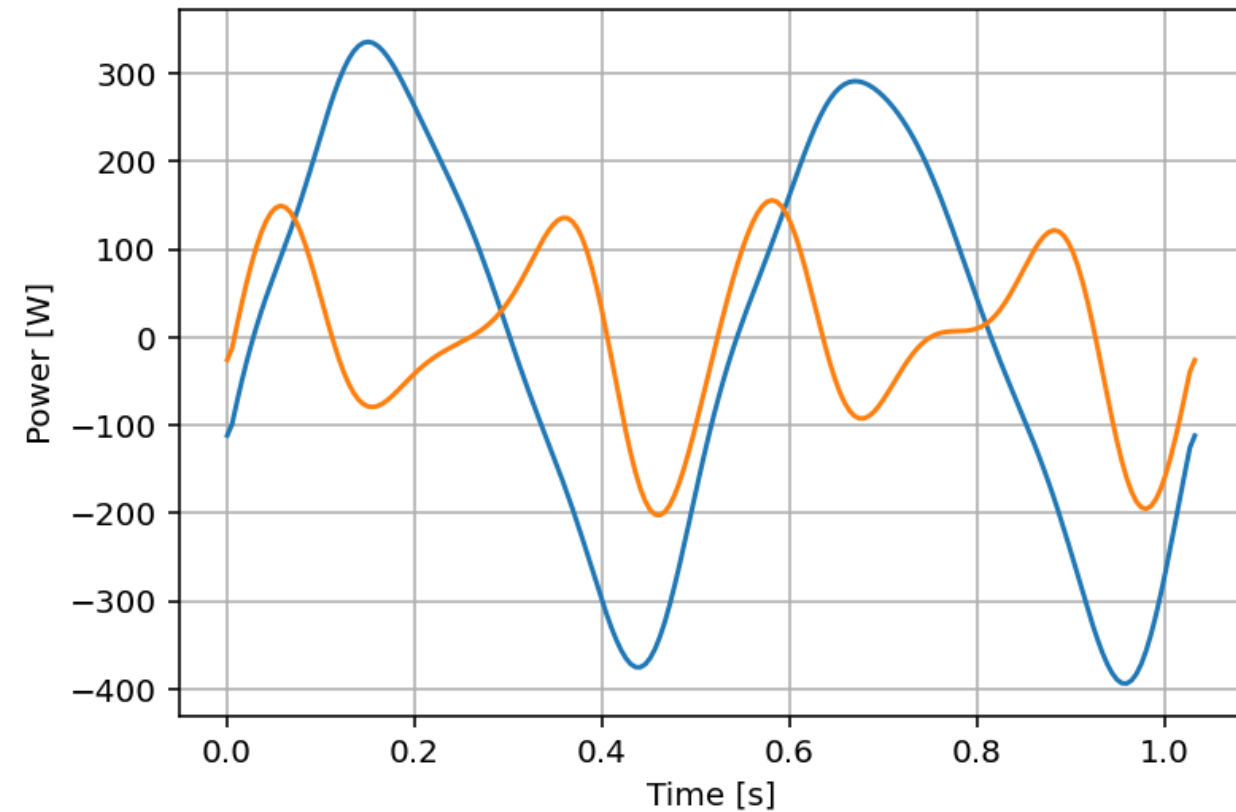


Biomechanical Effects

Mechanical and elastic energy before and after

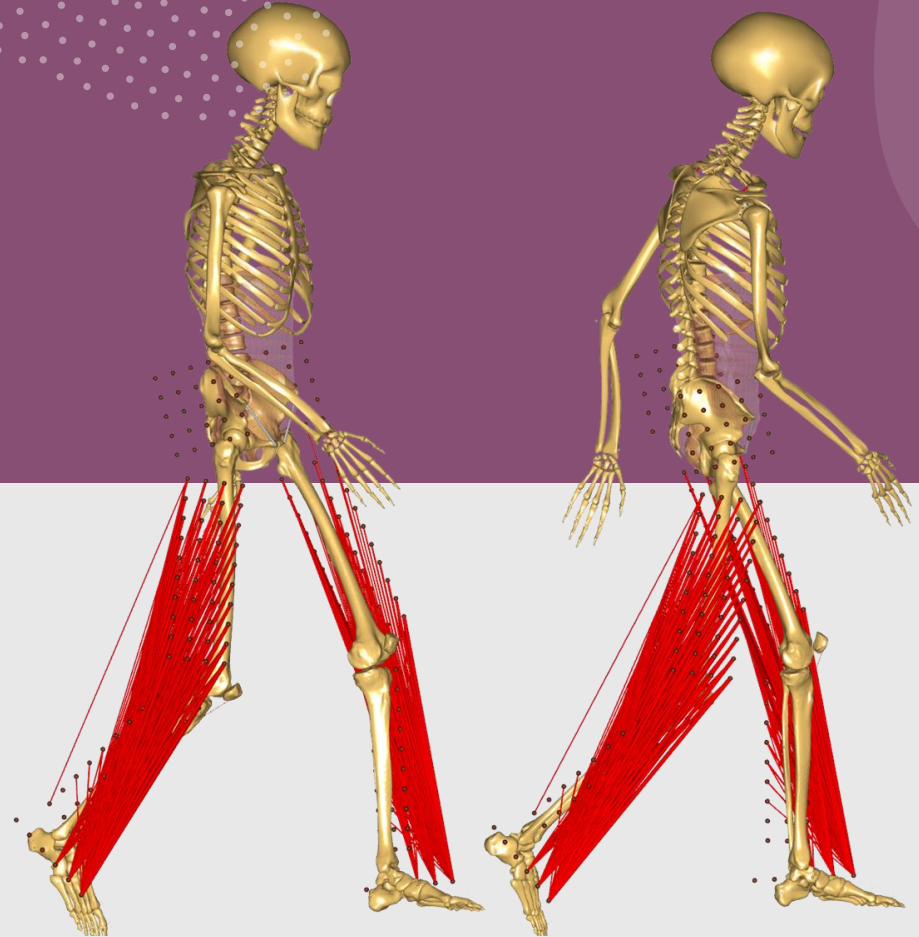


Muscle power



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:

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

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

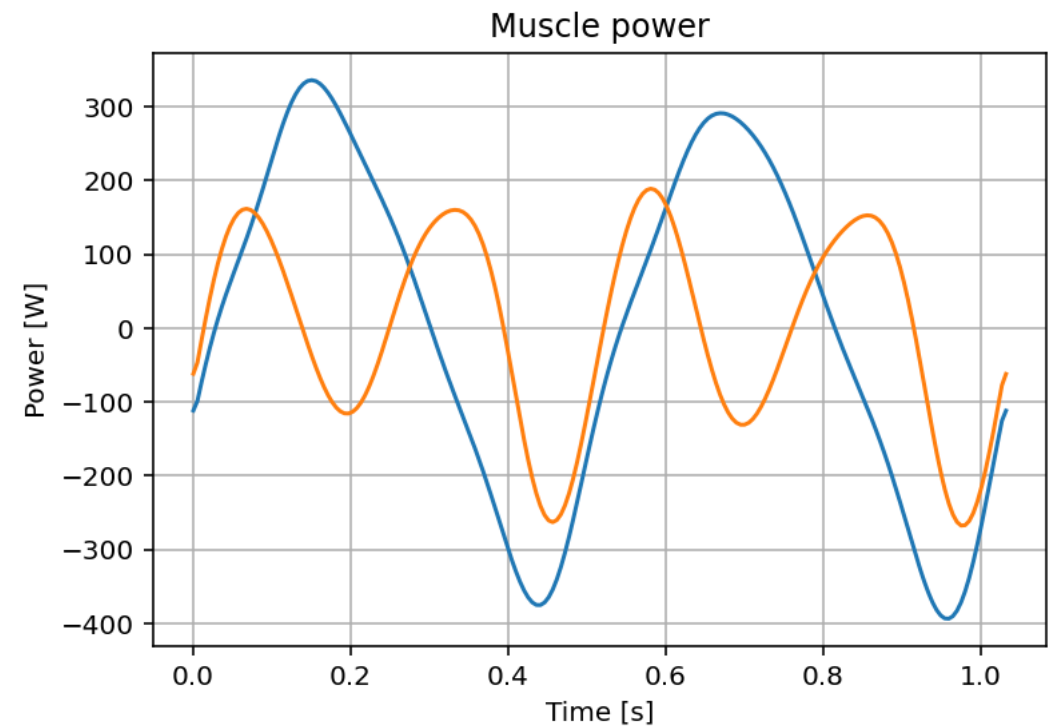
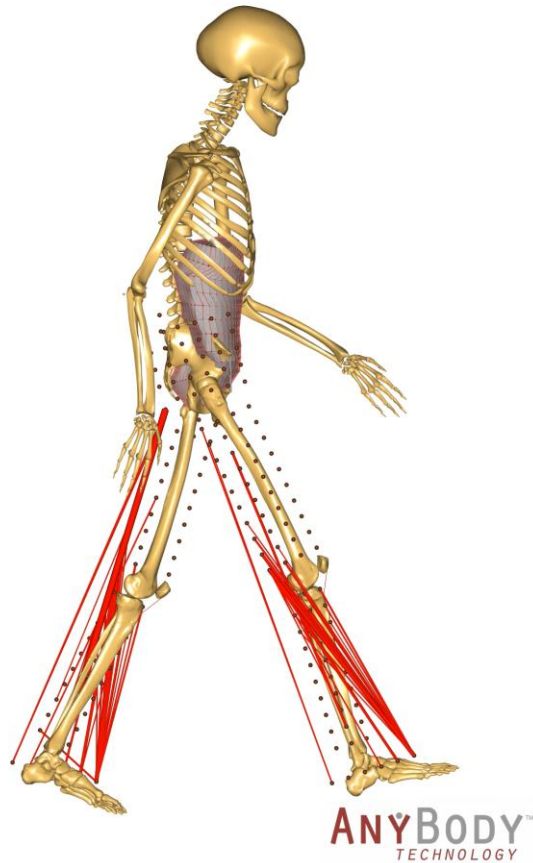
Now:

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

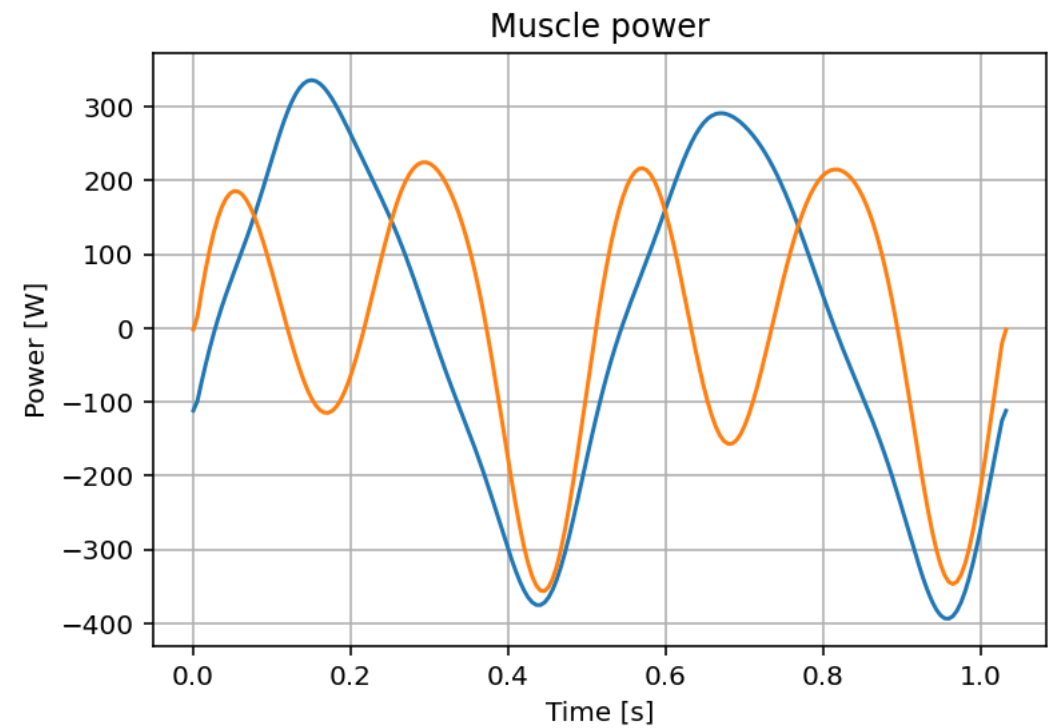
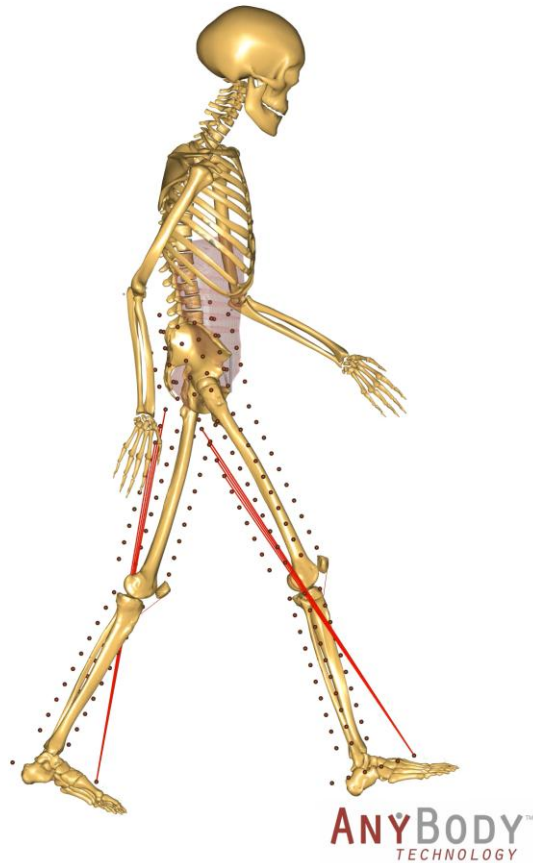
Penalization parameter

Reduce total amount of
“spring”

Solution with 47 springs

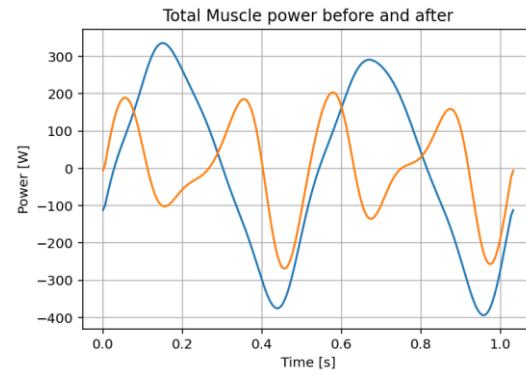


Solution with 8 springs

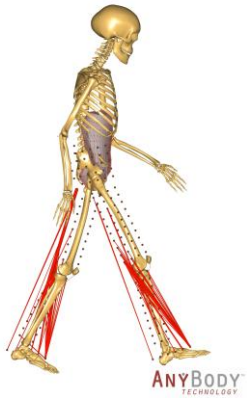




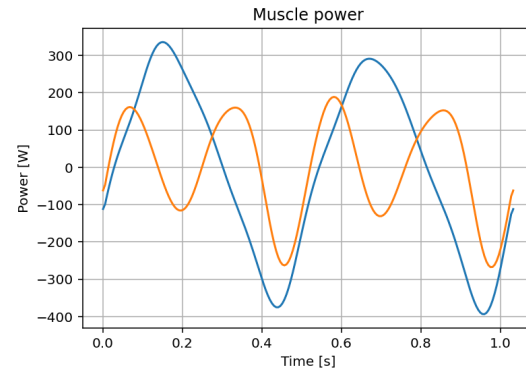
266 springs



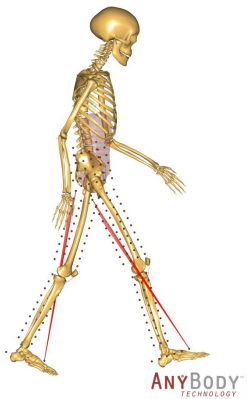
Energy span = 19.46 J



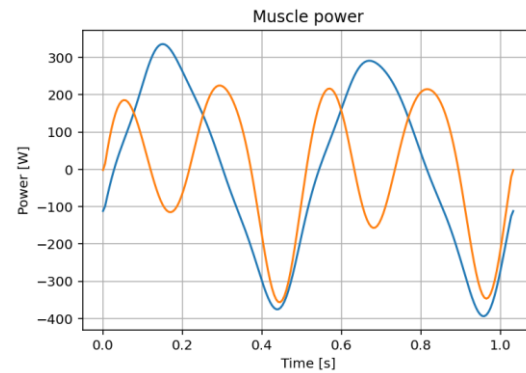
47 springs



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

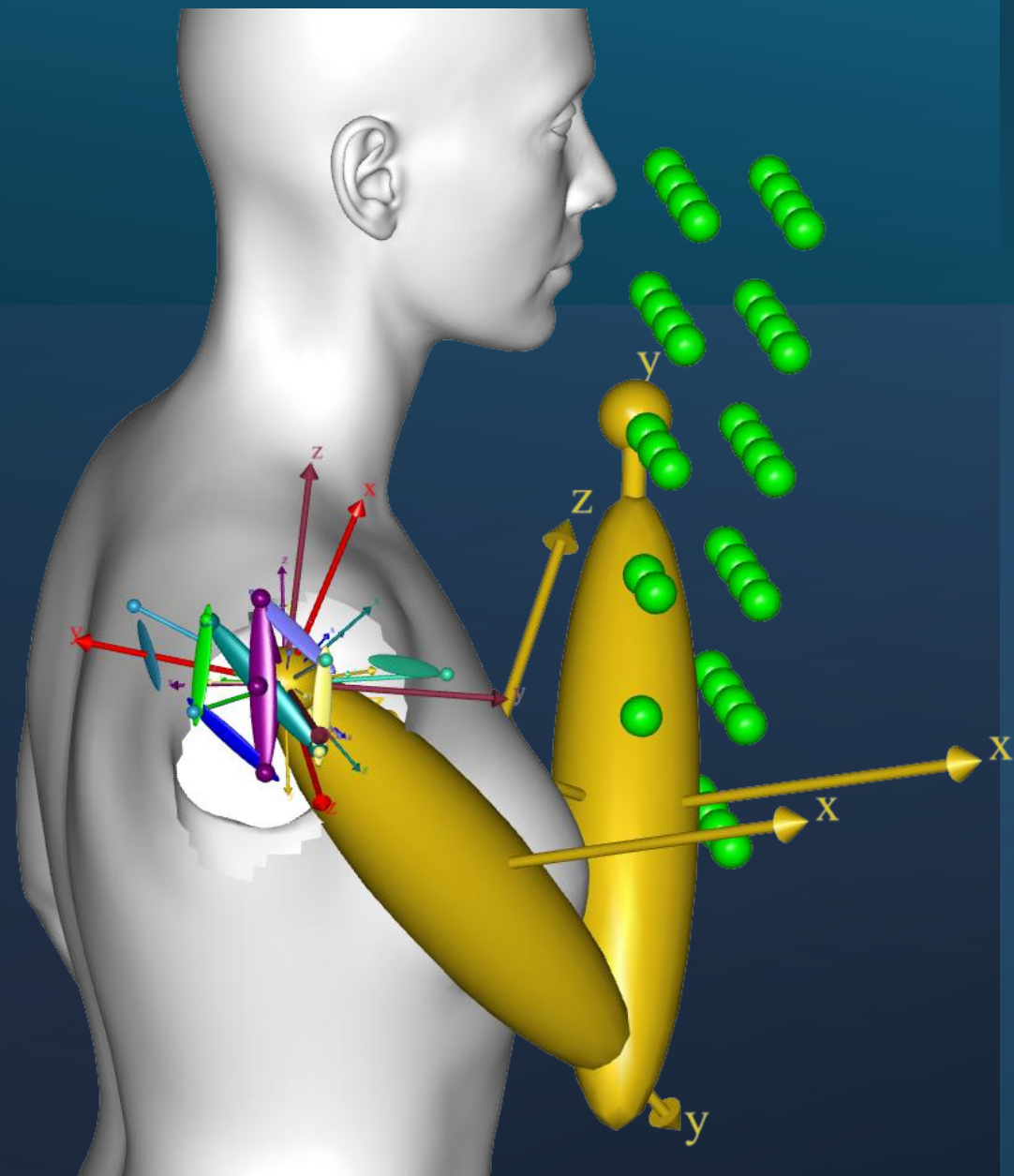
- Recently, marathon records have been broken with shoes that have tailored stiffness.

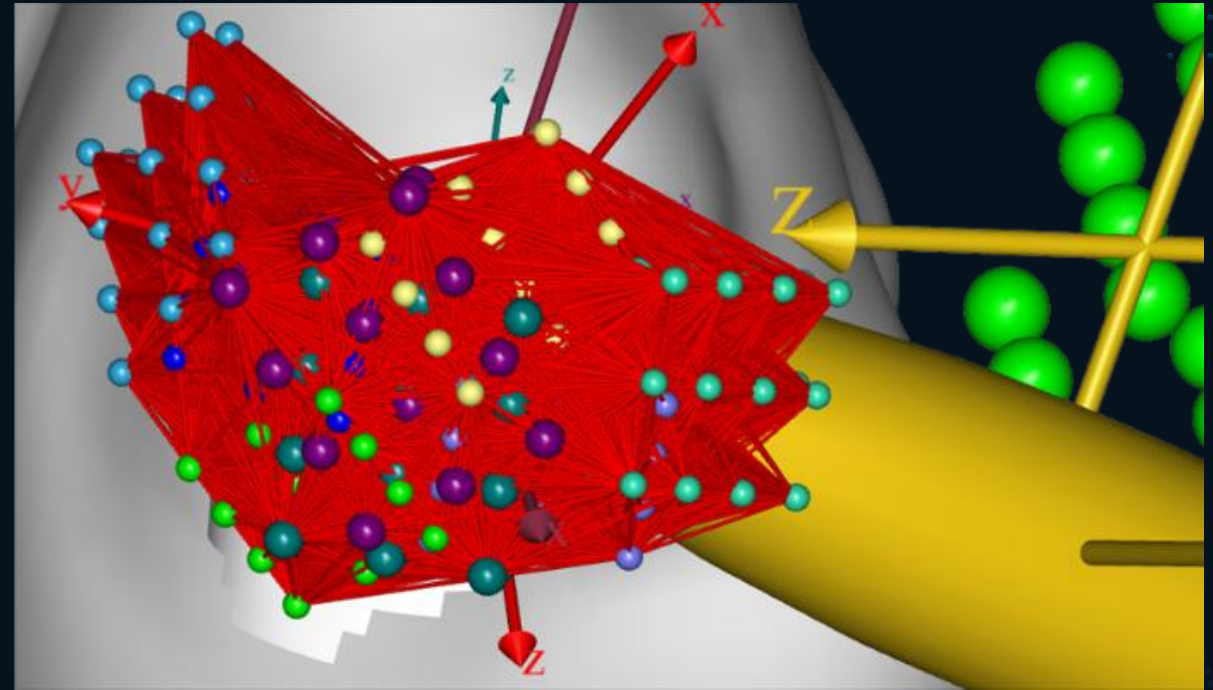
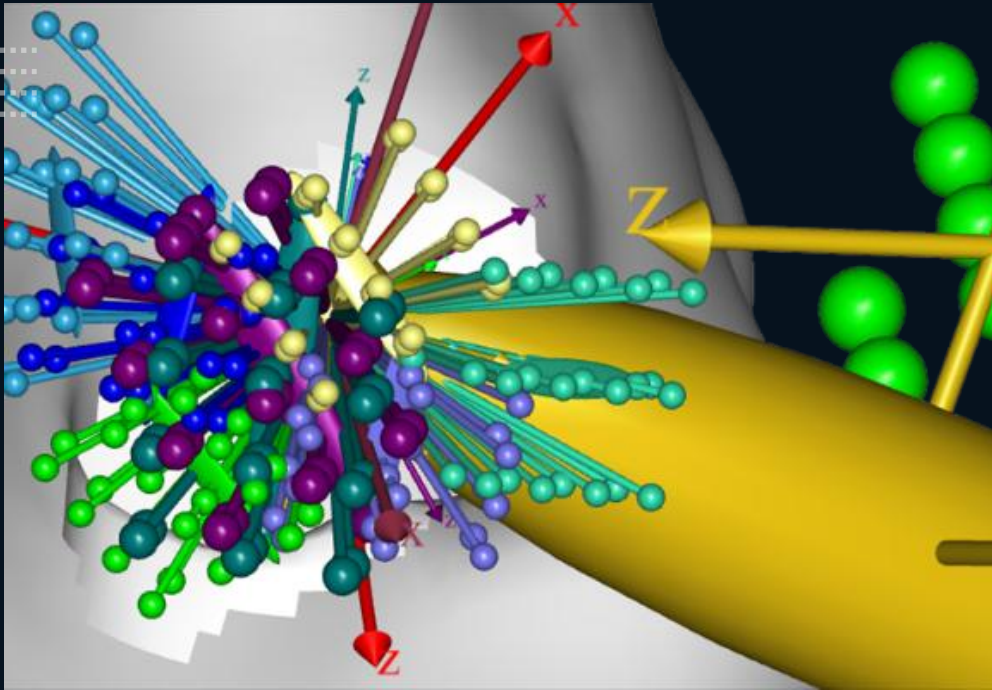


AI-generated image

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.
-

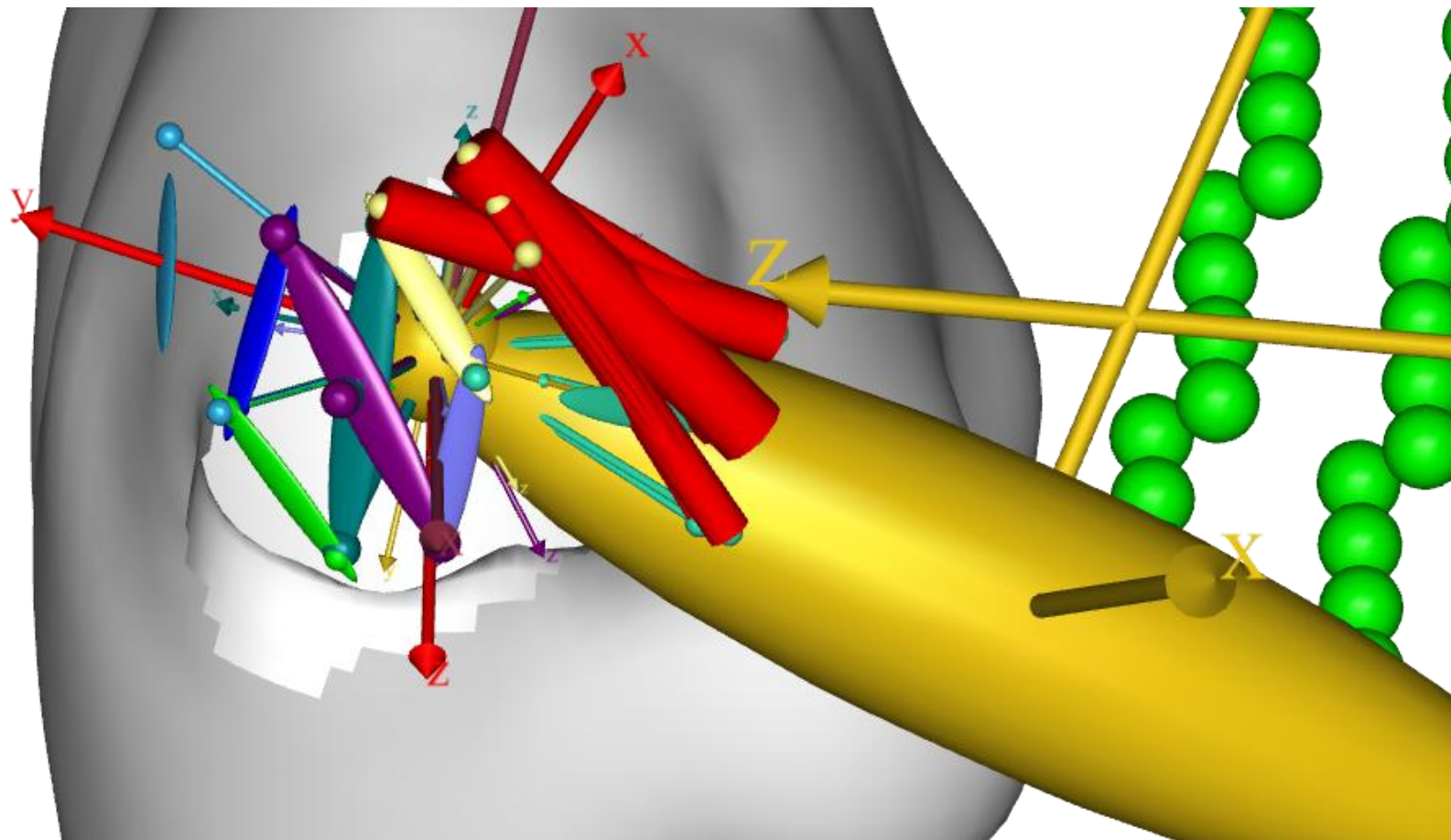




Similar example for
the shoulder

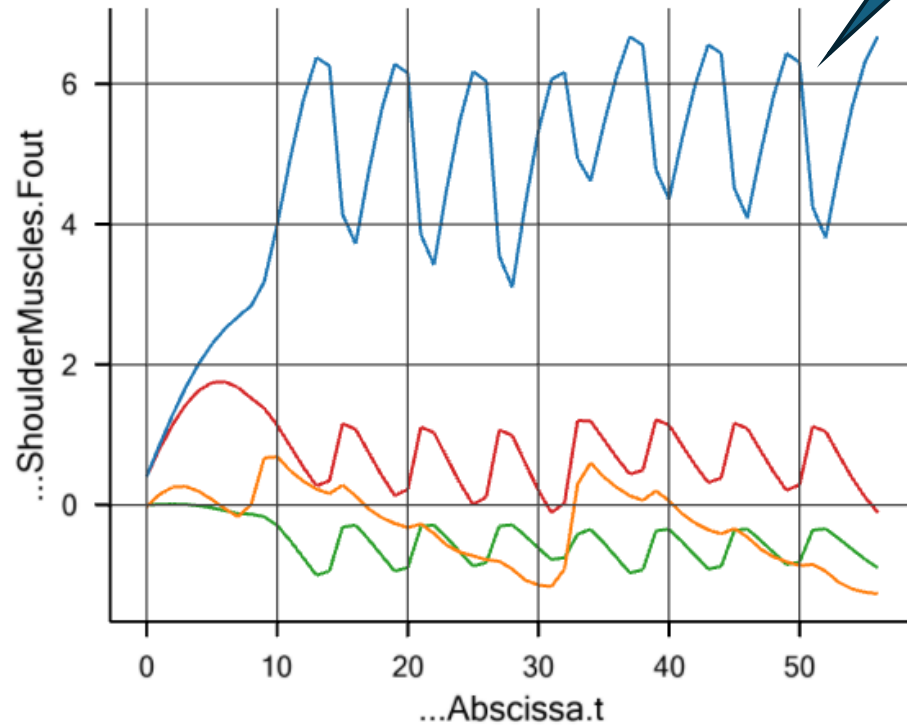
- CXD shoulder orthosis
- 13,248 possible springs
- Springs with too large strain eliminated
- 8,339 springs left
- 16,678 variables in the topology optimization problem
- <https://liftyahealth.com/>

Result of topology optimization



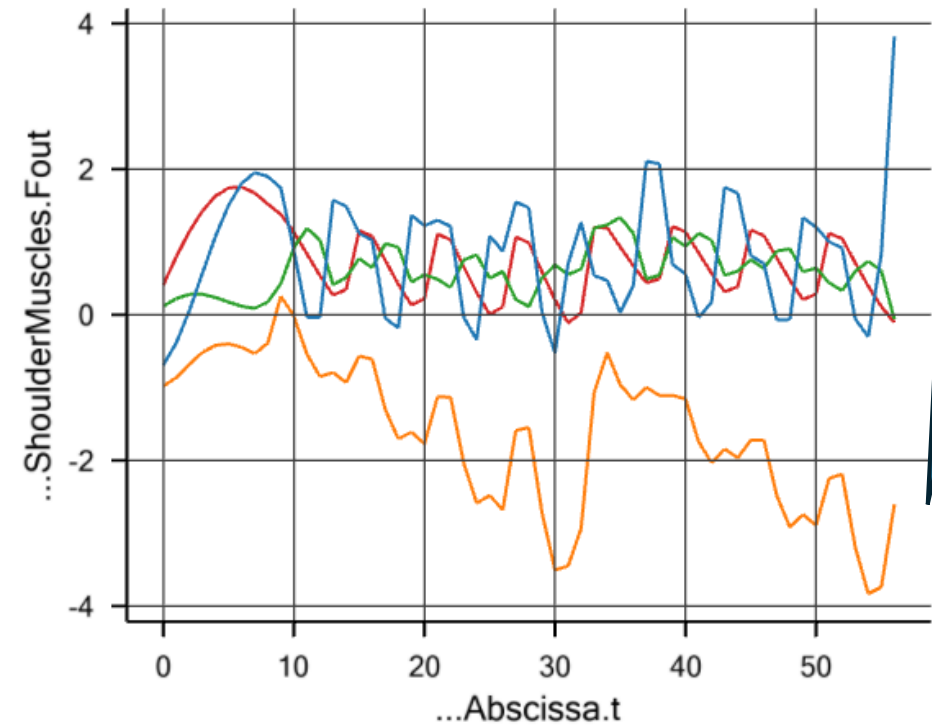
Effect of the spring

**Shoulder and elbow moments
without springs**



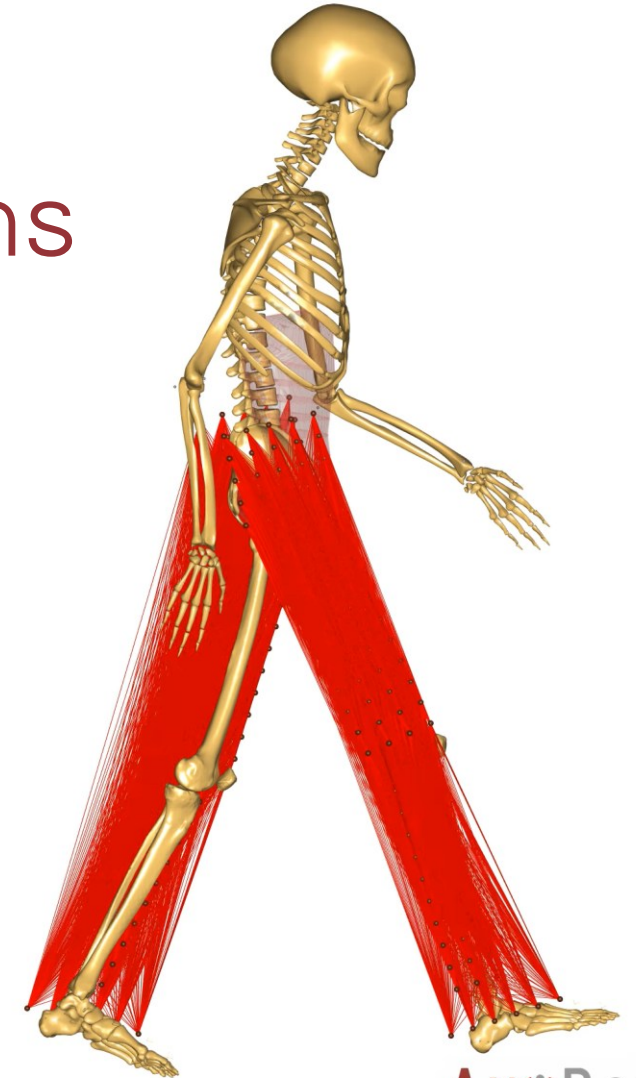
Shoulder flexion

With springs



Internal rotation

Topology Optimization of Exoskeletons



Resources

- www.anybodytech.com
 - Events, Webcast library, Publication list, ...
- www.anyscript.org
 - Wiki, Blog, Repositories, Forum
- **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

Welcome to AnyScript.org

An open community for users of the AnyBody Modeling System and a repository for sharing models and results.

Webcast: Sequentially coupled musculoskeletal multibody and Finite Element modeling for biomechanical analysis of the human masticatory system

Date: November 17, 2026

Time: 9AM CET & 5PM CET

Location: Online

This webcast presents a sequentially coupled modeling framework linking musculoskeletal multibody simulation (MMBS) in the AnyBody Modeling System with finite element (FE) analysis of the mandible. The framework is developed to contribute to more realistic biomechanical models of the masticatory system, for example, for preoperative planning in craniomaxillofacial surgery. Starting from a generic multibody model of the masticatory system, the mandible, skull, and muscle paths are anisotropically scaled to the patient specific target geometry using a three step approach that includes linear scaling, nonlinear RBF scaling, and nonlinear STL morphing. The resulting time dependent muscle forces and landmark displacements under unilateral clenching were then transferred as loading and boundary conditions into a subject specific FE model with heterogeneous bone material properties.

The talk will walk through this scaling and coupled modeling framework, present results from systematic sensitivity analyses of FE analysis on bone material properties, muscle forces, and muscle attachment areas, and offer practical recommendations for building more realistic, personalized models of the masticatory system to support implant evaluation and surgical planning.

Presenters:

Ann Kristin Becker, Research Assistant
Research Laboratory for Biomechanics and Implant Technology, Department of Orthopedics, Rostock University Medical Center, Rostock, Germany

Iman Soodmand, Research Assistant
Research Laboratory for Biomechanics and Implant Technology, Department of Orthopedics, Rostock University Medical Center, Rostock, Germany

[Registration site](#)

Tutorials

Learn musculoskeletal modelling with AnyBody by following step by step tutorials

[Go to tutorials](#)

Videos

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[Browse Youtube](#)

Wiki

Information, tips, tricks and FAQs for working with the AnyBody Modeling System.

[Browse the Wiki](#)

1300+

publications

filter by:

Industry

Research area

Body part

100+

webcasts

filter by:

Industry

Publication list

Resources / Publication list

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sports exoskeleton work place ergonomics orthopedics defense aerospace automotive consumer products furniture

Research area

gait methods validation animal sensitivity analysis rehab seating fea AnyBody Tech selected

Body part

knee lower extremity foot spine upper extremity hand shoulder hip mandible wrist trunk elbow ankle leg

NEW

Year 1324 Publications

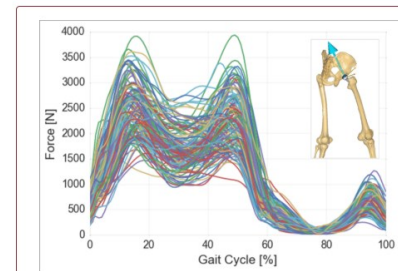
2026	Andres A, Wickert K, Roland M, Orth M, Braun B, Histig T, Diebels S, Pohlemann T, (2026), "Integrated study of the distal femur Biphasic Plate: Exploring in vivo, in vitro, and in silico methodologies". Ann. Biomed. Eng., [DOI, WWW]	NEW	orthopedics	leg
2026	Tang X, Wang X, Xue X, Liu H, Pu M, (2026), "Design and performance evaluation of unpowered hip-assisted exoskeletons". Biomimetics (Basel), vol. 11, pp. 625. [DOI, WWW]	NEW	exoskeleton	hip
2026	Xie D, Yu H, Du Z, Hua X, Shen X, Wang Z, Ye C, Tao H, (2026), "Stage-dependent muscle force patterns during femoral fracture reduction: a patient-specific modeling study". Comput. Methods Biomech. Biomed. Engin., pp. 1-11. [DOI]	NEW	orthopedics	leg
2026	Sakashita Y, Akiyama Y, Okamoto S, (2026), "Effect of discrepant gait assistance on the motion and stability of unplanned gait termination". IEEE Trans. Neural Syst. Rehabil. Eng., vol. PP, pp. 1-1. [DOI, WWW]	NEW	exoskeleton	gait
2026	Alibeyoglu F, Özcan C, Kaymaz I, Dagsuyu İM, (2026), "Biomechanical evaluation of orthognathic surgery using patient-specific musculoskeletal modeling: A pilot case study". J. Maxillofac. Oral Surg., [DOI, WWW]	NEW	orthopedics	man
2026	Jolas E, Guitteny S, Fougeron N, Aissaoui R, Pontonnier C, Dumas R, (2026), "Exposing implausible knee loading: 3D load-balancing reveals limitations in traditional two-step musculoskeletal modeling". J. Biomech., pp. 113514. [DOI, WWW]	NEW	knee	leg lower e
2026	Rosanò ER, Hulleck A, Liu T, El-Rich M, Loibl M, Galbusera F, Kleinstück F, Fekete T, Haschtmann D, Richner-Wunderlin S, Pellisé F, Obeid I, Pizones J, Alanay A, Yilgor C, La Barbera L, Ferguson SJ, Ignasiak D, European Spine Study Group E, (2026), "Not just alignment: body shape influences adult spinal deformity biomechanics". Eur. Spine J., [DOI, WWW]	NEW	spine	methods
2026	Daroudi S, Hosseini SN, Mohseni M, Bahramian M, Dehghan P, Arjmand N, (2026), "Interaction effects of stoop, full-squat, and semi-squat lifting techniques and hand-load position, magnitude, and asymmetry on knee and spine loads; a subject-specific musculoskeletal modeling investigation". Scientia Iranica, [WWW]	NEW	sports	work place
2026	Abdullah M, Hulleck AA, Liu T, Ignasiak D, Khalaf K, El-Rich M, (2026), "Influence of body-shape-based mass scaling and thoracic disc stiffness on flexible-thorax model predictions of thoracolumbar loading during lateral bending". Sci. Rep., [DOI, WWW]	NEW	orthopedics	spine
2026	Gu D, Kang D, Kim YJ, Lee YH, Moon JI, Park S, Choi JK, Jung MK, Kim Y, (2026), "Biomechanical effectiveness and wearability of a passive shoulder exoskeleton in an automotive assembly". Appl. Sci. (Basel), vol. 16, pp. 7192. [DOI, WWW]	NEW	automotive	exoskeleton work place ergonomics upper extremity

Publications list

Webcast library

Resources / Webcast library

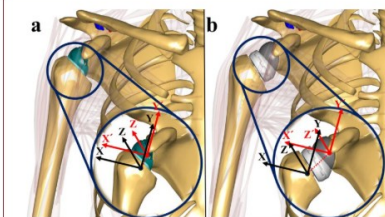
All Aerospace All use cases Animal Assistive devices Automotive Consumer Ergonomics Exoskeletons
Product presentations Sports Universities Workplace ergonomics



25. June 2026

Motion capture dataset of 137 post-operative total hip replacement patients: current and future applications

Dr David Lunn, Senior Lecturer at Leeds Beckett University, UK

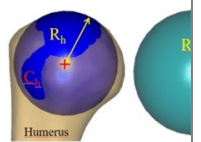


17. March 2026

29. May 2026

Age-related changes in human musculoskeletal modeling-based analysis

Assistant Professor Katarzyna Nowakowska



16. January 2026

Webcasts list

Questions

Meet us

- Send email to sales@anybodytech.com

Trial version

- Send email to sales@anybodytech.com

Presentation questions

- Send email to dsc@anybodytech.com

Thank you for your
attention!

