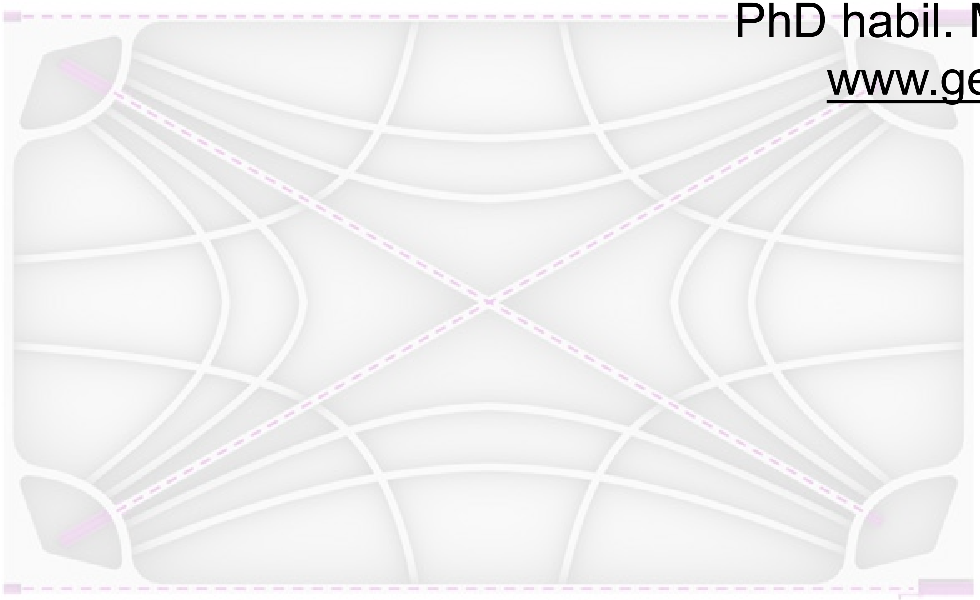
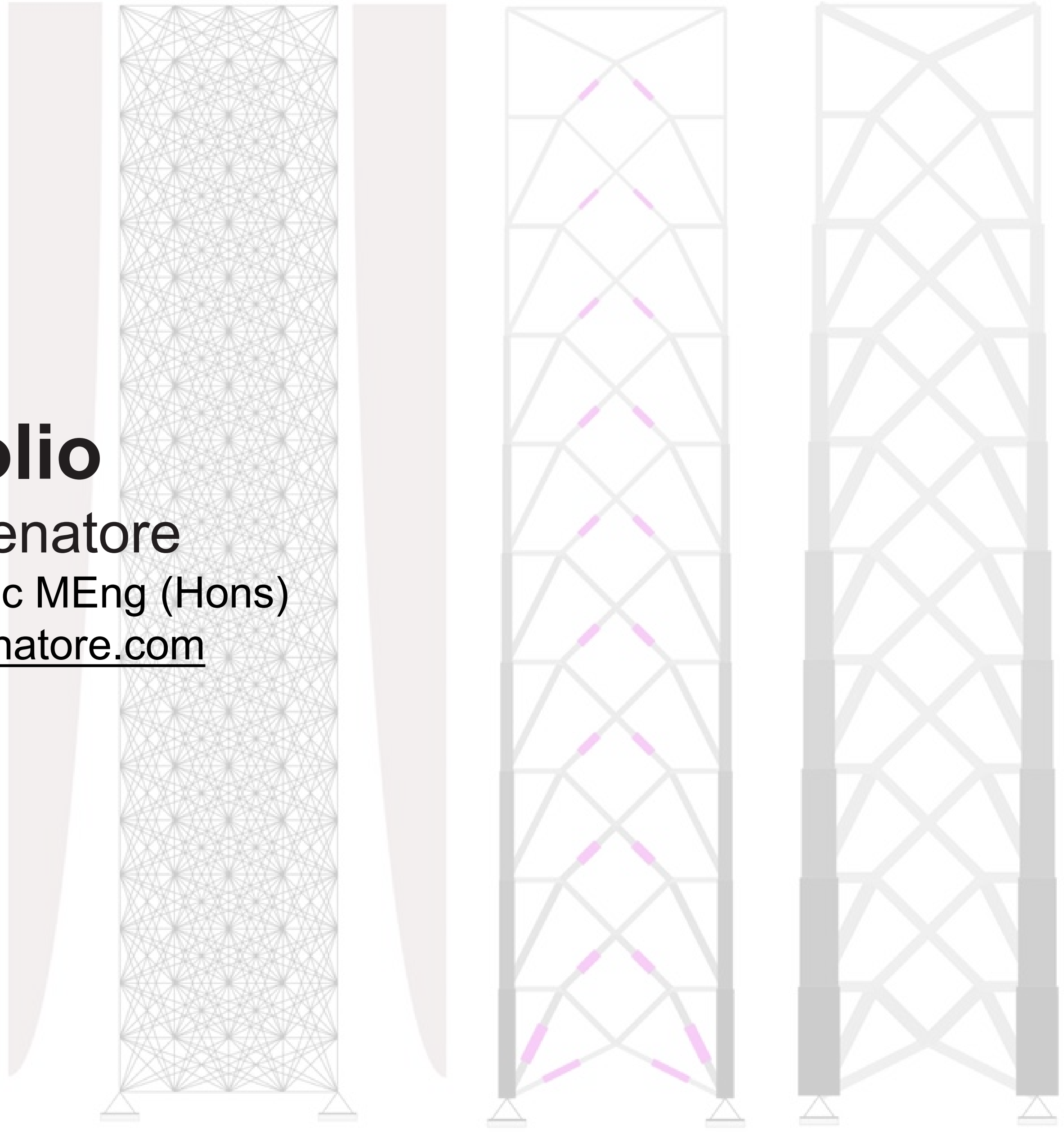




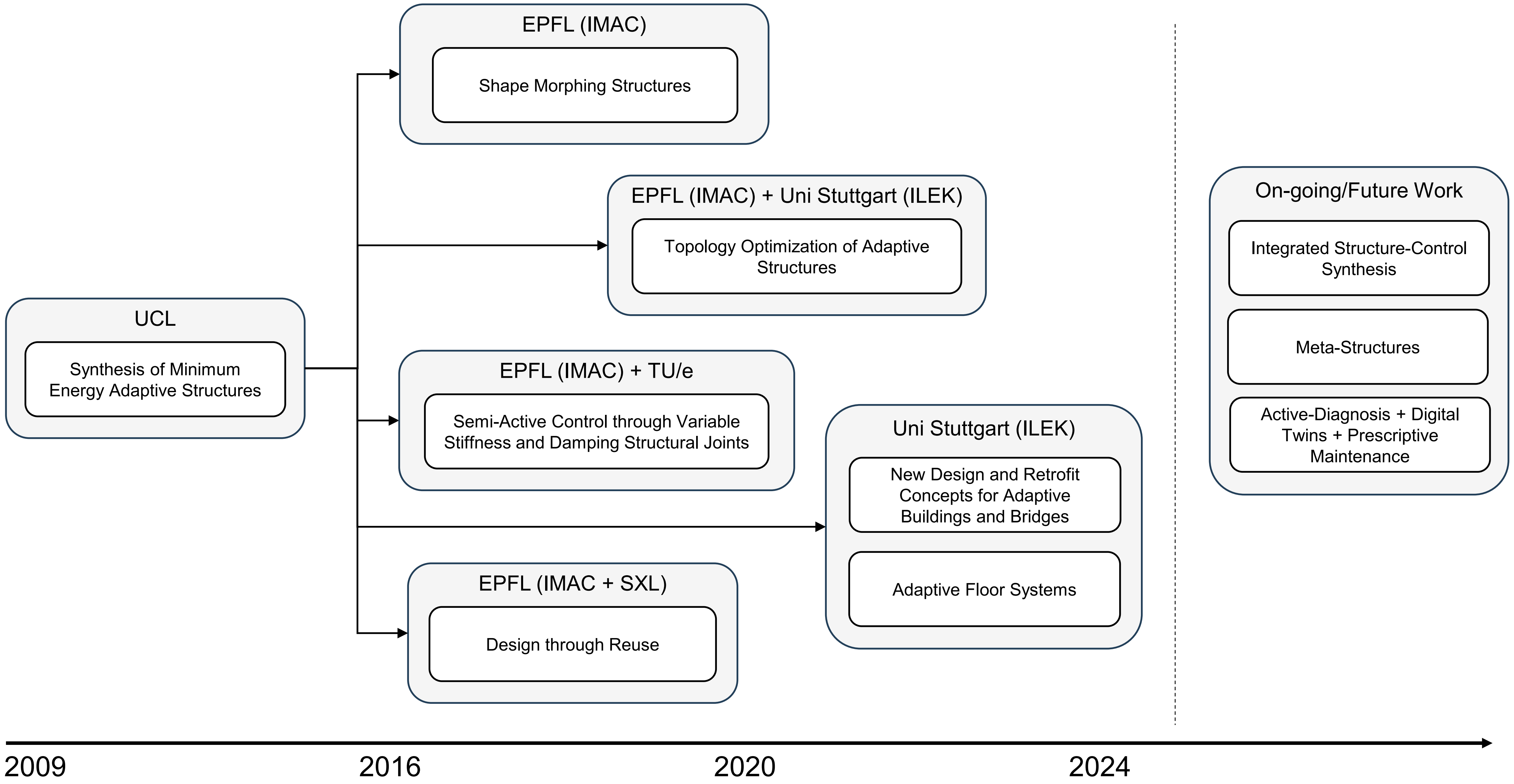
Portfolio

Gennaro Senatore

PhD habil. MRes MSc MEng (Hons)

www.gennarosenatore.com

Table of Contents


EPFL (IMAC)
Shape Morphing Structures
EPFL (IMAC) + Uni Stuttgart (ILEK)
Topology Optimization of Adaptive Structures
UCL
Synthesis of Minimum Energy Adaptive Structures
EPFL (IMAC) + TU/e
Semi-Active Control through Variable Stiffness and Damping Structural Joints
Uni Stuttgart (ILEK)
New Design and Retrofit Concepts for Adaptive Buildings and Bridges
Adaptive Floor Systems
EPFL (IMAC + SXL)
Design through Reuse
On-going/Future Work
Integrated Structure-Control Synthesis
Meta-Structures
Active-Diagnosis + Digital Twins + Prescriptive Maintenance
2009
2016
2020
2024

Minimum Energy and Carbon Adaptive Structures

Gennaro Senatore has developed innovative computational methods for designing adaptive structures equipped with sensing and actuation systems. These structures actively counteract external loads and environmental forces by adjusting internal forces and morphing their shape.

The solutions derived from these methods result in a new class of load-bearing structures that are **material-, energy-, and carbon-efficient**. They can be **extremely slender** while maintaining precise control over deflections, making them particularly advantageous for **stiffness-governed designs** such as high-rise buildings, long-span bridges, and self-supporting roof systems.

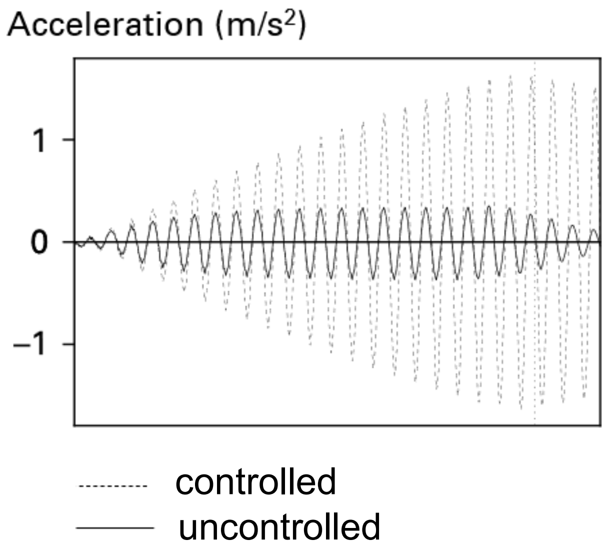
Adaptation can be employed to keep the structure within predefined response limits, such as maintaining a specific control target shape. Alternatively, the system can operate without a predetermined target, performing **real-time optimization** to achieve an optimal structural response—adjusting both shape and internal stress distribution dynamically. Structural adaptation can also be applied to recover from damage states and to retro-fitting in order to extend the service lifespan of aging structures.

https://www.gennarosenatore.com/research/adaptive_structures/minimum_energy_adaptive_structures

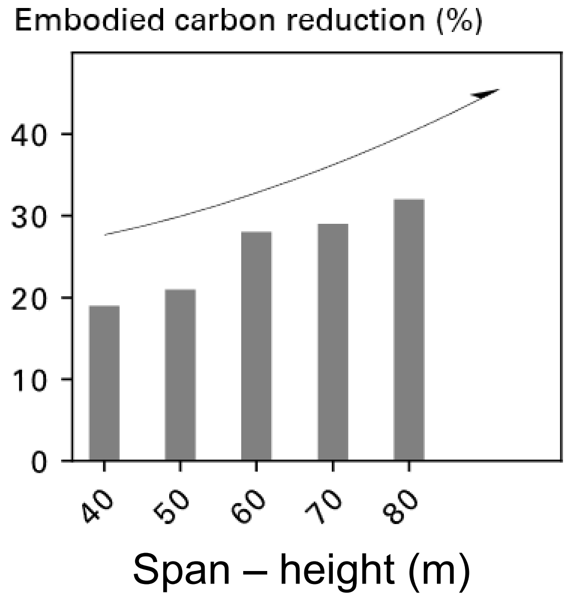
https://www.gennarosenatore.com/research/adaptive_structures/structural_adaptation_through_shape_morphing

Structural Adaptation - Objectives

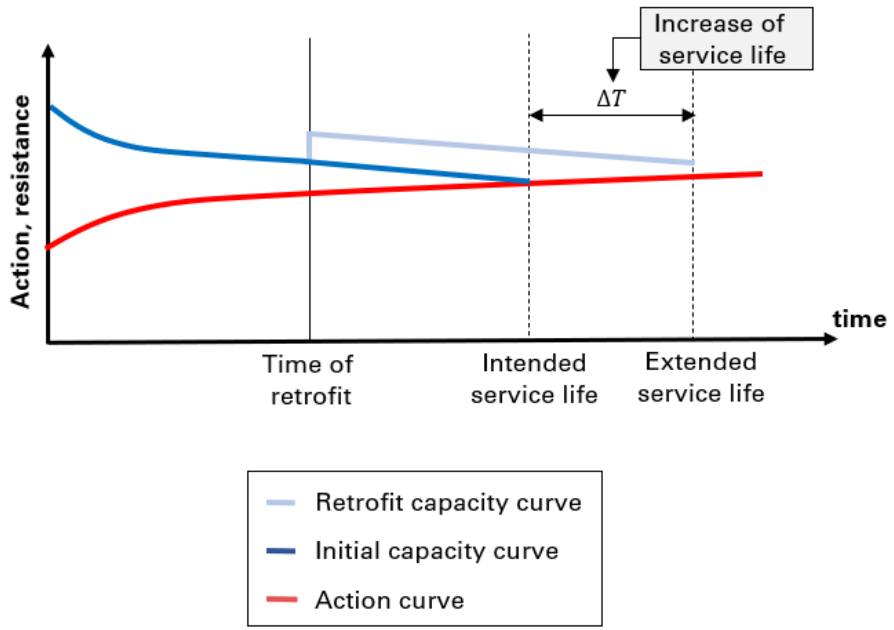
Response reduction



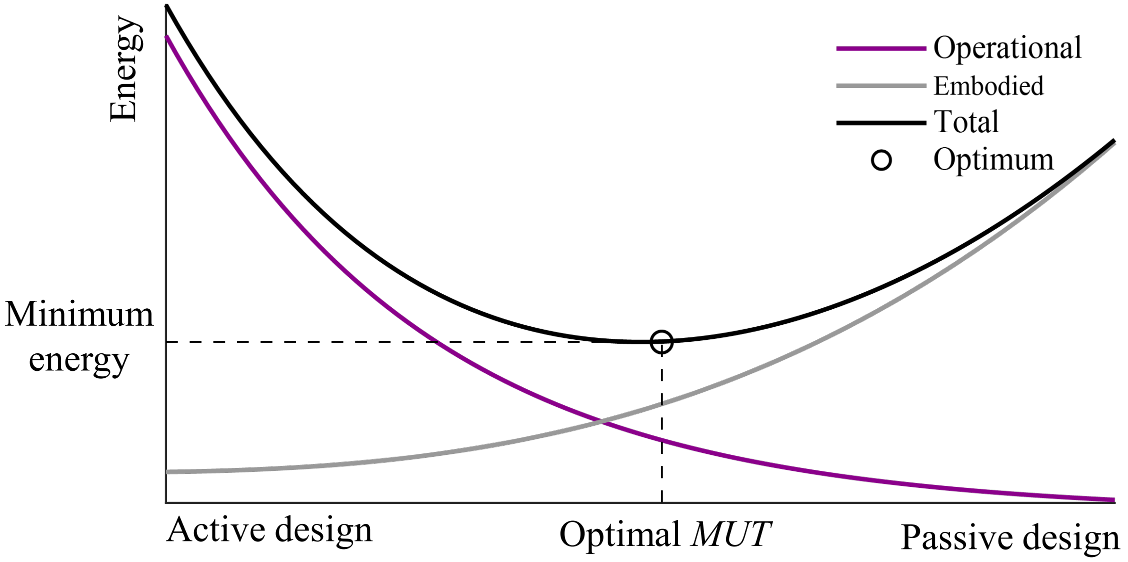
Mass & Carbon reduction



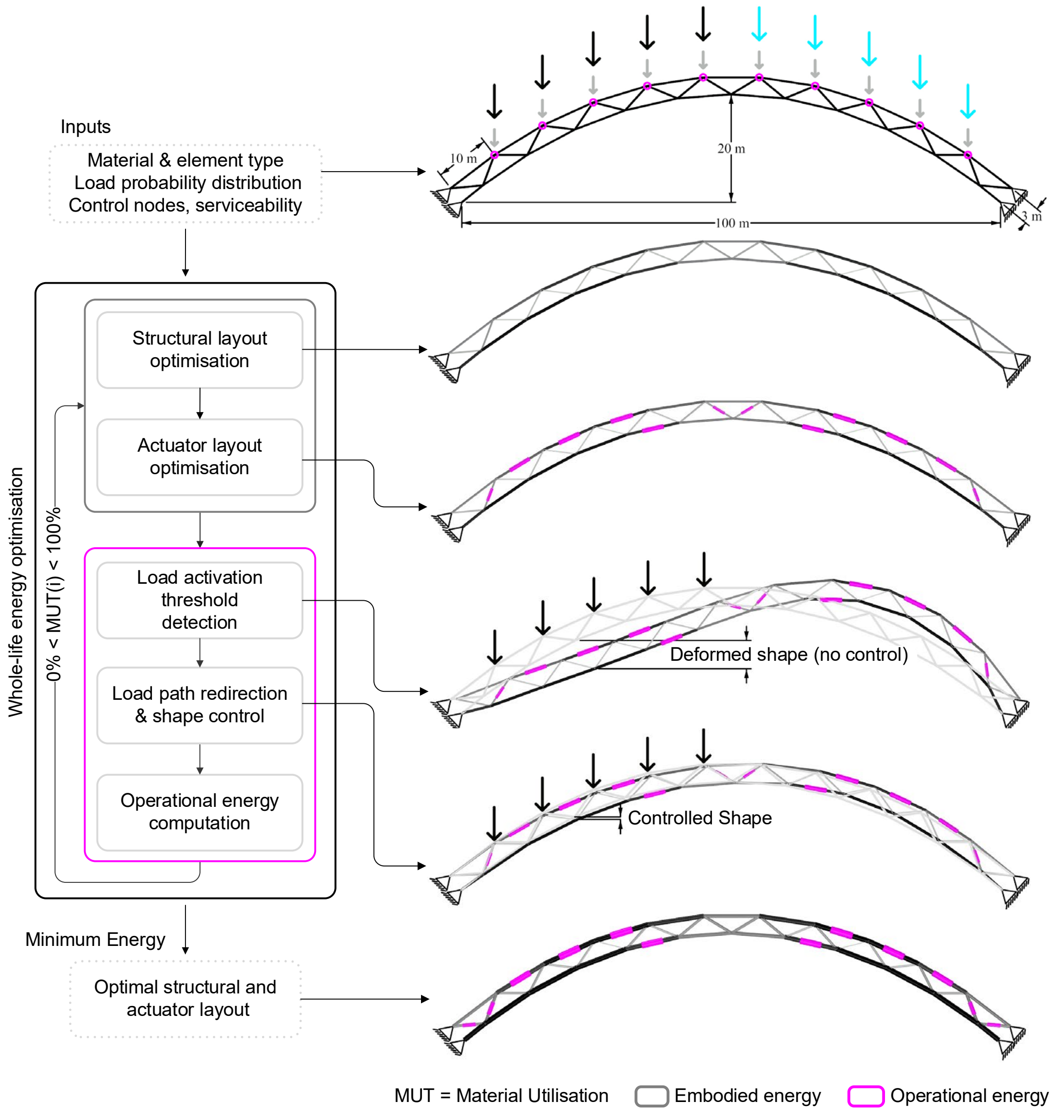
Service life extension



Synthesis of Minimum Energy Adaptive Structures

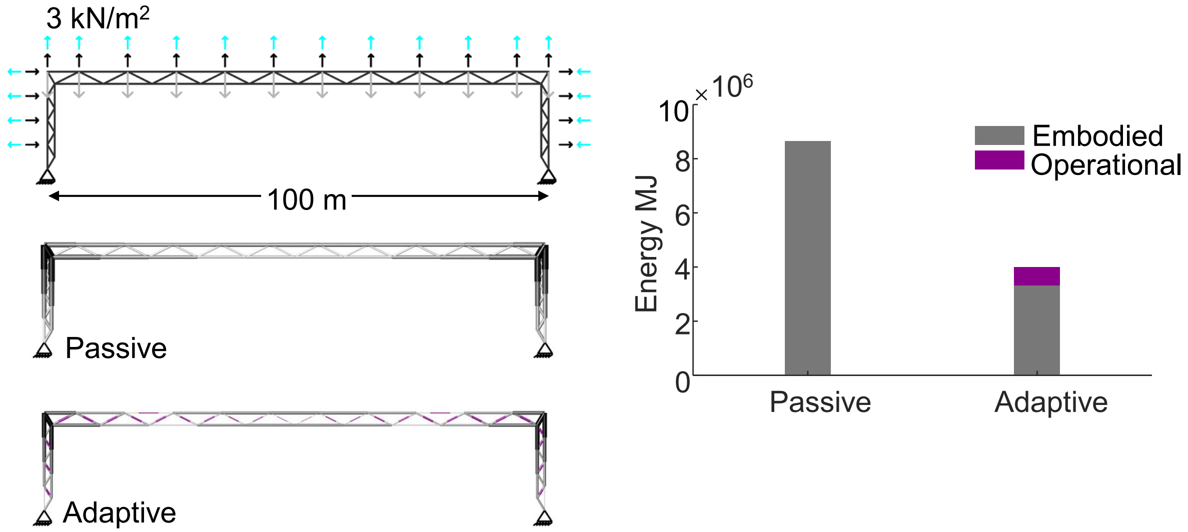


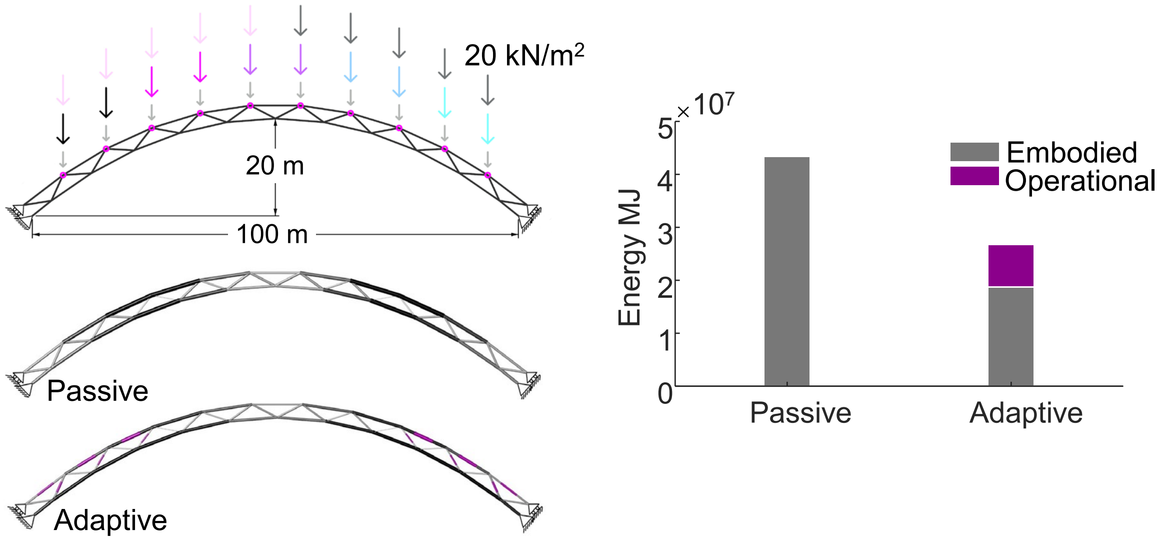
$$MUT = \frac{|\sigma|}{\sigma^{adm}}$$ Material utilization (MUT)
Strength capacity over demand

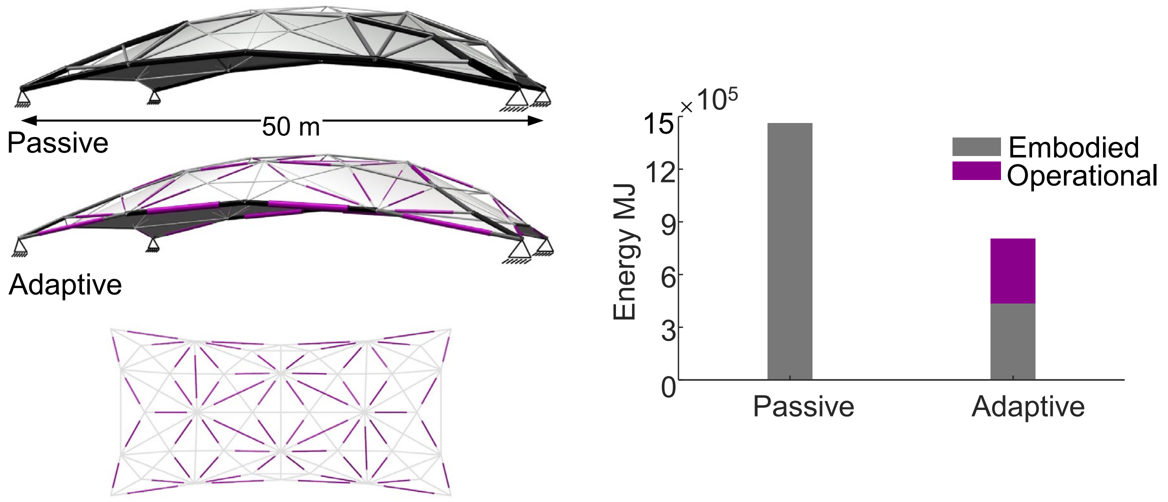


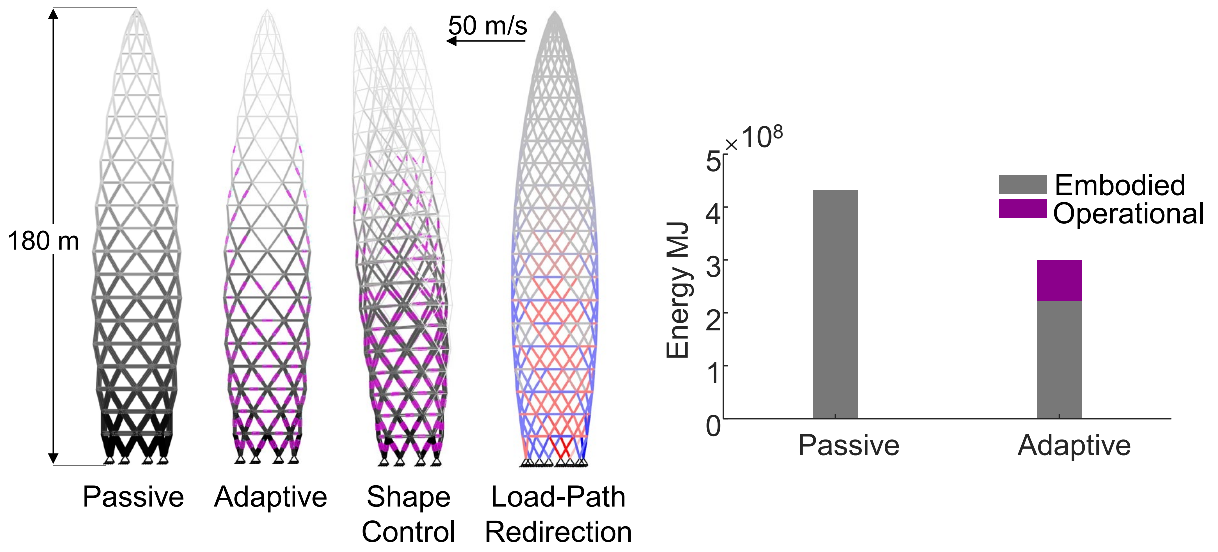
G. Senatore, P. Duffour and P. Winslow, "Synthesis of Minimum Energy Adaptive Structures," Structural and Multidisciplinary Optimization, vol. 60, no. 3, pp. 849-877, 2019.

Case Studies

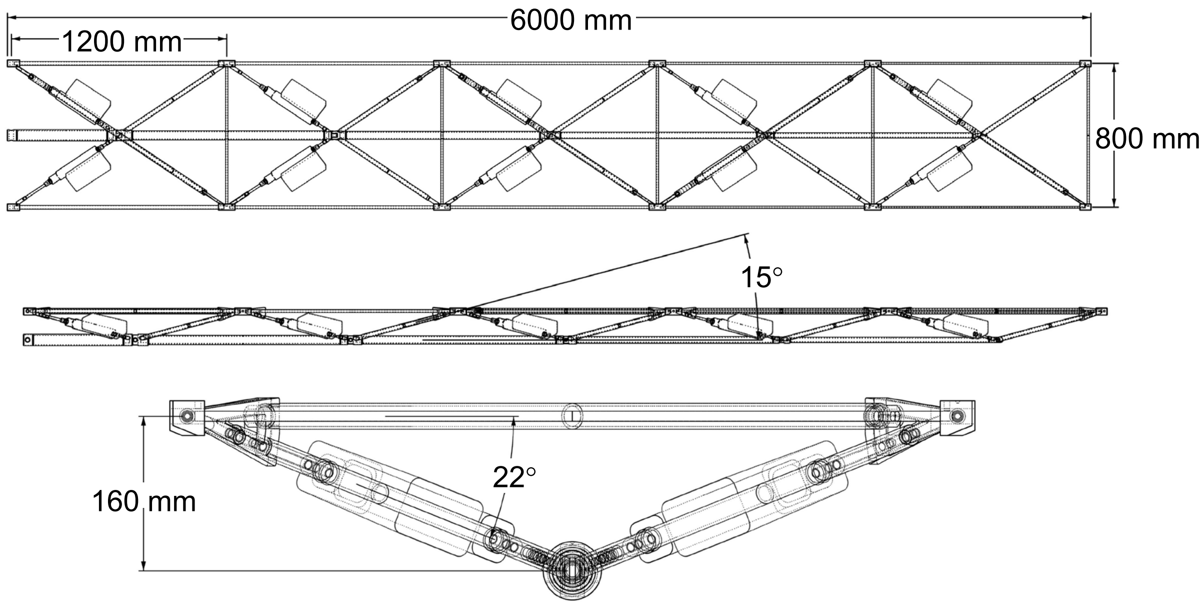




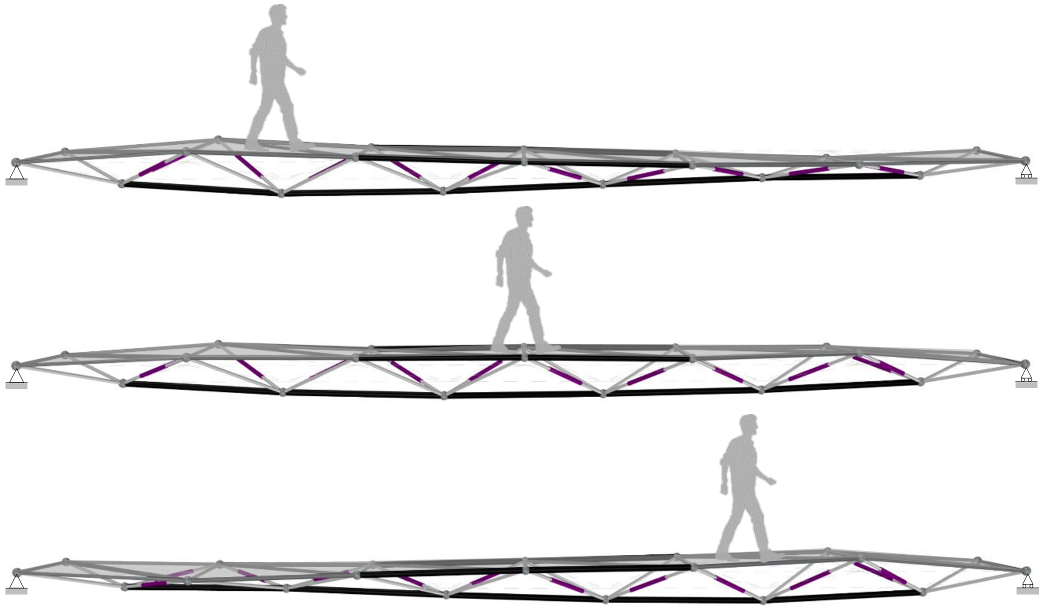




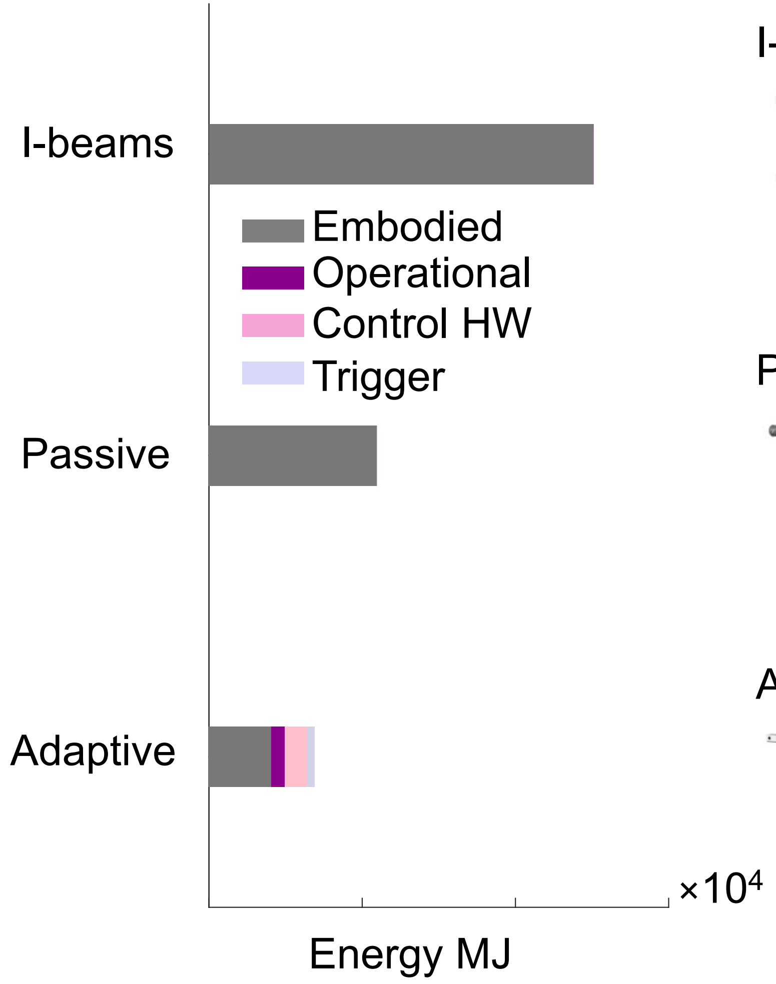

Video demonstration

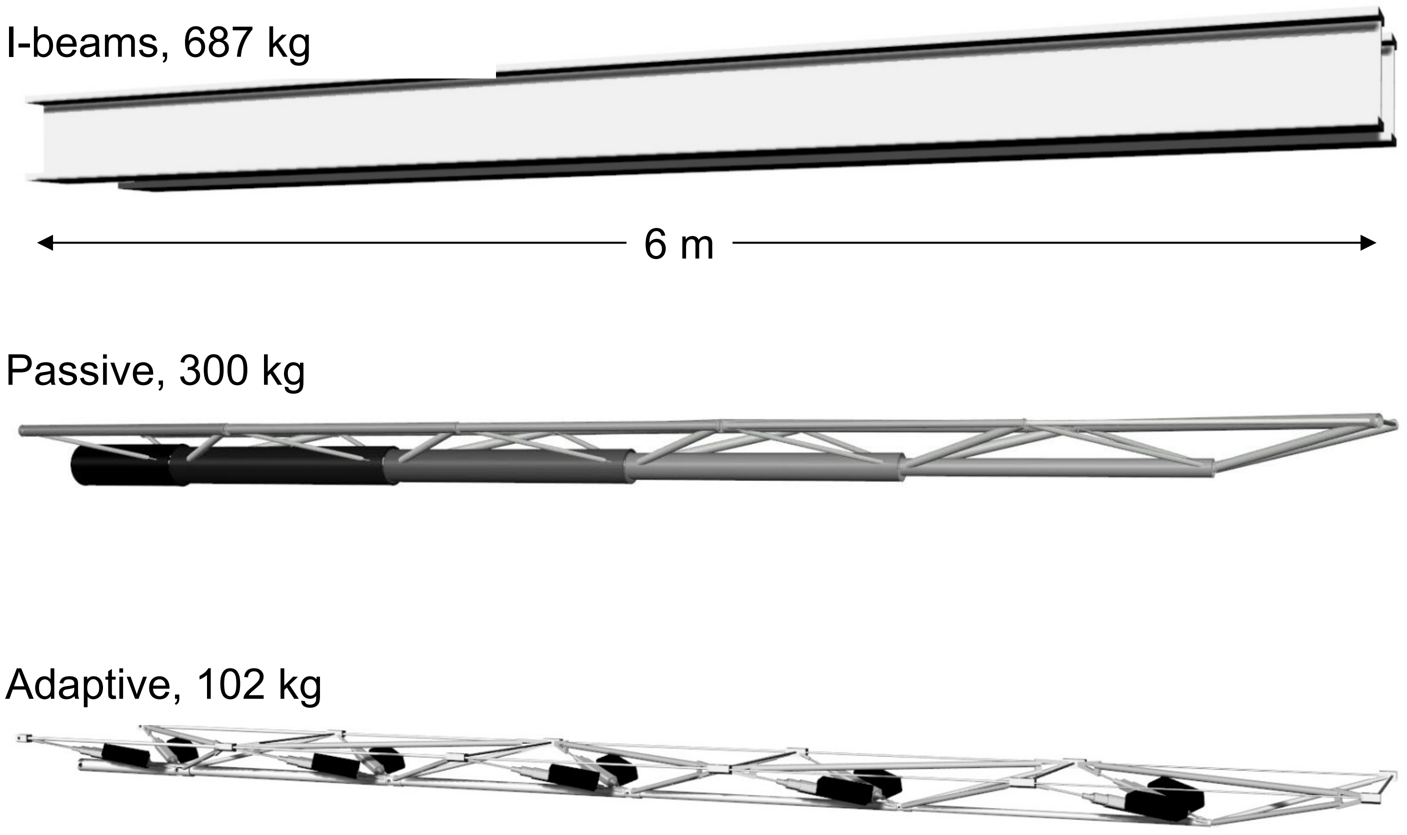

6000 mm
1200 mm
800 mm
15°
22°
160 mm


Video demonstration



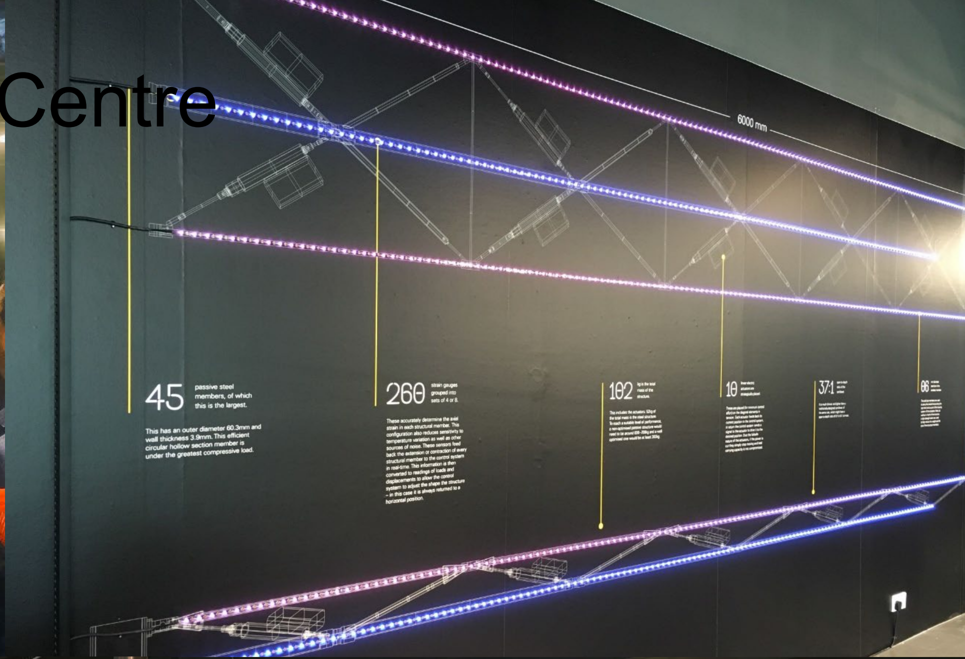
Energy Assessment – Adaptive vs Passive Solutions





Total energy savings
40% compared to passive truss
70% compared to I-beams

Exhibition – The Building Centre



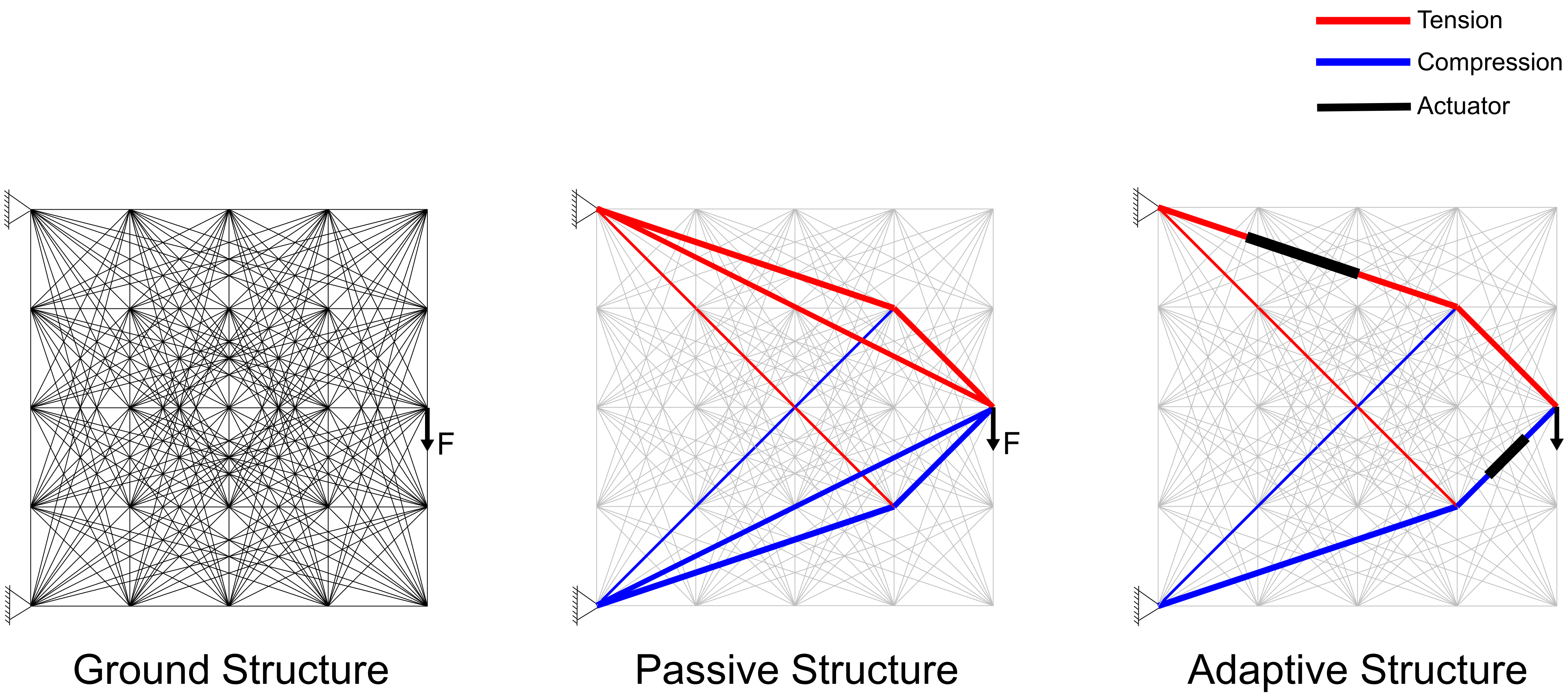
Structure-Control Topology Synthesis

This work introduces the first-ever formulation for the All-In-One topology optimization of adaptive structures. This formulation enables a **simultaneous synthesis** of the **structural topology** and the **actuator placement** in a single problem statement producing global optimum solutions. The objective function includes the mass of both structural elements and actuators. Design variables encompass the topology of structural members, the placement of actuators, and the cross-section al areas of elements. State variables comprise element forces and deformations, nodal displacements, and actuator commands. Constraint functions ensure that feasible solutions meet equilibrium and geometric compatibility requirements, as well as limits on stress, stability, nodal displacements, and actuator forces. Auxiliary constraints are formulated to linearize the formulation into a Mixed-Integer Linear Problem (MILP).

The solutions produced with this method have an **absolute minimum weight** comprising the mass of structural and actuation systems. Numerical benchmarks against **global optima** provide the first-ever formal numerical proof concerning the optimality of adaptive solutions against topology-optimized passive solutions.

https://www.gennarosenatore.com/research/adaptive_structures/all-in-one_structure-control_topology_synthesis

Structure-Control Topology Synthesis



G. Senatore and Y. Wang, “Topology Optimization of Adaptive Structures: New Limits of Material Economy,” Computer Methods in Applied Mechanics and Engineering, vol. 422, 2024

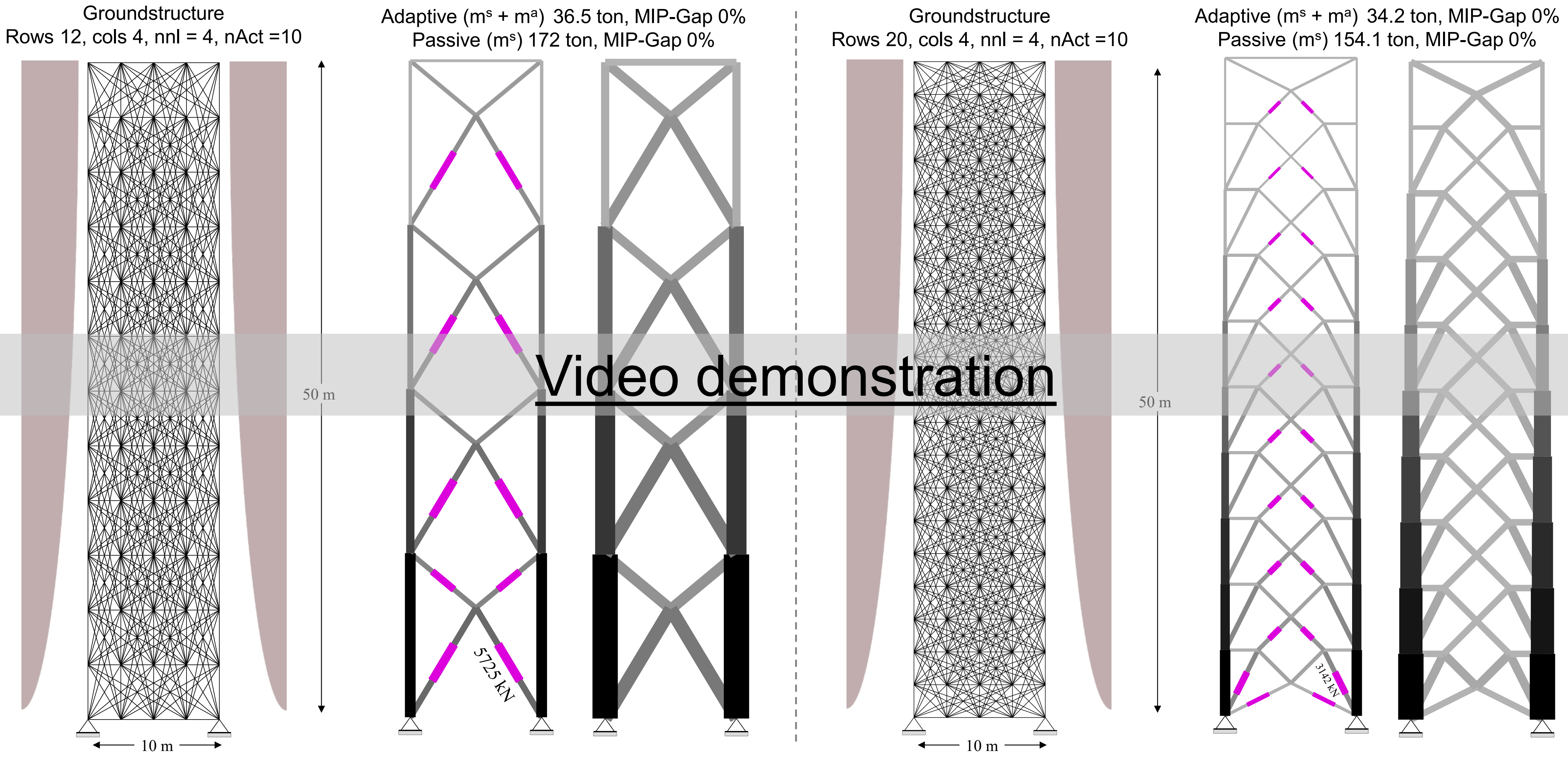
All-In-One Structure-Control Topology Synthesis (MILP)

1	$\min\limits_{\mathbf{x}}$	$\sum_i^{n^{el}} \rho_i L_i \sum_j^{n^a} A_{ij}^{el} a_j^c + c^{act} \sum_i^{n^{el}} F_i^{act}$	System mass = structure + actuators
		s.t.	
		Structural Topology	
2		$\sum_j A_{ij}^{el} = 1, \forall i \in E^{GS}$	Cross-section assignment (includes zero-area)
3		$\sum_{j>1} A_{ij}^{el} = 1, \forall i \in E^{fix}$	Existence of select elements
4		$\sum_j A_{ij}^{el} = \sum_j A_{kj}^{el}, \forall (i,k) \in E^{sym}$	Symmetry layout constraints
5		$\sum_{j>1} A_{ij}^{el} + \sum_j A_{kj}^{el} \le 1, \forall \langle i,k \rangle \in E^{cross}$	Avoid crossing elements
6*		$\dfrac{\sum_{i \in E_k^n} \sum_{j>1} A_{ij}^{el}}{\lvert E_k^n \rvert} \le A_k^n \le \sum_{i \in E_k^n} \sum_{j>1} A_{ij}^{el}, \forall k \in N^f$	Relation between nodes and element topology
7*		$\sum_{k \in N^{el}} A_k^n \le \lvert N_i^{el} \rvert \left(1 - \sum_{j>1} A_{ij}^{el}\right), N_i^{el} \ne \varnothing, \forall i \in E^{GS}$	Avoid overlapping elements
8*		$\sum_{i \in E_k^n} \sum_{j>1} A_{ij}^{el} \ge c^n A_k^n, \forall k \in N^f, c^n = \begin{cases} 3, & \text{if 2D} \\ 4, & \text{if 3D} \end{cases}$	Avoid mechanisms caused by collinear elements
		Actuator Placement	
9		$A_i^{act} \le \sum_{j>1} A_{ij}^{el}, \forall i \in E^{GS}$	Relation between actuator topology $\mathbf{A}^{act}$ and element topology $\mathbf{A}^{el}$
10		$\sum_i A_i^{act} \le \overline{n}^{act}, \forall i \in E^{GS}$	Actuator number upper bound
		State Conditions + Response Control	
11*		$\mathbf{BF} = \mathbf{P} + \mathbf{P}^{sws} + \mathbf{P}^{swa}$	Equilibrium
12		$\mathbf{B}_i^T \mathbf{d} = \sum_j e_{ij} + \Delta L_i, \forall i \in E^{GS}$	Geometric compatibility + control
13		$F_i = \dfrac{E_i}{L_i} \sum_j e_{ij} a_i^c, \forall i \in E^{GS}$	Constitutive
		Limit States	
14*		$\sum_j A_{ij}^{el} \max\left(c^b (a_i^c)^2, \underline{\sigma} a_i^c\right) \le F_i \le \sum_j A_{ij}^{el} \overline{\sigma} a_i^c$ $c^b = \dfrac{-\pi E (1+\lambda^2)}{4 L_i^2 (1-\lambda^2)}, \lambda = 1-\gamma, \gamma = \dfrac{t}{r^e}$, $\forall i \in E^{GS}$	Stress and buckling constraints
15		$e_{ij} \ge A_{ij}^{el} \left[\underline{e}_i^d, \left(\max\left(\underline{e}_i^d, \underline{e}_i^F\right)\right)\right]$ $e_{ij} \le A_{ij}^{el} \left[\overline{e}_i^d, \left(\min\left(\overline{e}_i^d, \overline{e}_i^F\right)\right)\right]$, $\forall i \in E^{GS}$	Deformation constraints
16		$-\overline{\mathbf{d}} \le \mathbf{d} \le \overline{\mathbf{d}}$	Displacement constraints
		Control Feasibility	
17		$0 \le \mathbf{F}^{act} \le \overline{F}^{act} \mathbf{A}^{act}$	Actuator force upper bound
18		$-\overline{\Delta L}\, \mathbf{A}^{act} \le \Delta\mathbf{L} \le \overline{\Delta L}\, \mathbf{A}^{act}$	Actuator length change limit
		Auxiliary constraints	
19		$-\mathbf{F}^{aux} \le \mathbf{F} \le \mathbf{F}^{aux}$	Relation between element force $\mathbf{F}$ and actuator force $\mathbf{F}^{act}$ to linearize the objective function
20		$0 \le \mathbf{F}^{aux} - \mathbf{F}^{act} \le \overline{a\sigma}(1 - \mathbf{A}^{act})$	

$\mathbf{A}^{el} \in \{0,1\}^{n^{el}}$, $\mathbf{A}^{n} \in \{0,1\}^{n^{f}}$, $\mathbf{A}^{act} \in \{0,1\}^{n^{el}}$	Design variables
$\mathbf{F} \in \mathbb{R}^{n^{el}}$, $\mathbf{F}^{aux} \in \mathbb{R}^{n^{el}}$, $\mathbf{F}^{act} \in \mathbb{R}^{n^{el}}$ $\mathbf{d} \in \mathbb{R}^{n^{f}}$, $\mathbf{e} \in \mathbb{R}^{n^{el} \times n^{a}}$, $\Delta\mathbf{L} \in \mathbb{R}^{n^{el}}$	State variables

$\mathbf{A}^{act} \in \{0,1\}^{n^{el}}$	Actuator assignment
$\mathbf{A}^{el} \in \{0,1\}^{n^{el}}$	Element assignment
$\mathbf{A}^{n} \in \{0,1\}^{n^{f}}$	Node assignment
$\boldsymbol{\alpha} \in \mathbb{R}^{n^{el}}$	element cross-section area
$\mathbf{F} \in \mathbb{R}^{n^{el}}$	element forces
$\mathbf{d} \in \mathbb{R}^{n^{dof}}$	nodal displacements
$\mathbf{e} \in \mathbb{R}^{n^{e}}$	element elastic deformation for Step1-MINLP
$\mathbf{F}^{aux} \in \mathbb{R}^{n^{el}}$	maximum element forces (auxiliary)
$\mathbf{F}^{act} \in \mathbb{R}^{n^{el}}$	actuator forces
$\Delta\mathbf{L} \in \mathbb{R}^{n^{el}}$	actuator commands (i.e., length changes)
E^{act}	index set of actuator positions
E^{cross}	index set of crossing element in the ground structure
E^{fix}	index set of elements that must be retained (i.e., not eliminated)
E^{GS}	index set of all elements in the ground structure
E_k^n	index set of all elements connected to node k
E^{sym}	index set of symmetric elements
N^{cdof}	index set of controlled degrees of freedom
N_i^{el}	index set of all nodes contained within the length of element i
N^{f}	index set of nodes not constrained by supports and with no applied loads
N^{GS}	index set of all nodes in the ground structure

High-Rise Buildings



New Limits of Material Economy

"... the ability to reduce strain and displacement response through actuation yields a global least-weight solution identical to a fully stressed design (i.e., Michell truss) that is obtained by neglecting geometric compatibility and displacement constraints."

"... the simultaneous optimization of structural topology and actuator placement produce solutions that approach, with the least deterioration, fully stressed designs and, in parallel, satisfy important constraints including displacements and buckling that would not be possible without adaptation."

G. Senatore and Y. Wang, "Topology Optimization of Adaptive Structures: New Limits of Material Economy," *Computer Methods in Applied Mechanics and Engineering*, vol. 422, 2024

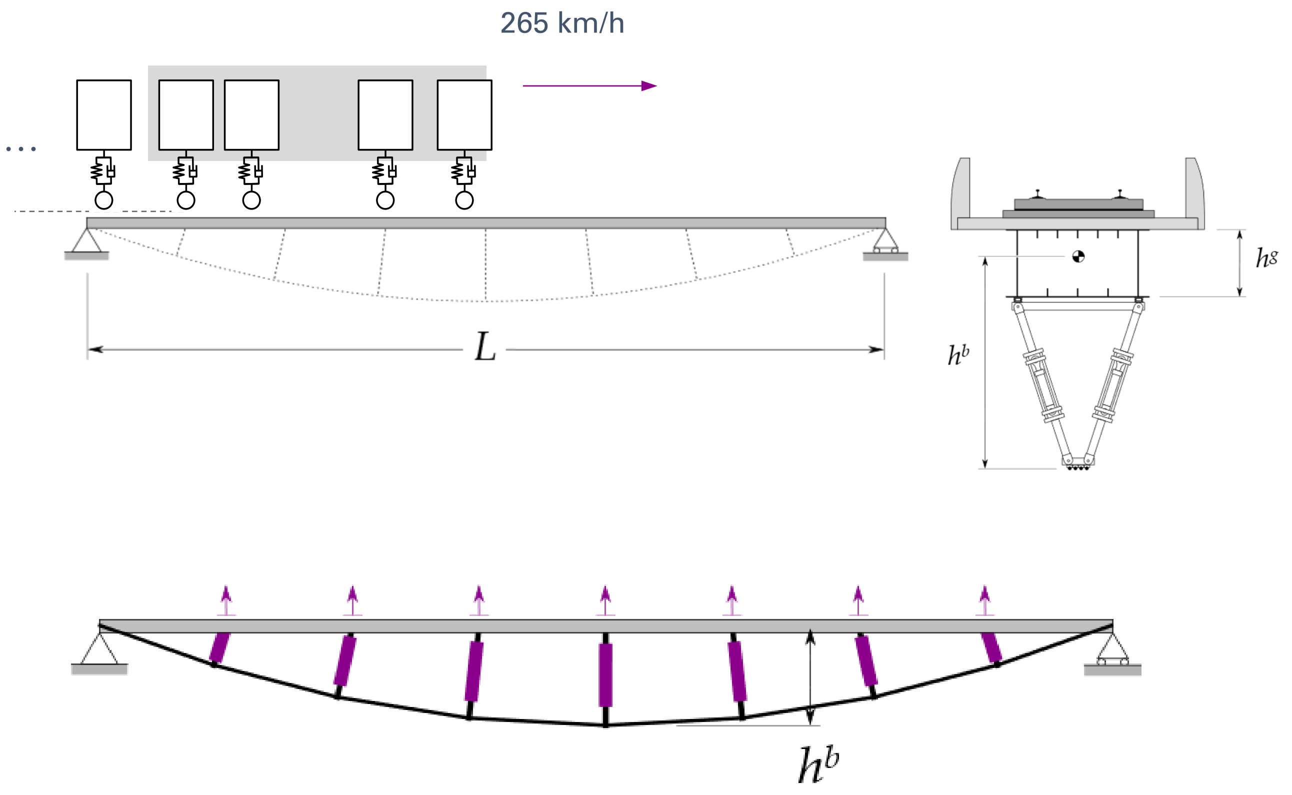
Adaptive Bridge Structures

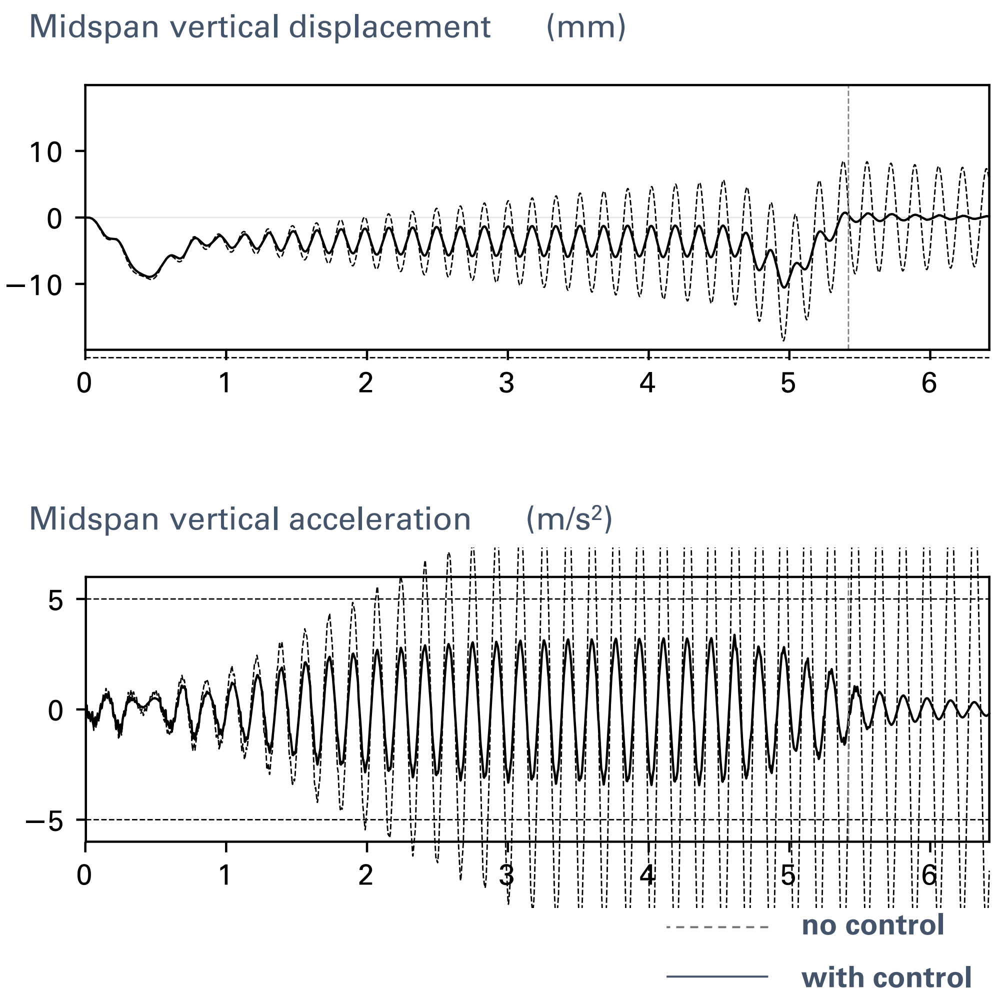
This work introduces methods for retrofitting aging bridges and designing new ones with active components, focusing on increasing span, reducing material use and emissions, and extending service life. High-speed railway (HSR) bridges face challenges in meeting serviceability limits for longer spans, often requiring substantial material increases. To address this, an **External Adaptive Tensioning** (EAT) system was developed, employing under-deck cables and active struts with linear actuators to counteract external loads. Studies on steel beam-bridge configurations show the EAT system achieves up to 32% mass and 25% CO_2 savings compared to passive designs.

Europe's aging bridge infrastructure presents a growing concern, with 40-50% of bridges over 50 years old facing increased traffic loads. **Active retrofitting** demonstrates potential to extend service life. Using linear actuators in hanger cables and stays, active control can reduce the stress response mitigating fatigue and extending service life beyond 75 years by maintaining stresses below the Constant Amplitude Fatigue Limit (CAFL). For prestressed concrete bridges, the EAT system shows promise in addressing corrosion risks by compensating deflections caused by loss in prestress force, reducing the moment response in the Ultimate Limit State (ULS) and extending service life.

https://www.gennarosenatore.com/research/adaptive_structures/adaptive_bridge_structures

Design of New Bridges with External Adaptive Tensioning (EAT)





A. P. Reksowardojo, G. Senatore, M. Bischoff, and L. Blandini, "Design and control of high-speed railway bridges equipped with an under-deck adaptive tensioning system," Journal of Sound and Vibration, vol. 579, p. 118362, Jun. 2024, doi: 10.1016/j.jsv.2024.118362.

External Adaptive Tensioning (EAT)

Span L (m)	**Carbon footprint reduction**
40	19%
50	21%
60	28%
70	29%
80	27%

Reduce vibration response under diverse loading including high-speed train

Reduce dynamically induced stress

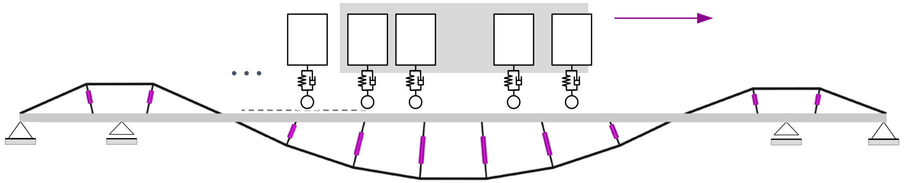
Extend service life, reduce damage accumulation

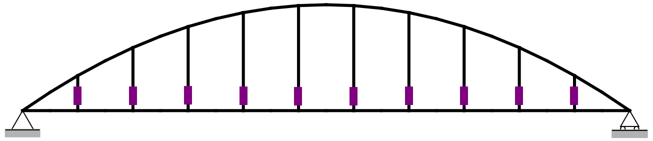
Reduce carbon footprint

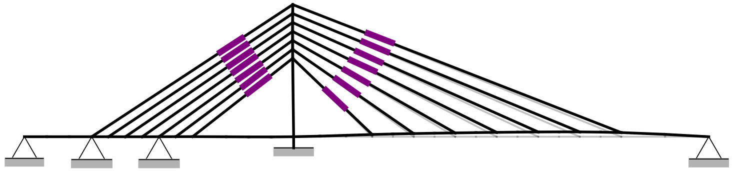
Retrofit Bridge Structures with Active Components

Girder

Cable-stayed





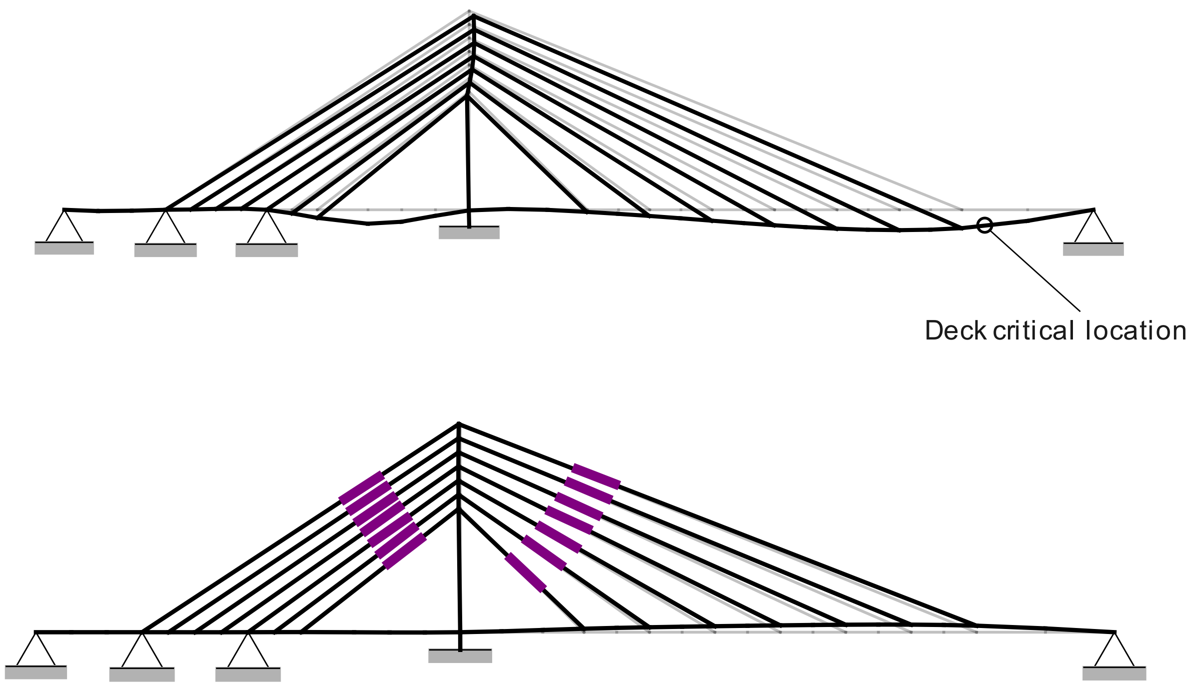


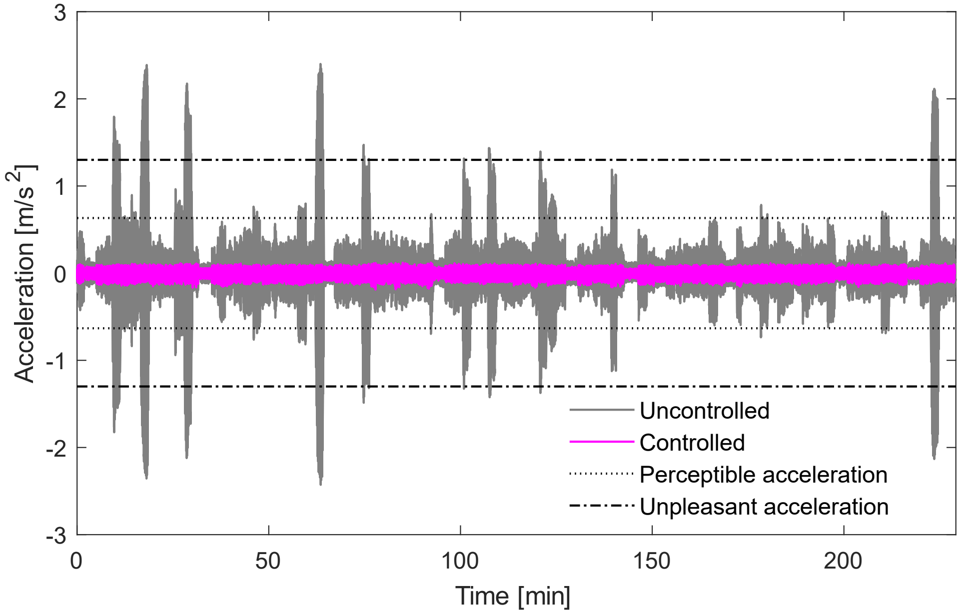
External Adaptive Tensioning

Active hangers

Within cross section

Actuator Configuration (Fleher Bridge)

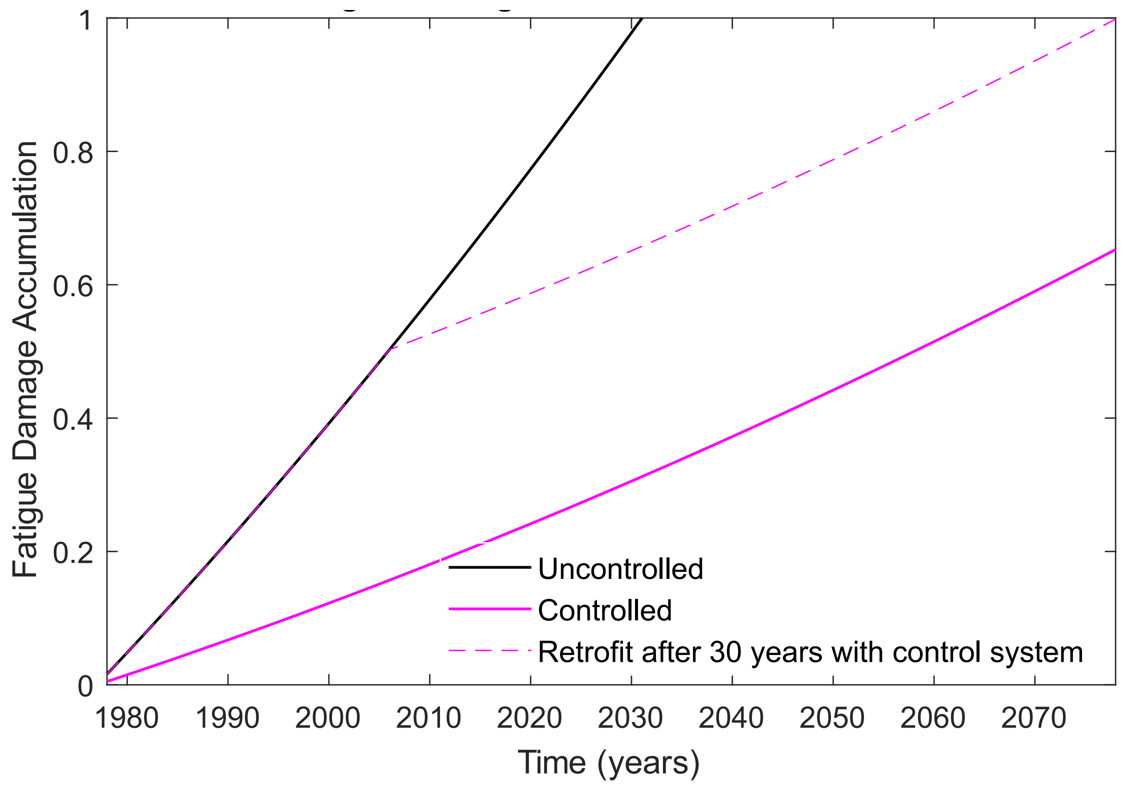


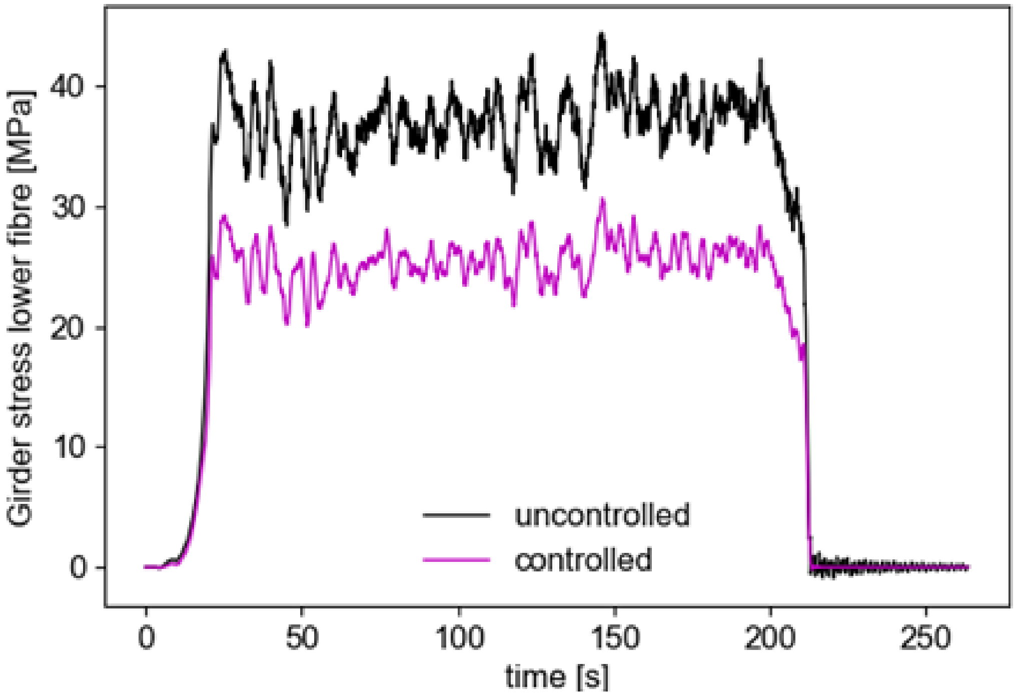


Acceleration response under 30000 vehicle crossing

K. A. Canny, G. Senatore, and L. Blandini, "Investigation of retrofitting strategies to extend the service life of bridge structures through active control," *Journal of Bridge Engineering (ASCE)*, 2025. DOI: 10.1061/JBENF2.BEENG-6925

Service Life Extension through Active Control (Fleher Bridge)





Stress orthotropic deck lower fiber

Reduction of acceleration and stress response through active control results in significant mitigation of fatigue-induced damage

K. A. Canny, G. Senatore, and L. Blandini, “Investigation of retrofitting strategies to extend the service life of bridge structures through active control,” *Journal of Bridge Engineering (ASCE)*, 2025. DOI: 10.1061/JBENF2.BEENG-6925

Active Retrofitting Strategies for Bridge Service Life Extension

Pronounced reduction in the response under loading

Significant fatigue life extension, potential “infinite” fatigue life

12-year extension damage induced by corrosion in reinforced concrete single span highway bridge

Required control forces remain within the limits reached by modern actuators

When the actuators are placed in the main load path, an increase in stress response could occur in non-critically stressed elements

Future work

High-fidelity modeling + consideration of reliability

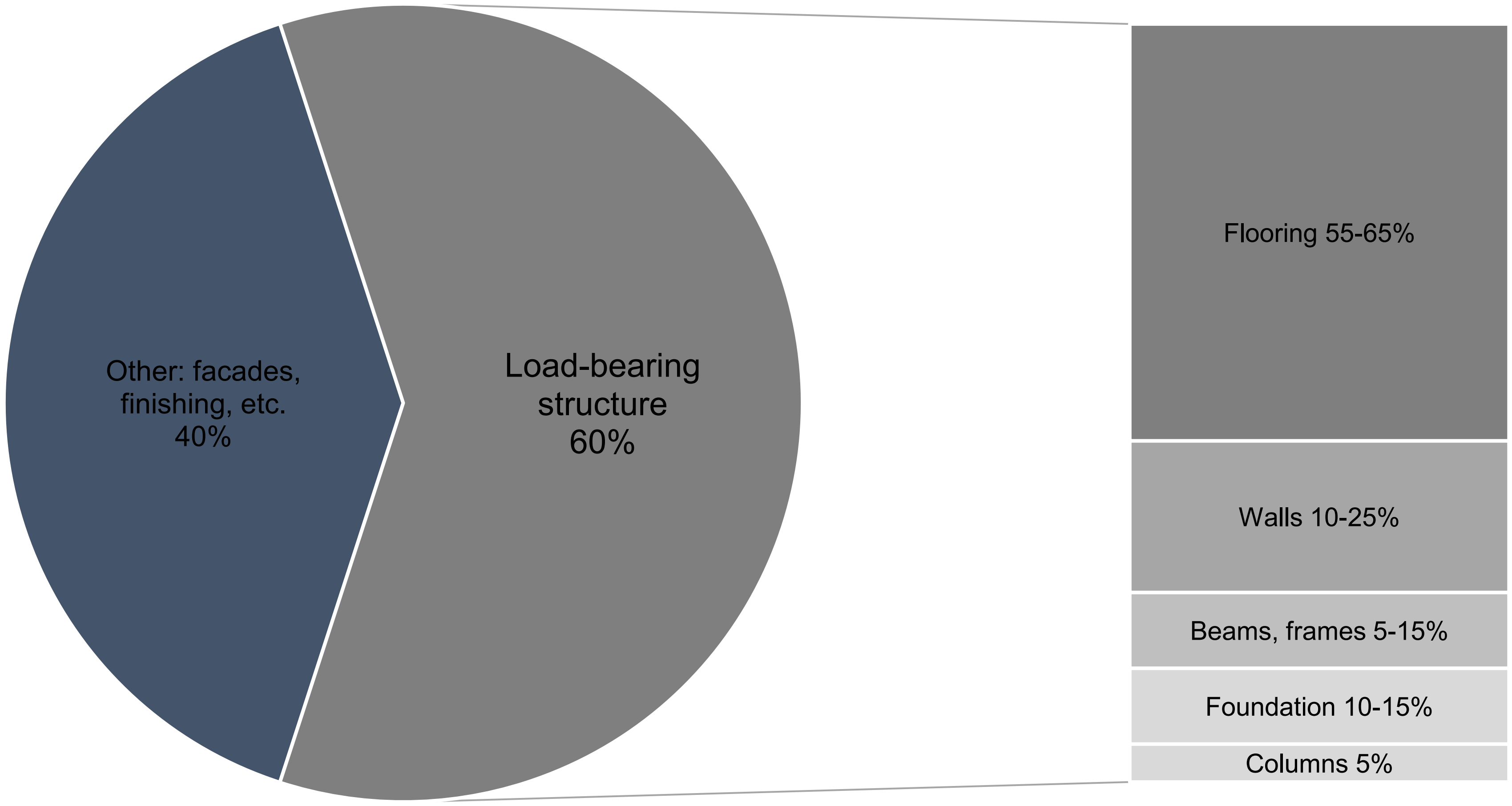
Adaptive Floor Systems

Concrete flat slabs are significantly oversized because the material is not optimally distributed to resist bending from external loads. Floor slabs account for over 50% of the material mass in typical concrete buildings, therefore lightweight systems could greatly reduce construction-related carbon footprints.

Adaptive ribbed slabs use tendons embedded in concrete ribs. These unbonded tendons are controlled by integrated actuators. Since the tendons are eccentric to the axis of the ribs-slab assembly, bending moments are generated that effectively reduce stress and displacements caused by external loads. Active control is required under strong loading events that occur infrequently; therefore, the structure-control system is optimal in terms of mass and energy efficiency. Numerical studies shows that adaptive slab solutions achieves up to **67% material savings compared with an equivalent passive flat slab**.

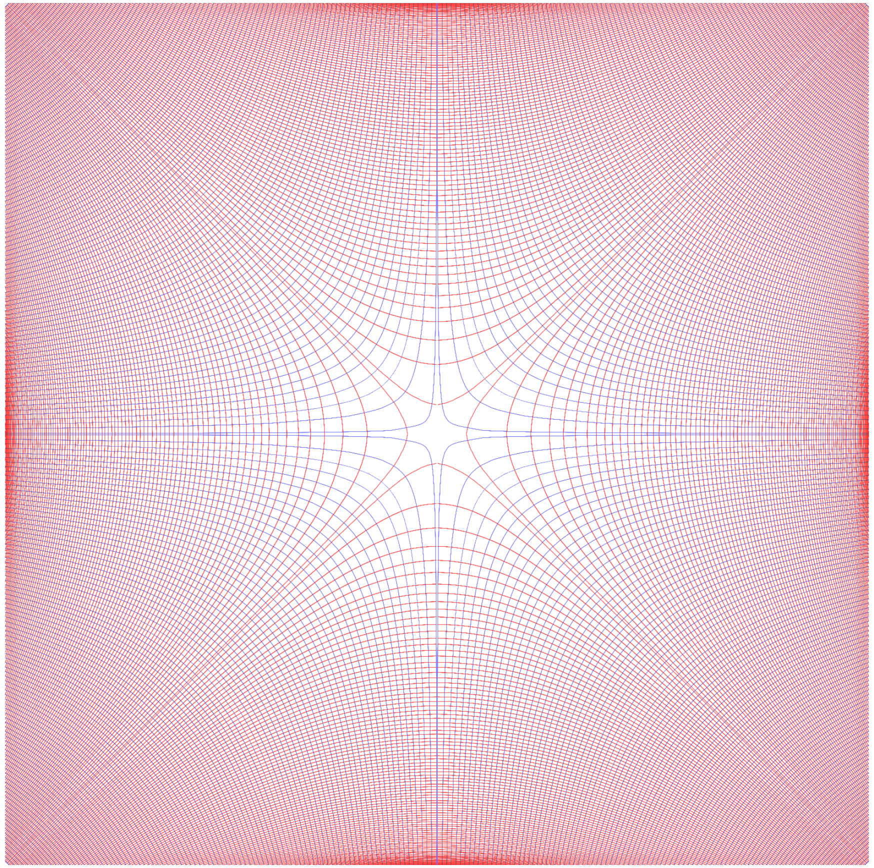
https://www.gennarosenatore.com/research/adaptive_structures/adaptive_floor_systems

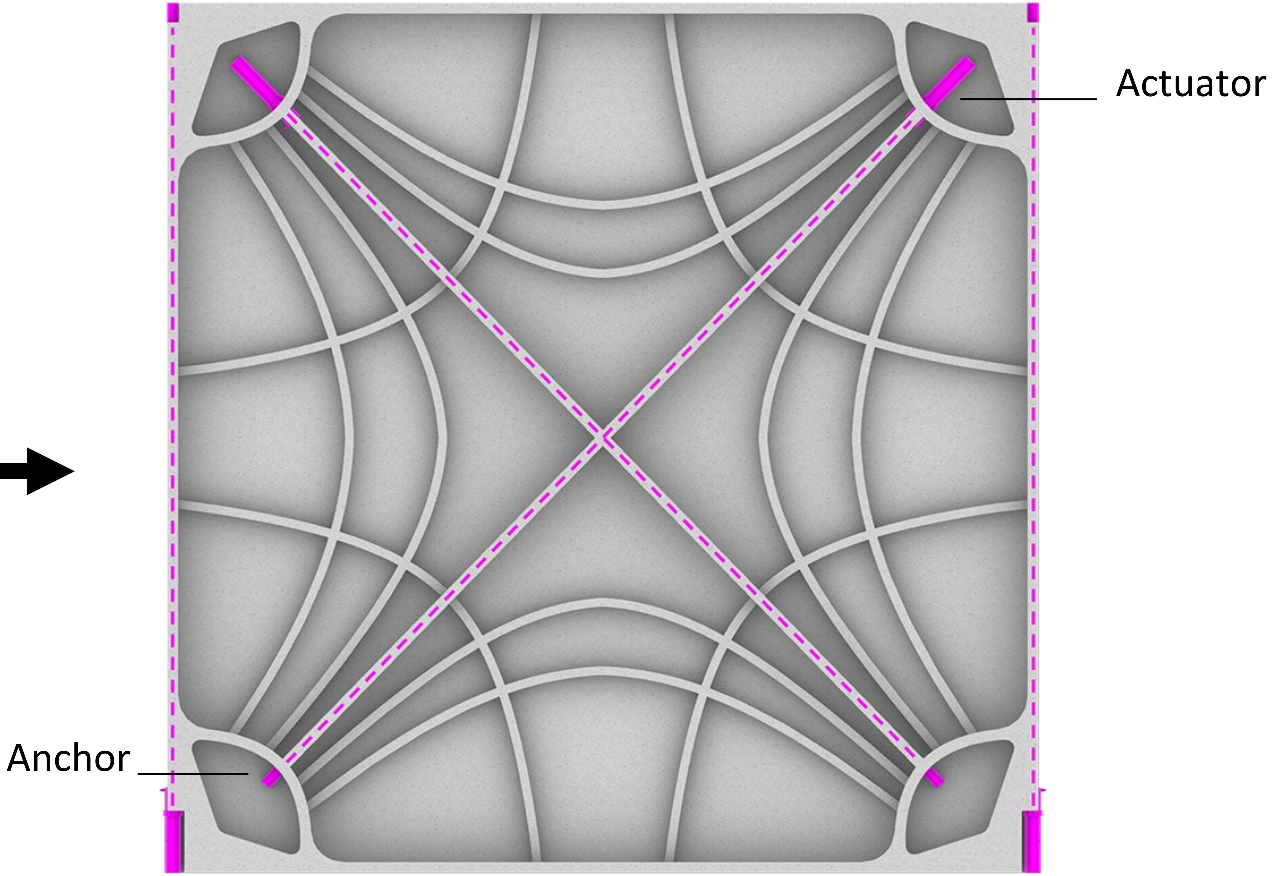
Environmental Impact of Structures per Function



van der Lugt, P., Martin, I.L. and Dufourmont, J., Discussing timber myths: a dialogue between our ambitions and the facts, Amsterdam Institute for Advanced Metropolitan Solutions, 2023.

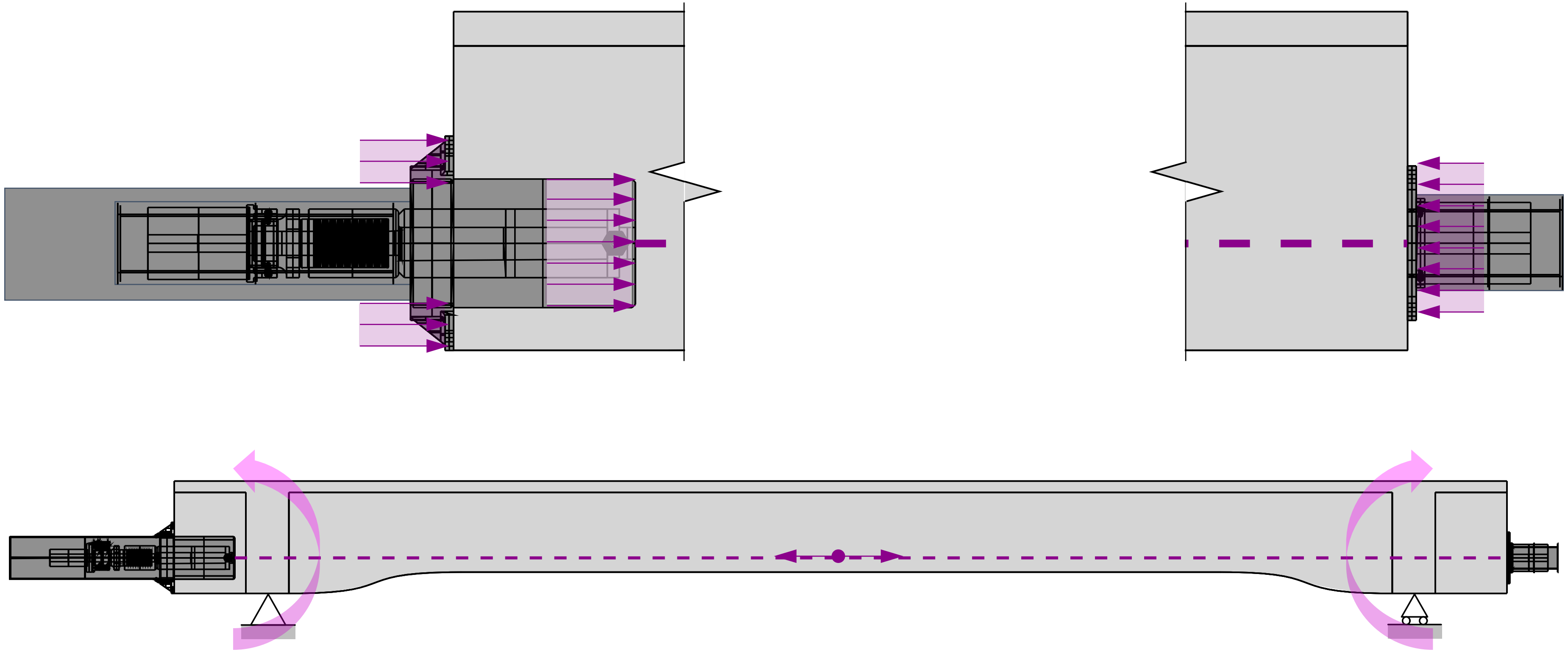
Synthesis of Adaptive Ribbed Floors





Sizing and rib placement obtained through a bilevel optimization process.
Placement of ribs include “passive” and “active” ribs

Active Rib

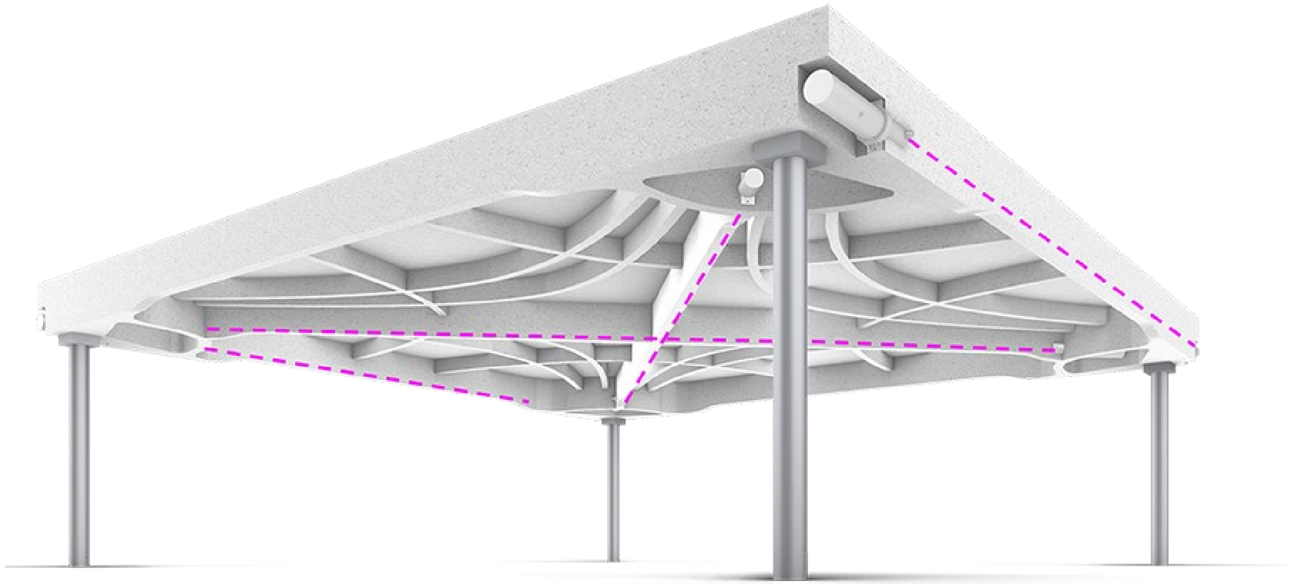


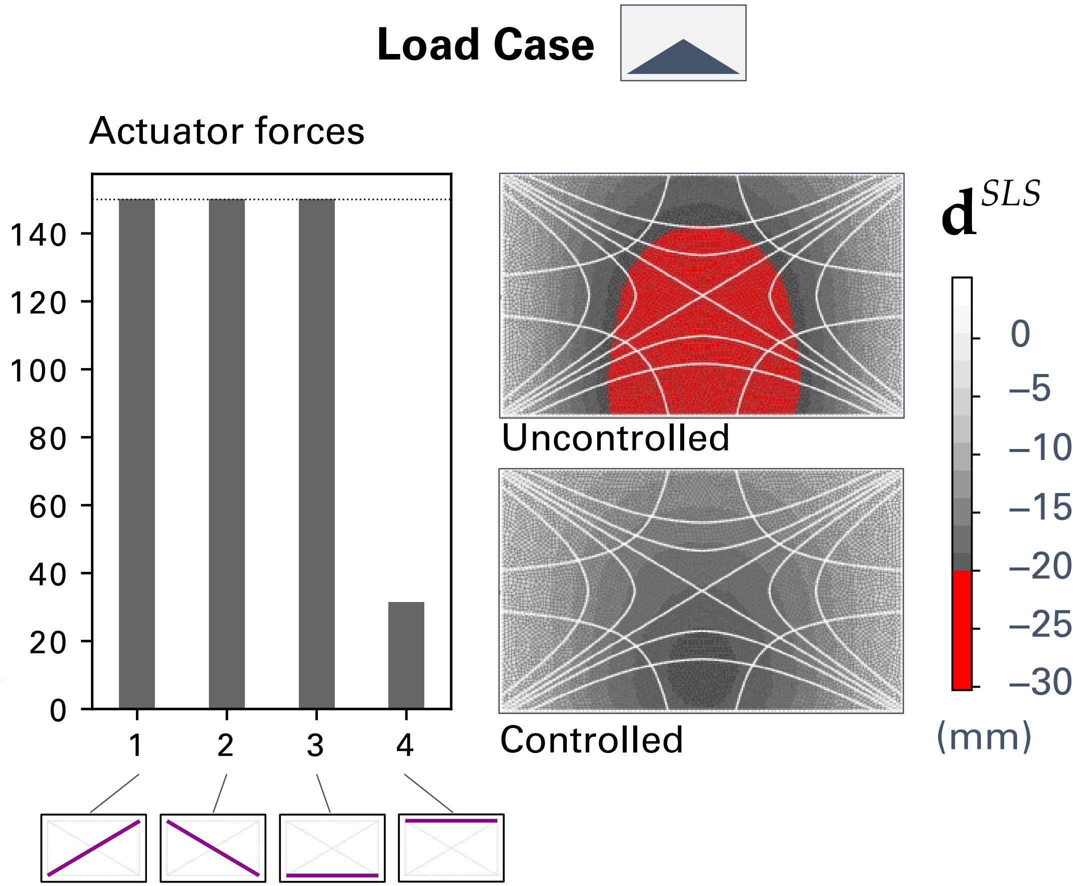
The tension force is applied eccentrically to the neutral axis of the slab-ribs assembly causing a bending moment that counteracts the effect of the external load.

Experimental Validation – Active Rib Prototype

[Video demonstration](#)

Adaptive Ribbed Slab – Controlled Response





A. P. Reksowardojo, G. Senatore, M. Bischoff, and L. Blandini, “Design and Control Benchmark of Rib-Stiffened Concrete Slabs Equipped with an Adaptive Tensioning System,” *Journal of Structural Engineering*, vol. 150, no. 1, p. 04023200, Jan. 2024.

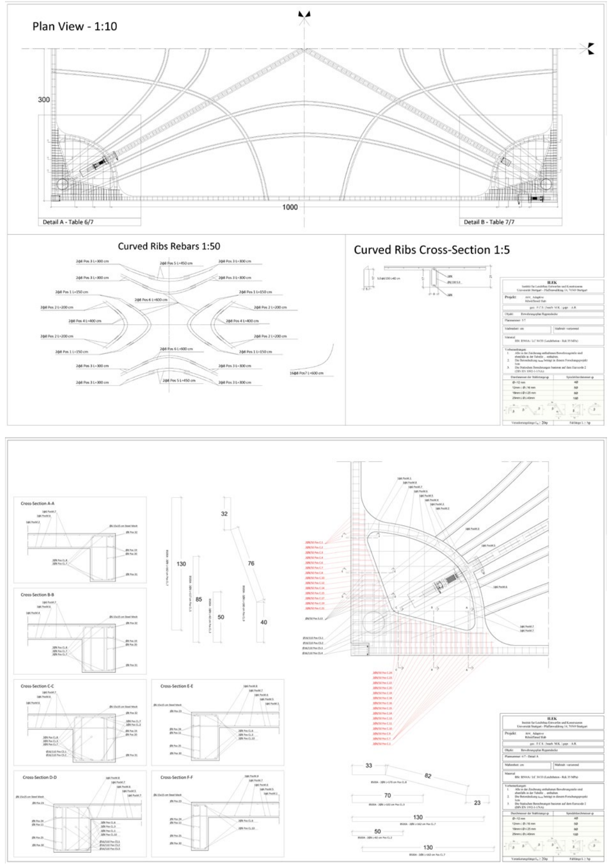
Performance Metric Benchmark

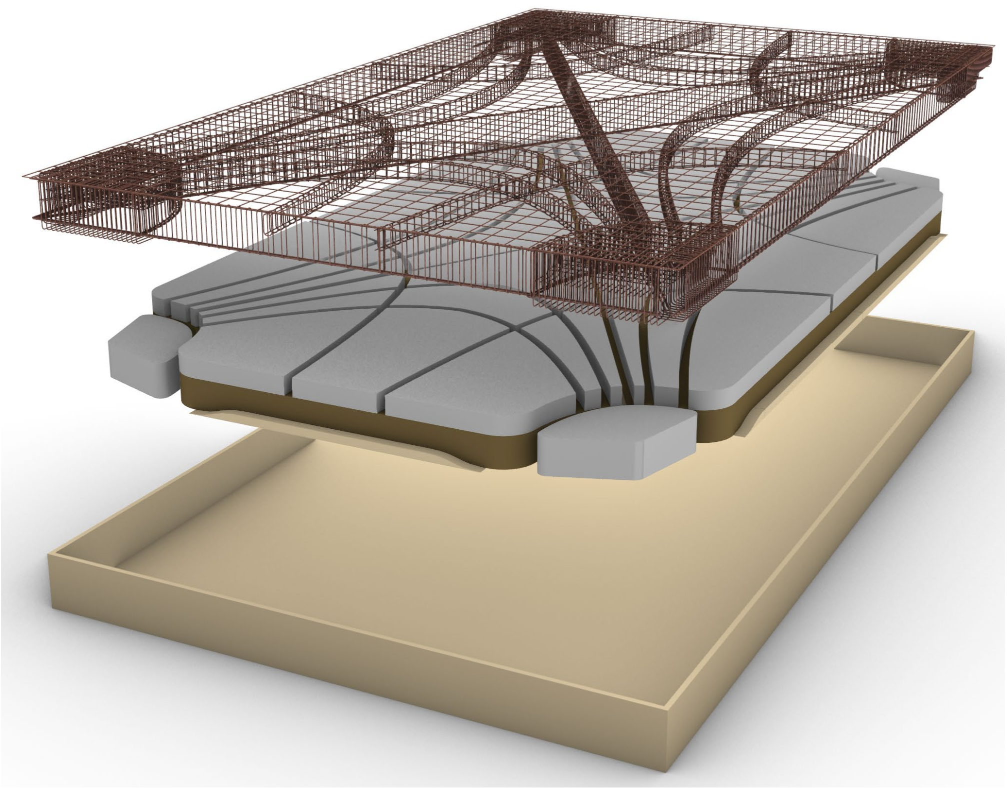
(a) 2022 energy mix in southwest Germany (Energie Baden-Württemberg 2022)

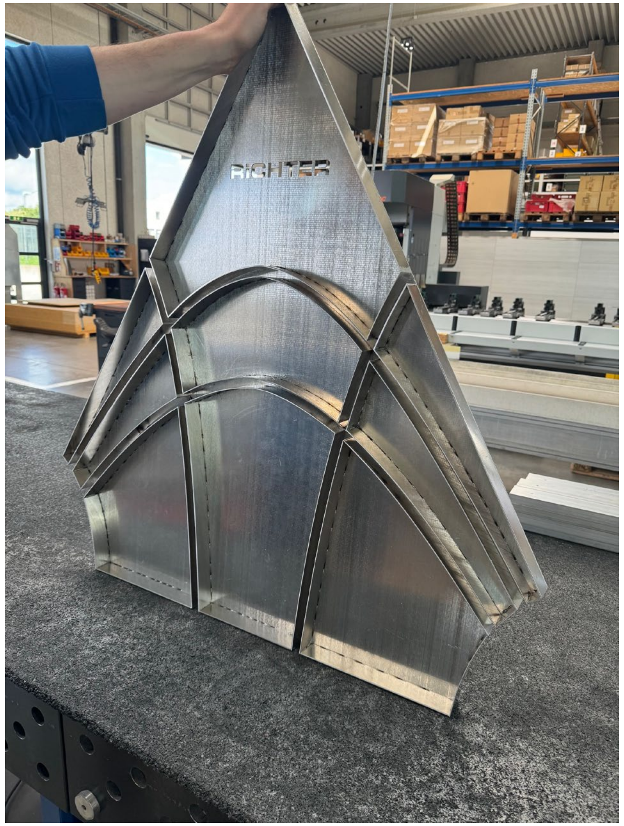
Metric		(1) **Flat − passive**	(2) **Rib-stiffened − passive**	(3) **Voided − passive**	(4) **Rib-stiffened − adaptive**
CO^{em} ($kgCO_2$-eq)		5.308×10^4	4.236×10^4	3.437×10^4	1.662×10^4
CO^{op} ($kgCO_2$-eq)		0	0	0	0.646×10^4
$CO^{em} + CO^{op}$ ($kgCO_2$-eq)		5.308×10^4	4.236×10^4	3.437×10^4	2.308×10^4
Carbon reductions	wrt. (1)	-	20%	35%	57%
	wrt. (2)	-	-	19%	46%
	wrt. (3)	-	-	-	33%

A.P. Reksowardojo, G. Senatore, M. Bischoff, L. Blandini, "Design and control benchmark of rib-stiffened concrete slabs equipped with an adaptive tensioning system," Journal of Structural Engineering (ASCE), vol 150, 2023.

Adaptive Slab Prototype

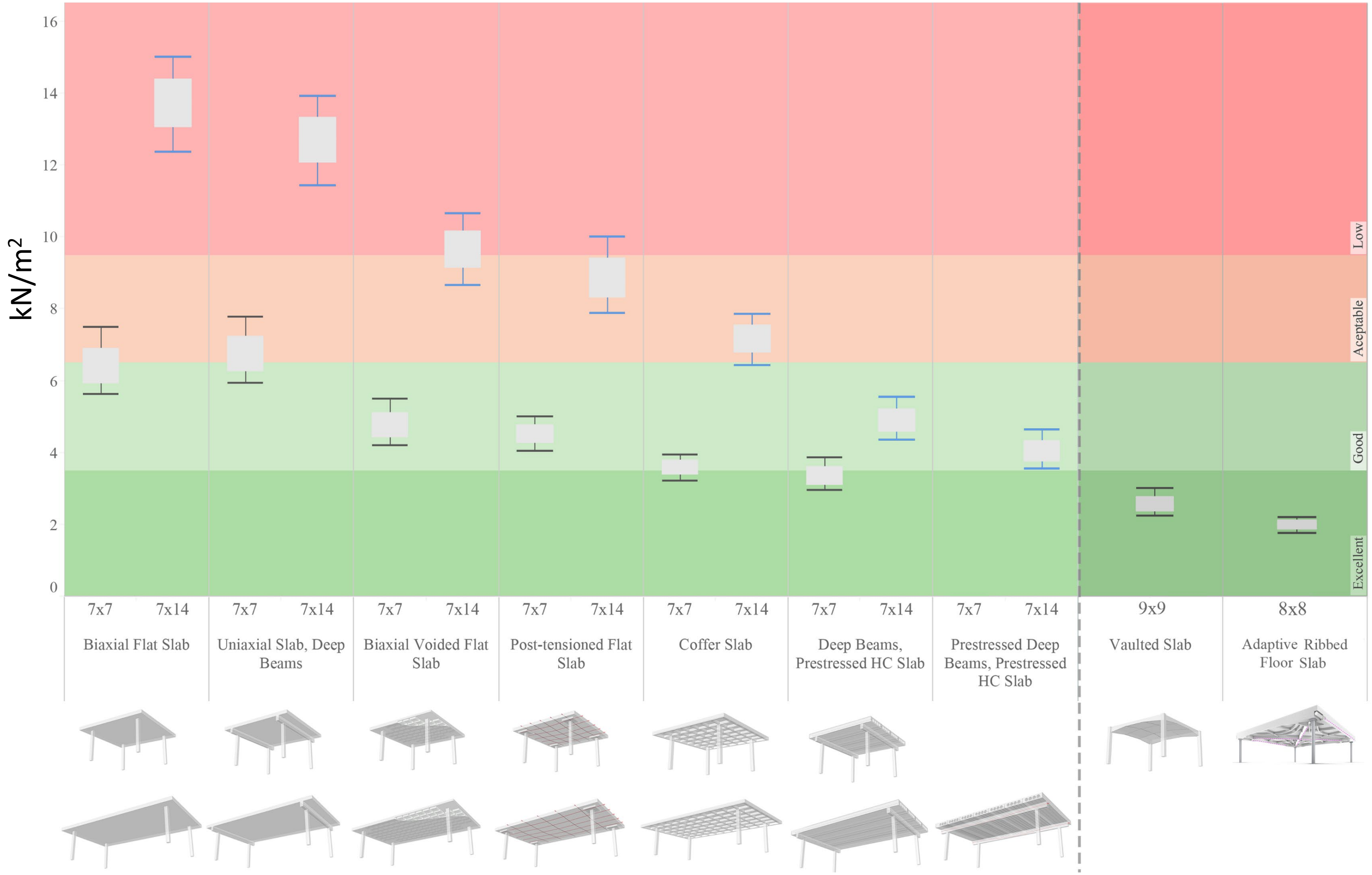






A 10 x 6 m prototype slab is under construction.
The void formers are fabricated through CNC by folding 2 mm aluminum plates

Structural Resource Use Intensity Benchmark – Floor Slabs



P.B. Lourenço, T. Maloutas, M. Santamouris, B. Widera, F. Ansaloni, C. Balaras, I. Katurić, D. Kolokotsa, T. Rossetto, G. **Senatore**, A. Tomaszewicz, E. Medeiros, K. Gkatzogias, D. Pohoryles, E. Romano, "A practical guide to the New European Bauhaus self-assessment method and tool", Joint Research Center – European Commission, 2024.

Vibration Control through Adaptive Stiffness and Damping Components

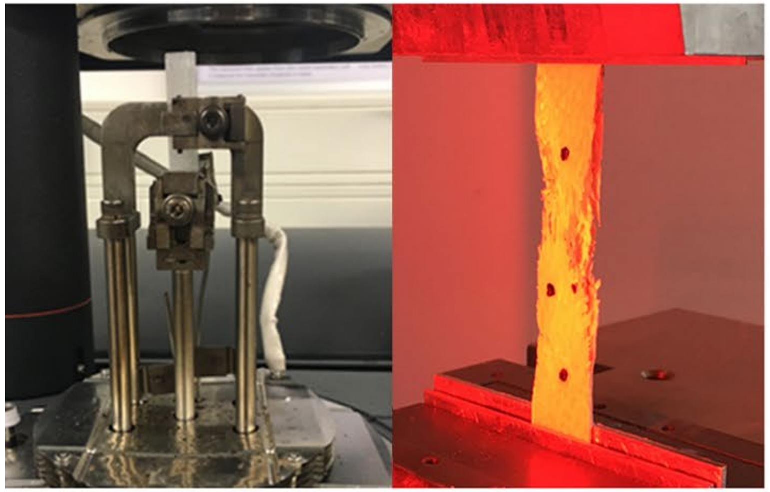
Gennaro Senatore has co-directed the development of an innovative vibration control strategy based on **adaptive stiffness** and **damping** structural components. Such adaptive components are new **semi-active** control devices that can be integrated into most structural systems (multi-story buildings, bridges, roof systems, airplane wings, wind turbine blades, etc.) because they also function as load-bearing elements. Stiffness and damping properties of such adaptive components can be controlled through **thermal actuation** (solid-state) without involving complex mechanisms based on moving parts.

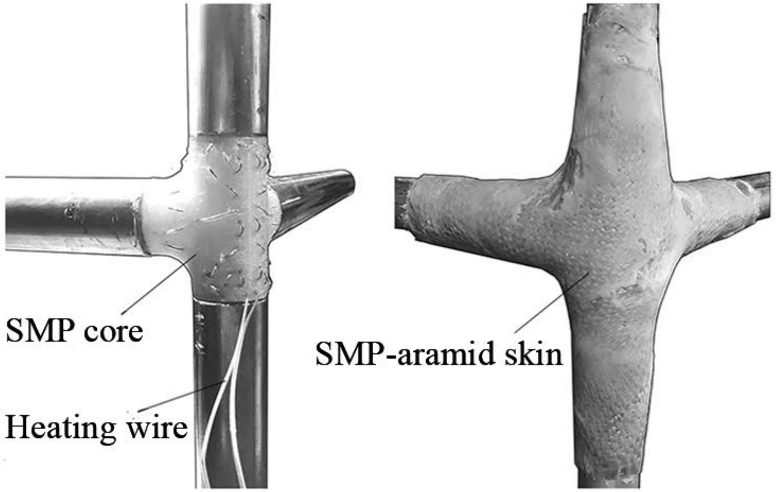
The actuation mechanism is inherent within the properties of the material enabling a reliable control system. Thermal actuation of the adaptive components enables a controlled shift of the structure's natural frequencies and increases the structural damping ratio, which can effectively reduce the dynamic response of structures under a wide range of conditions including harmonic loading, earthquakes and pedestrian/vehicular traffic.

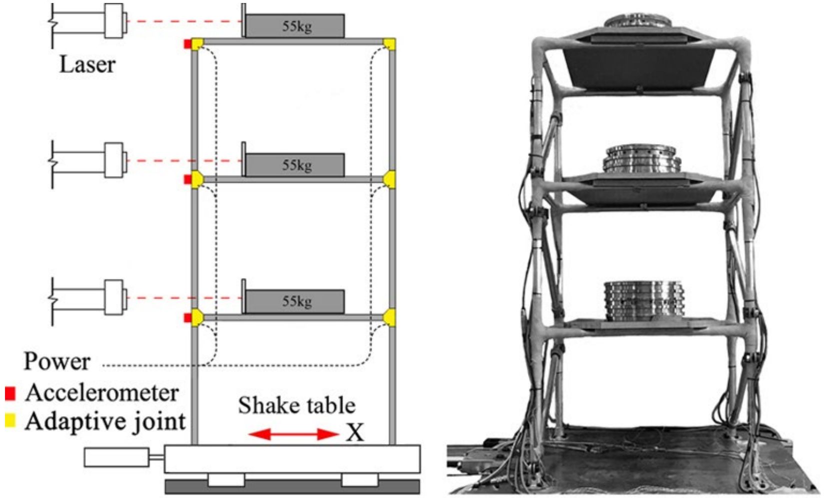
https://www.gennarosenatore.com/research/adaptive_structures/vibration_control_through_variable_stiffness_and_damping_structural_components

Semi-Active Response Control through Frequency and Damping Shift

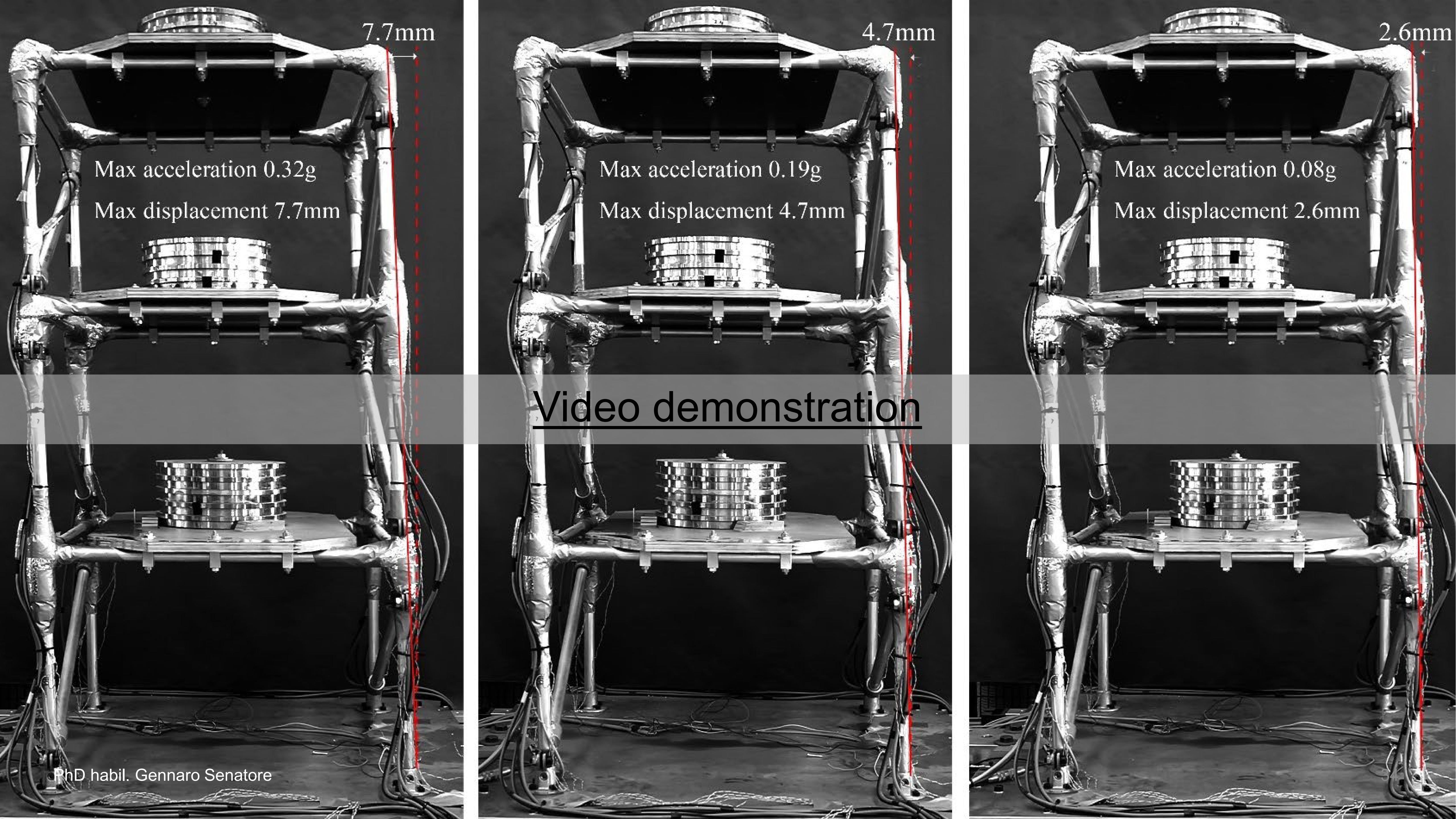
Material	Component	Structure
Glass-to-rubber transition through thermal actuation	Component stiffness reduction Increase of material damping	Frequency shift Increase of structural damping







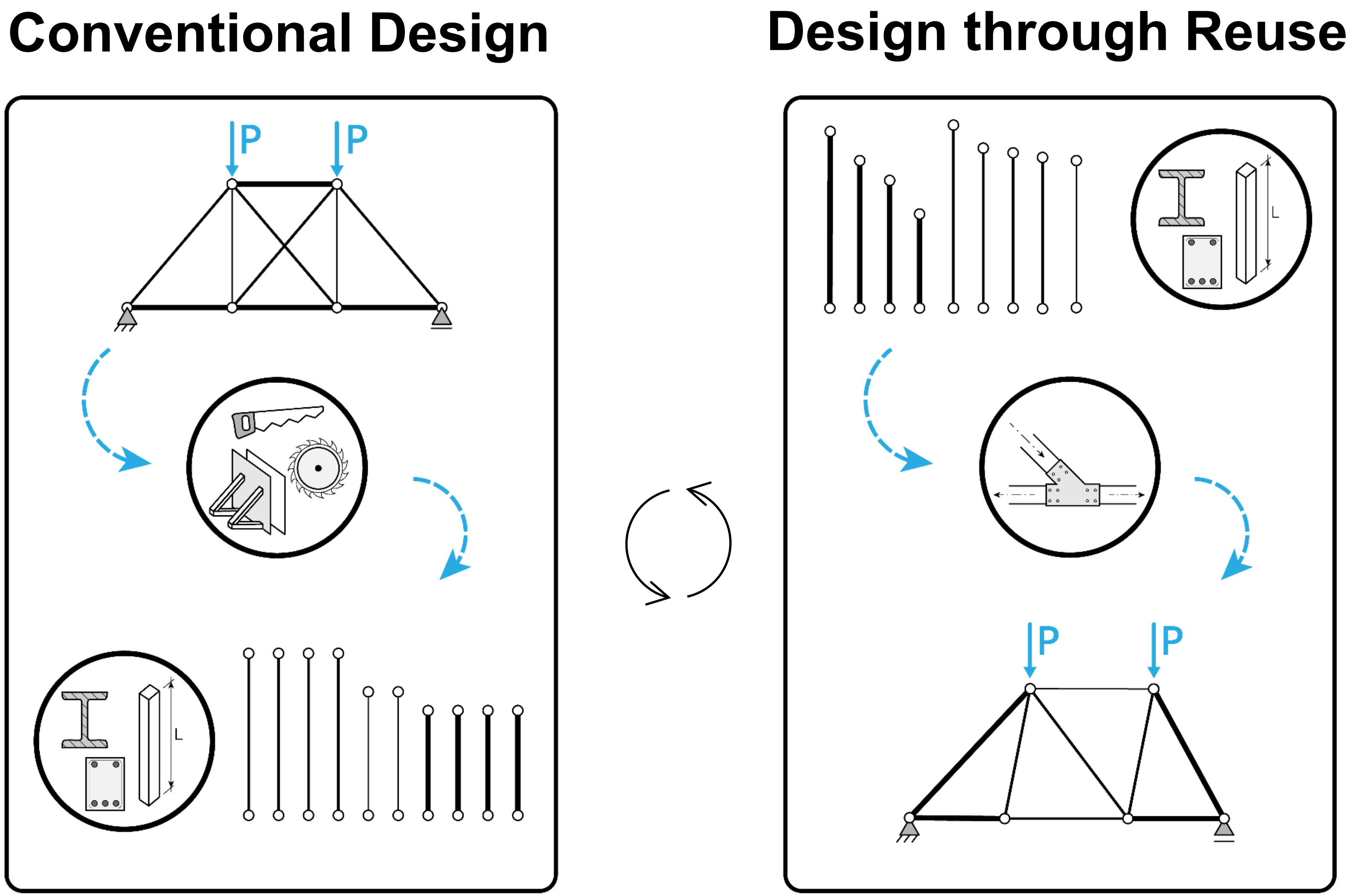
Q. Wang, G. Senatore, K. Jansen, A. Habraken et P. Teuffel, "Design and characterization of variable stiffness structural joints," Materials & Design, vol. 187, p. 108353, 2020.


7.7mm
Max acceleration 0.32g
Max displacement 7.7mm
4.7mm
Max acceleration 0.19g
Max displacement 4.7mm
2.6mm
Max acceleration 0.08g
Max displacement 2.6mm
Video demonstration
PhD habil. Gennaro Senatore

Design of Structures through Reuse

Gennaro Senatore co-directed the development of a new computational methodology to design structures through **reuse**. In line with circular economy principles, the existing building stock could be thought of as a large source of available construction materials. In this context, an effective strategy to reduce structures' adverse environmental impacts (EI) is to **reuse components over multiple service cycles**, which avoids the use of material resources, reduces energy for reprocessing and waste production. **Discrete structural optimization** techniques have been formulated to design spatial trusses and frames that make the best use of a stock of reclaimed structural elements (e.g. obtained from demolished structures). The objective is the minimization of EI through optimization of stock element assignment and partitioning as well as the structure topology and geometry subject to typical strength and deflection requirements.

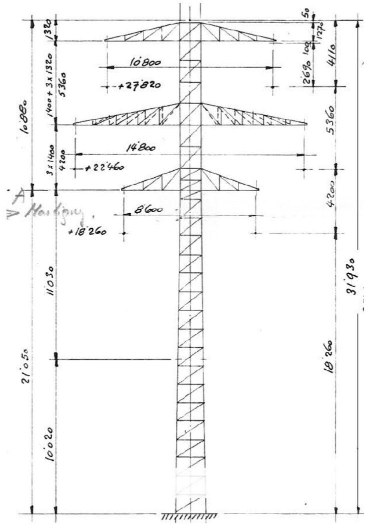
www.gennarosenatore.com/research/design_of_structures_through_reuse

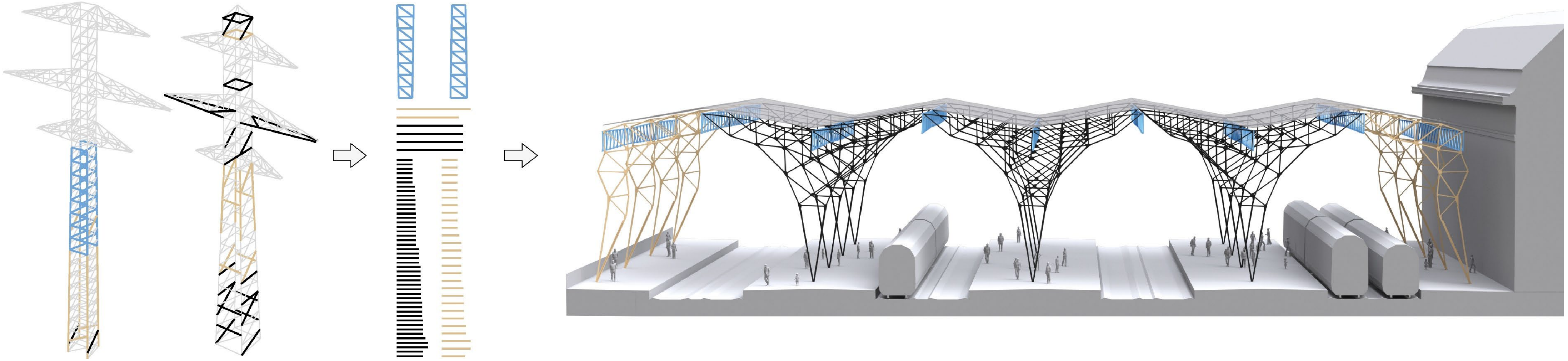


[Video demonstration](#)

J. Brütting, "Optimum design of low environmental impact structures through component reuse," Ph.D. dissertation, EPFL, 2020.

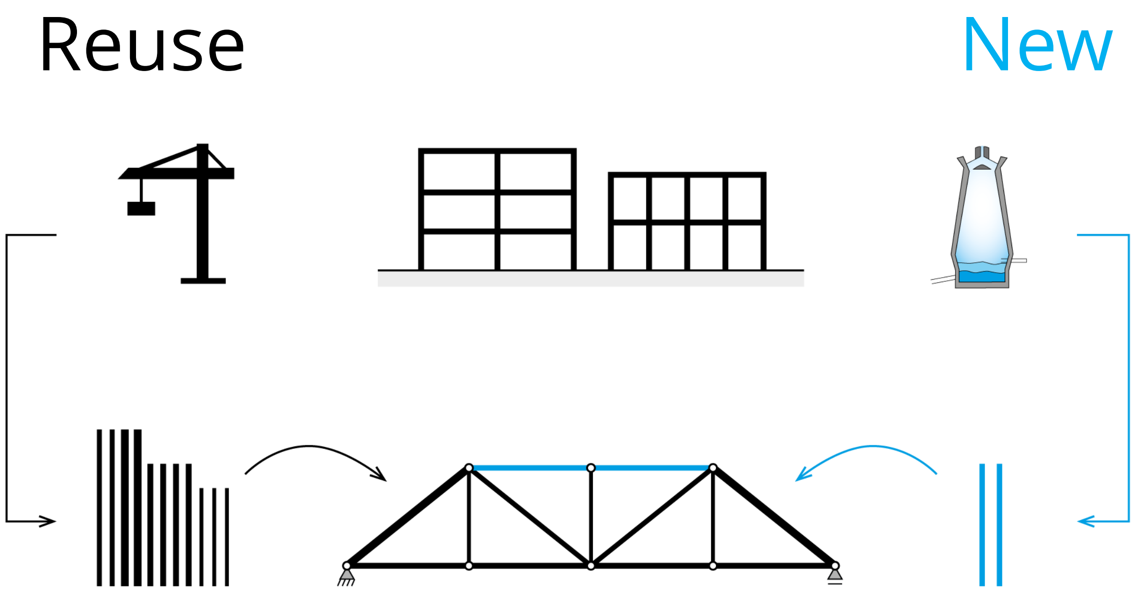
Stock-Constrained Structural Optimization

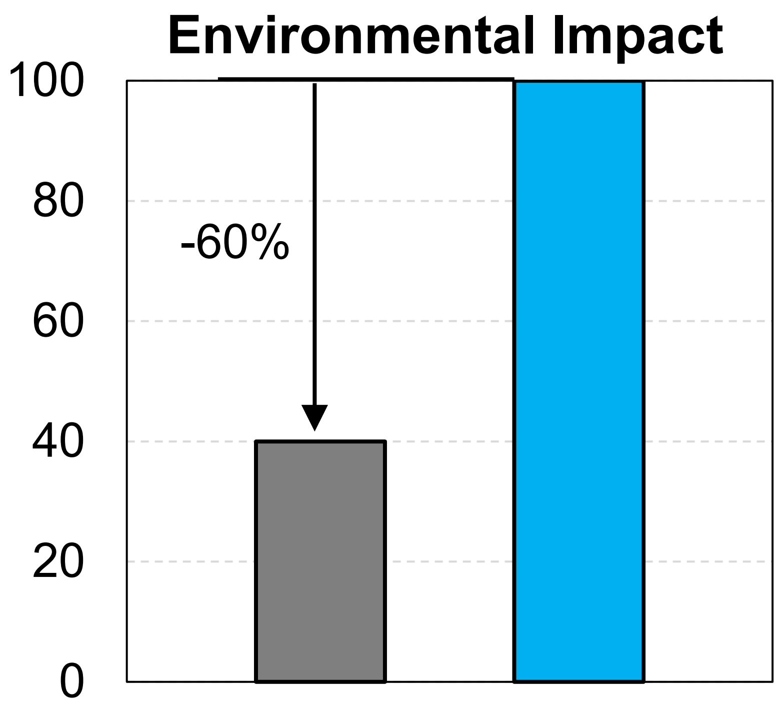




J. Brütting, J. Desruelle, G. Senatore and C. Fivet, "Design of Truss Structures through Reuse," *Structures,* vol. 18, pp. 128-137, 2019.

Environmental Impact Benchmark





Reuse + Optimization → reduce EI significantly

The combination of reuse and new elements produces structures of least environmental impact (EI)

J. Brütting, C. Vandervaeren, G. Senatore, N. De Temmerman and C. Fivet, "Environmental impact minimization of load-bearing structures made from reused and new elements," *Energy and Buildings*, vol. 215, p. 109827, 2020

Interactive Structural Analysis and Design

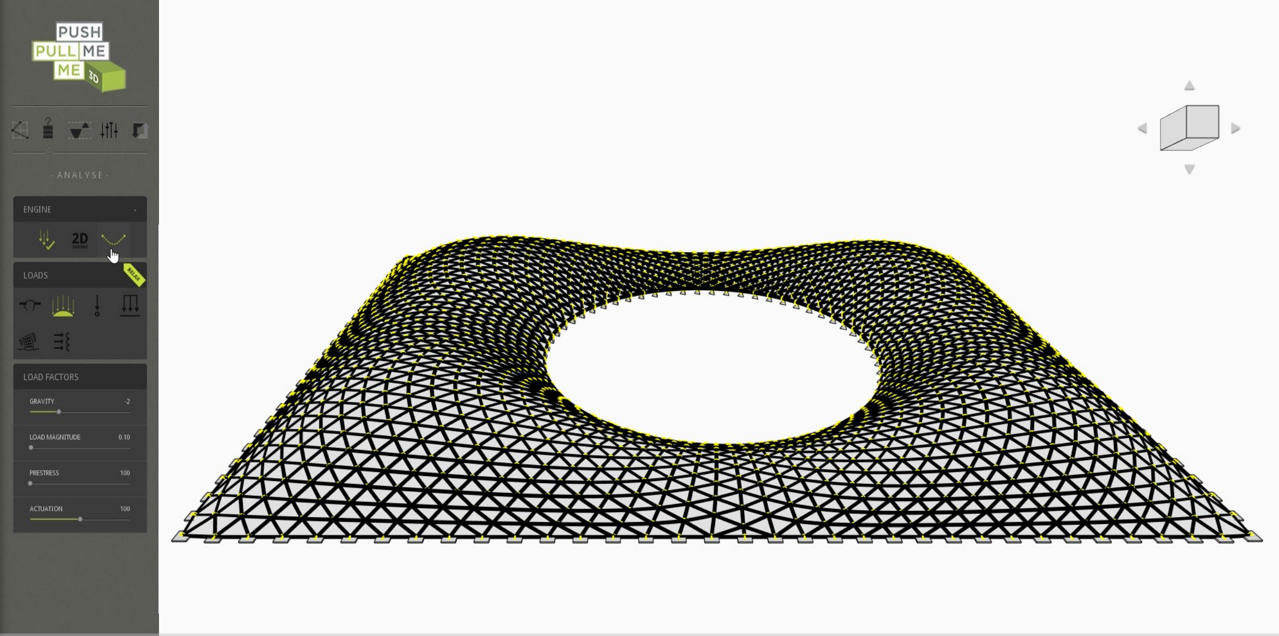
Real-time physics simulation has been widely used in computer games, but its full potential in engineering design and education remains underexplored. By integrating computational techniques from computer graphics with established numerical methods for structural analysis, an interactive platform emerges—allowing students and designers to develop both qualitative and quantitative insights into structural behavior. Real-time feedback and interactive modeling offer significant advantages in teaching, making complex structural concepts more intuitive and engaging.

PushMePullMe is an interactive physics engine developed by Gennaro Senatore to support teaching in structural mechanics and design. It employs a **vector-form finite element method**, combining the **dynamic relaxation method** with the **co-rotational formulation** to analyze structures exhibiting geometric non-linearity. The software accounts for element and global buckling, enabling users to explore advanced tasks such as form-finding through **shape and topology optimization** in real time.

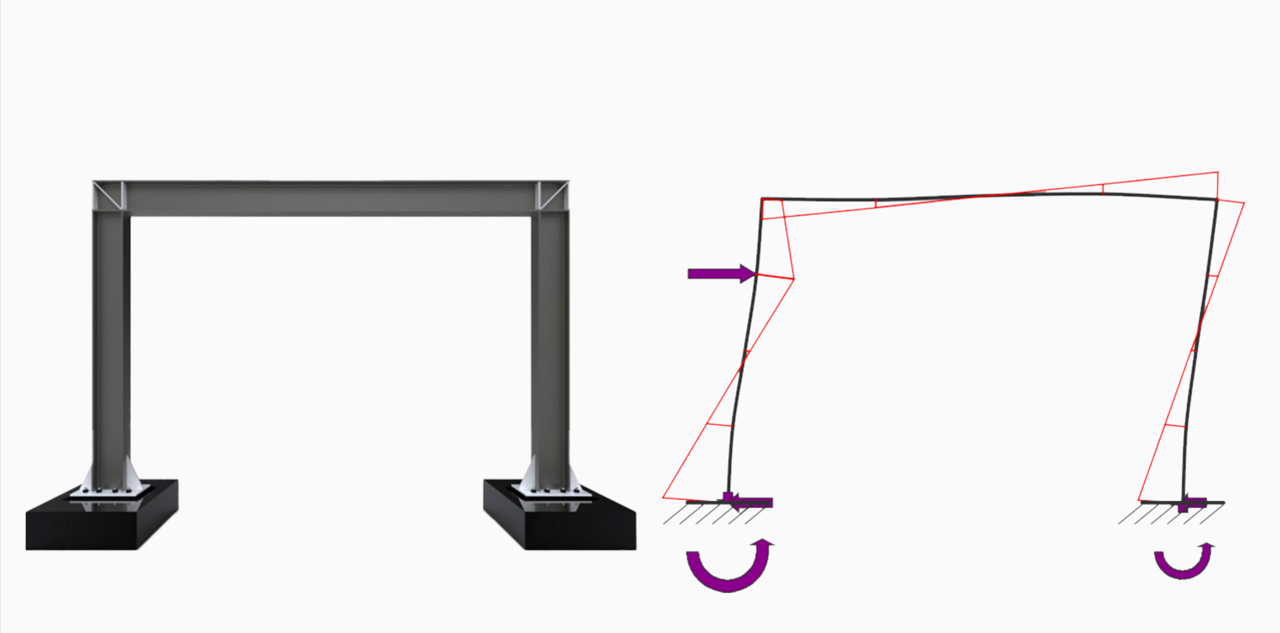
Users can manipulate structural models interactively—pushing and pulling with a mouse or touch interface—while stress distributions and deformations are visualized instantly. The intuitive interface makes the software accessible even to those with no prior structural engineering experience. PushMePullMe has been widely adopted by educators worldwide, enhancing the learning experience by bridging theoretical concepts with hands-on experimentation.

https://www.gennarosenatore.com/teaching/

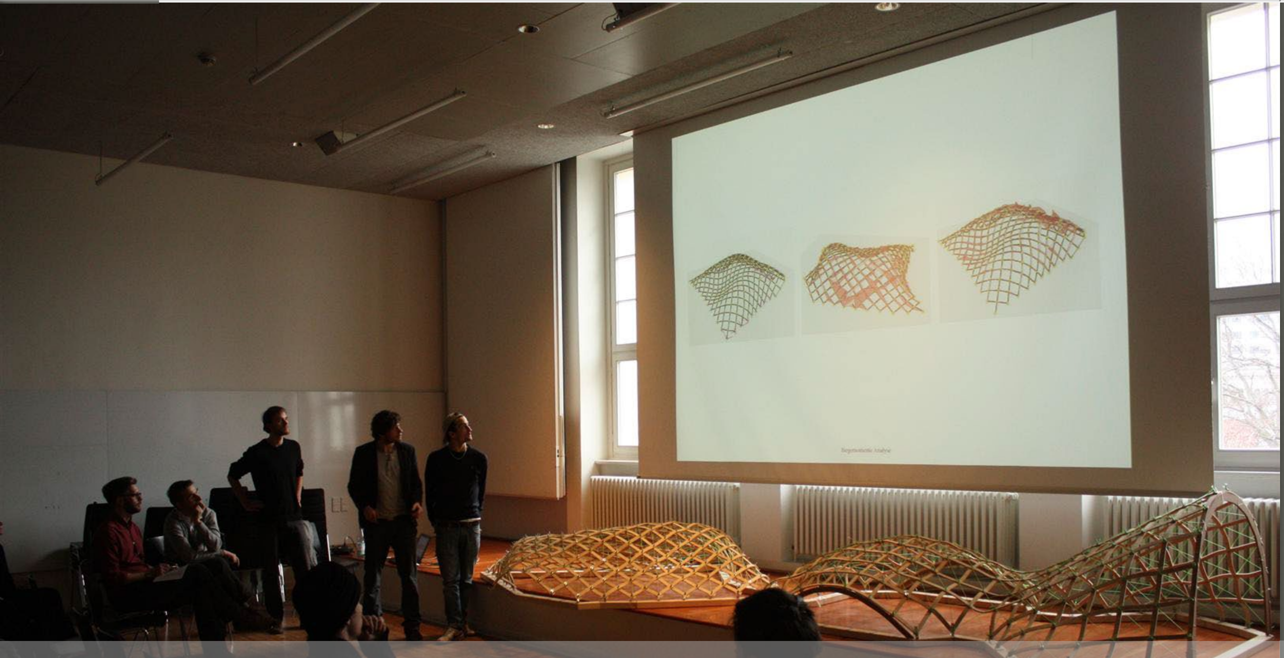
Software download at https://www.gennarosenatore.com/research/push_me_pull_me_3d



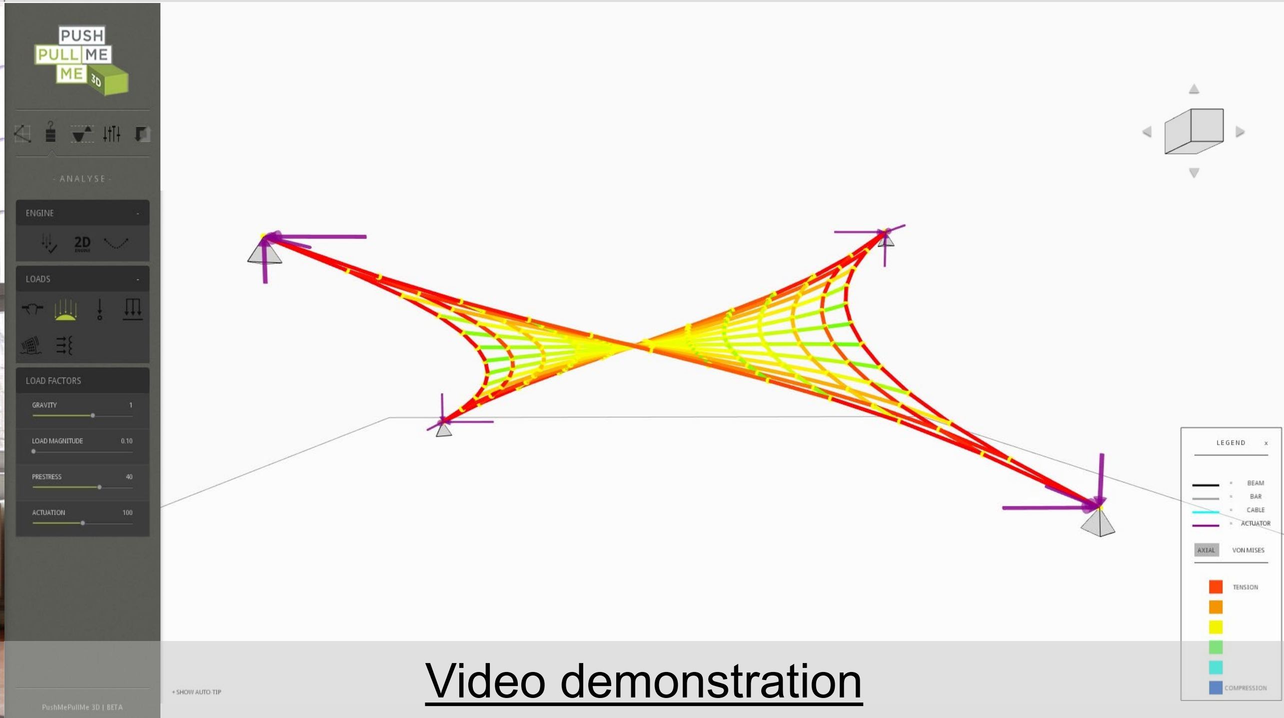
Video demonstration



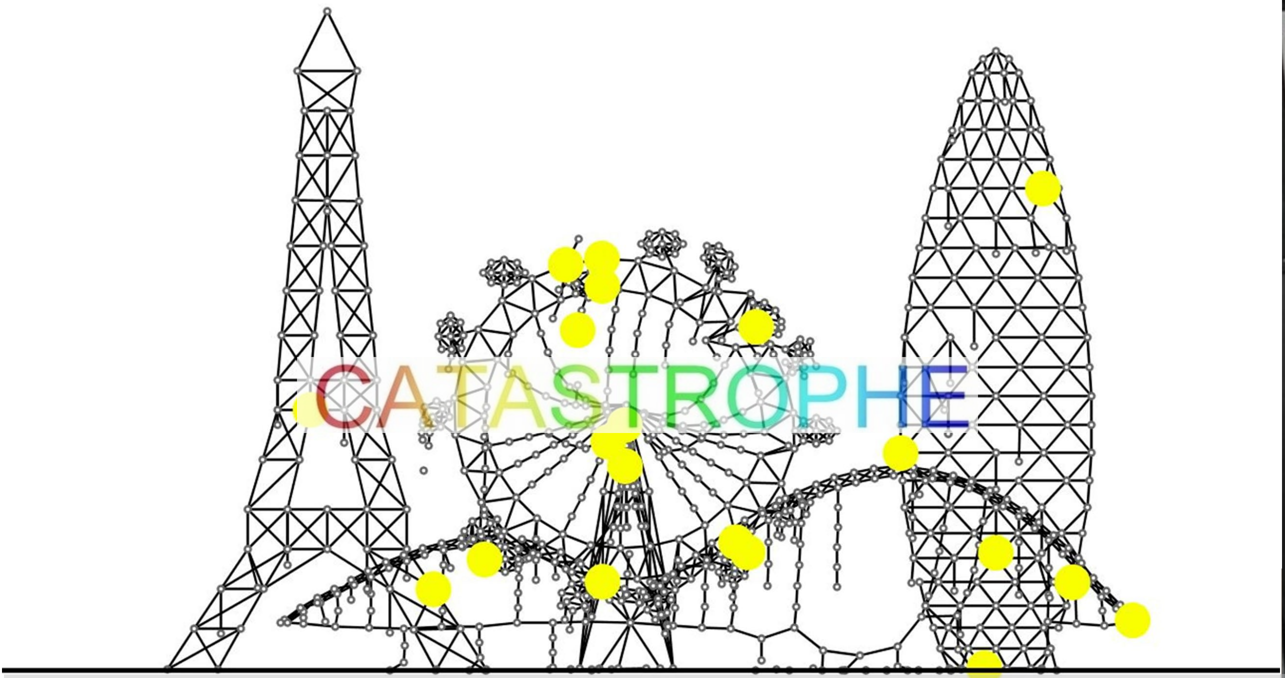
Video demonstration



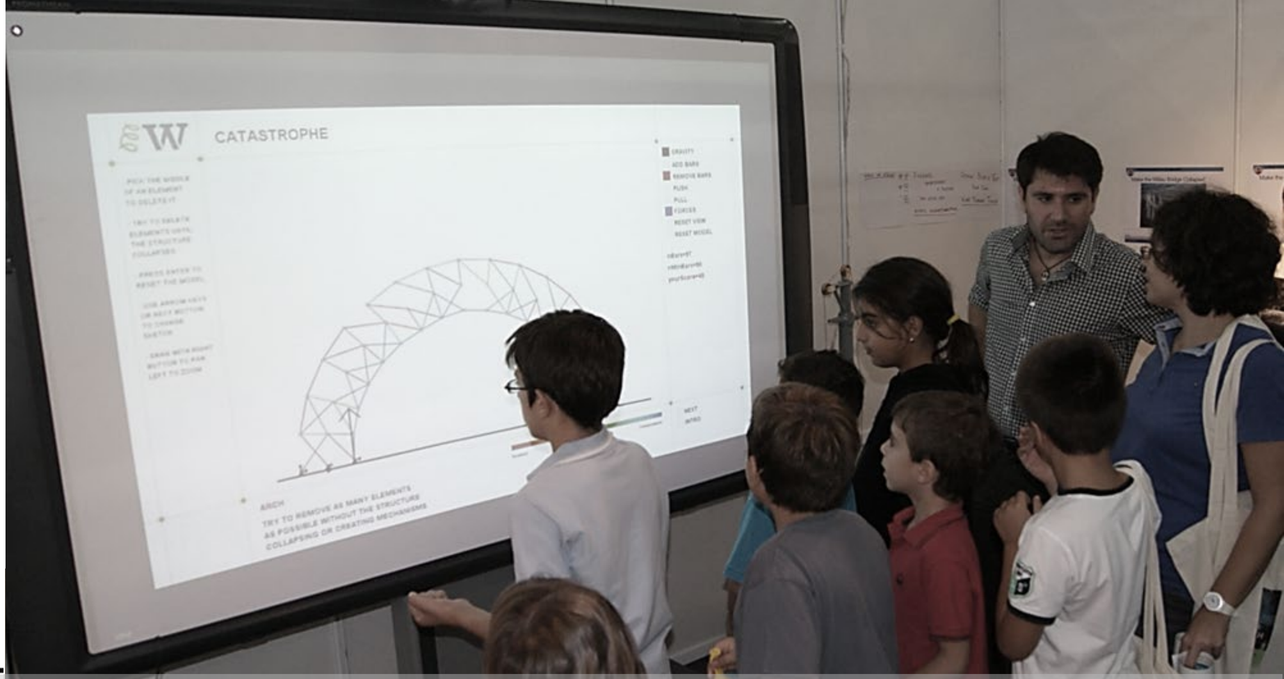
Workshop - Berlin University of the Arts



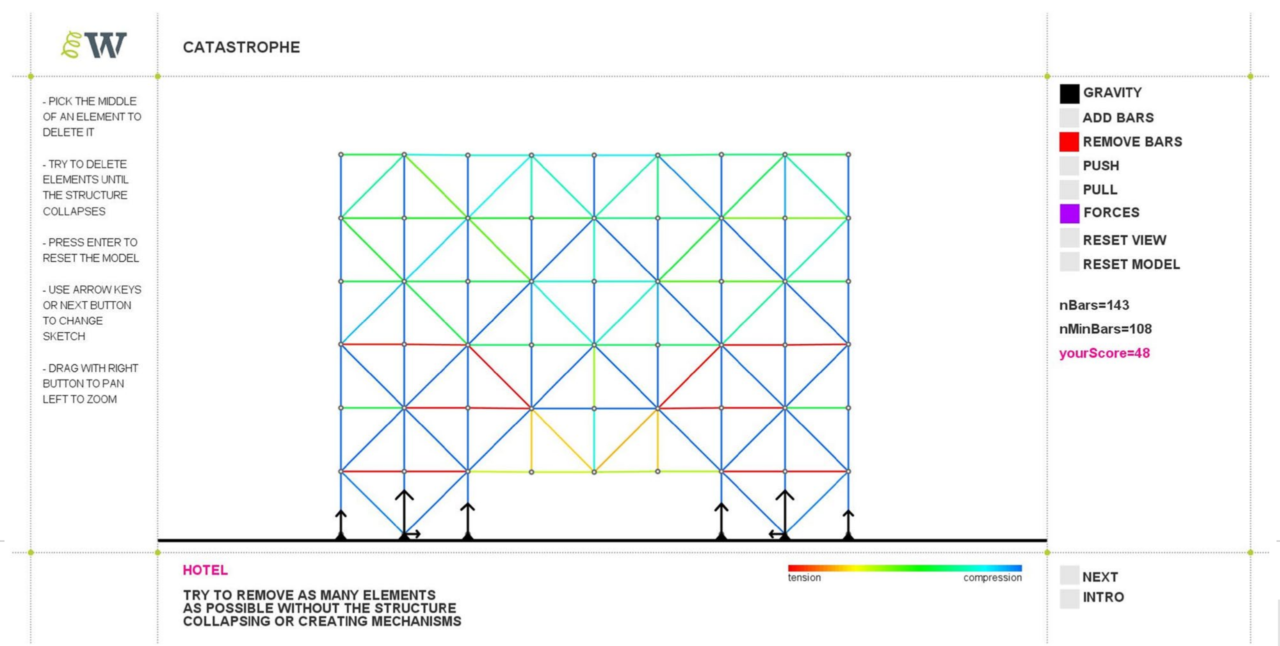
Video demonstration



Video demonstration

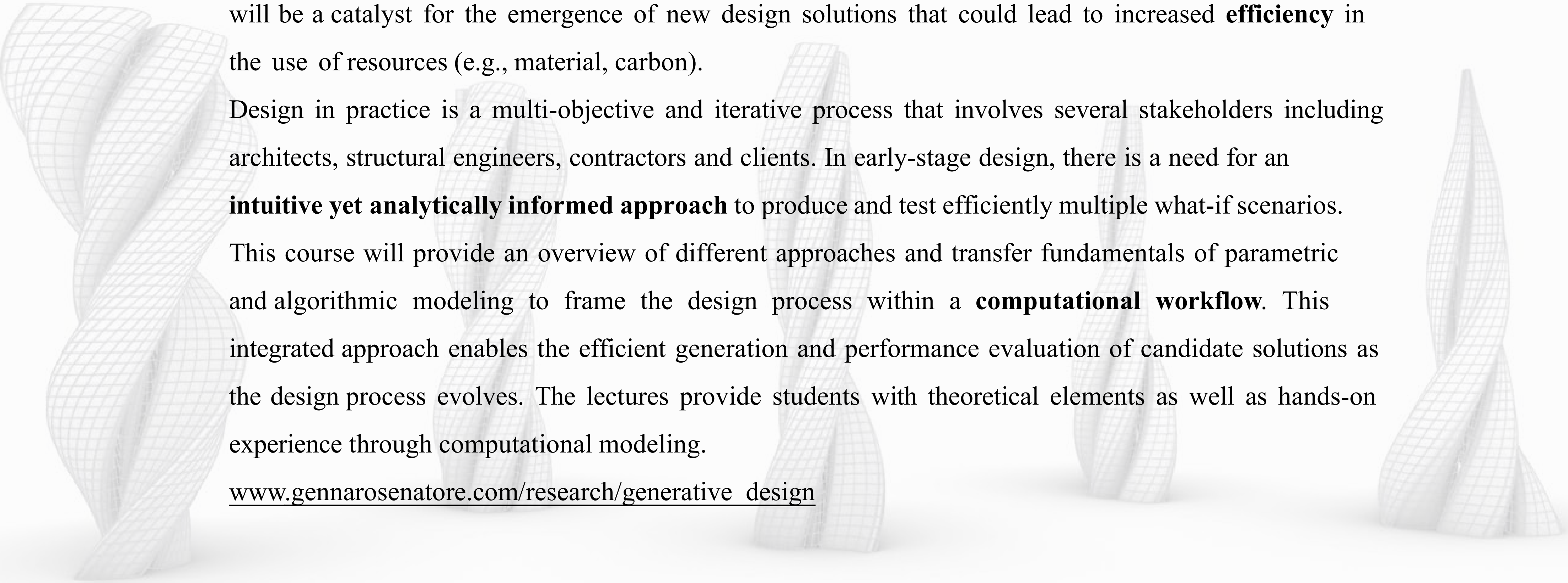


Workshop – University of Cyprus



Workshop – University of East Anglia

Computational Design



Digital technologies are a strategic asset to produce innovation in the building sector. Well-reasoned adoption of modern computer-aided-design software and hardware will improve productivity and will be a catalyst for the emergence of new design solutions that could lead to increased **efficiency** in the use of resources (e.g., material, carbon).

Design in practice is a multi-objective and iterative process that involves several stakeholders including architects, structural engineers, contractors and clients. In early-stage design, there is a need for an **intuitive yet analytically informed approach** to produce and test efficiently multiple what-if scenarios.

This course will provide an overview of different approaches and transfer fundamentals of parametric and algorithmic modeling to frame the design process within a **computational workflow**. This integrated approach enables the efficient generation and performance evaluation of candidate solutions as the design process evolves. The lectures provide students with theoretical elements as well as hands-on experience through computational modeling.

www.gennarosenatore.com/research/generative_design

Geometry Definition + Structural Analysis Feedback

Main

Computational workflow to generate the structure of a multi-story building, apply geometrical variations including floor rotation, height and floor area scaling.
Prepare the model for structural analysis sorting geometric components by columns, floor beams and bracing per floor.
Prepare the model for daylight analysis sorting geometric components by floor slab (surface), celing (surface), workplane (surface), and facade mesh panels (windows)

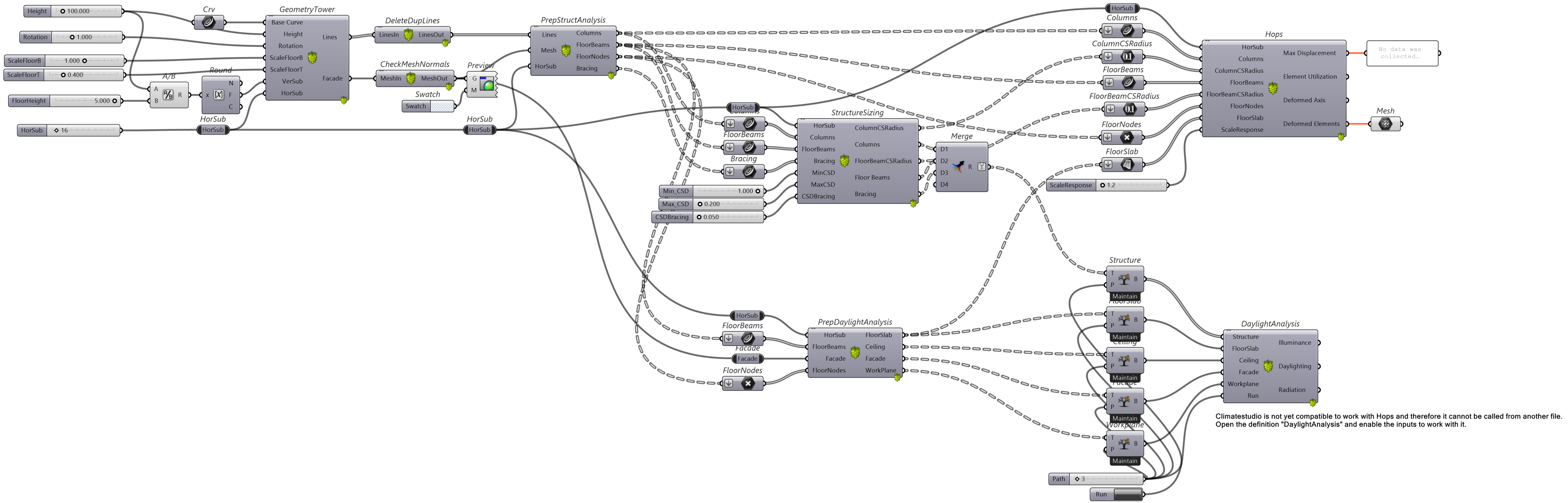
This workflow makes use of "Hops components" to subdivide the model into sub-tasks:
1. geometry generation
2. preparation for analysis
3. analysis

A hop component is practically a method (function) that takes inputs and gives outputs just like any other component in Grasshopper.
However, it is user-defined and it can be called from any other Grasshopper definition by setting the file path as one of the inputs.
This is a good way to manage the complexity of the algorithm by subdividing it into smaller parts.

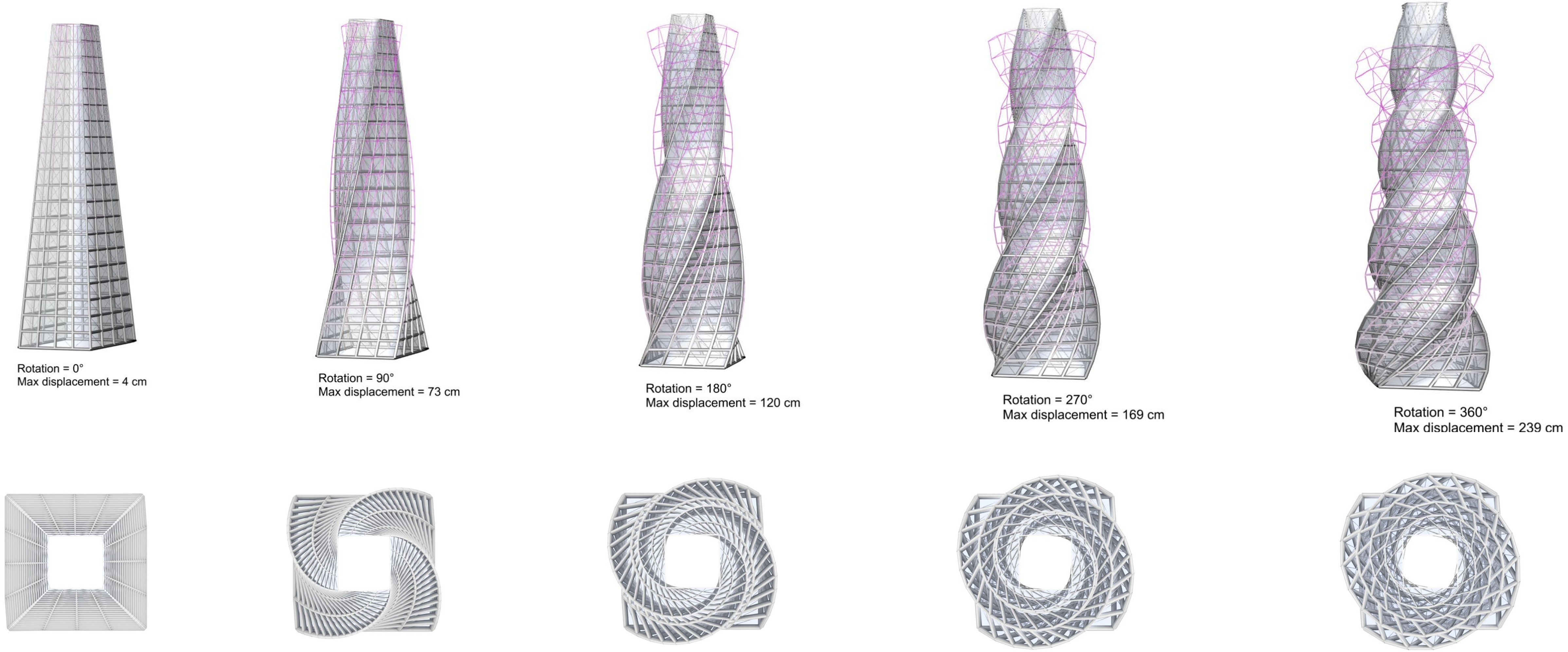
The input of a hops component can be set to single value, list and data tree. When set as a single value, the method will be applied on
each input separately. If it the input is set as a list, the whole list will be taken as input. To make hops undertand that the input is a list, set the

When the input is a data tree, each branch in the data tree will be interpreted as a separate list input. This means that if the input is organized
as a data tree, and the method (hop component) has to work with the whole data tree, the input must be flattened into a list outside the hop component
and then re-partioned into a data tree inside the hop component.

Further information about Hops components at https://developer.rhino3d.com/guides/compute/hops-component/



Maximum Displacement vs Rotation Variation



Publications

www.gennarosenatore.com/publications

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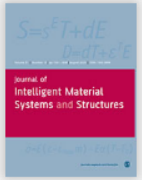
DOI



G. Senatore, F. Virgili, and L. Blandini, "Global Optimal Actuator Placement for Adaptive Structures: New Formulation and Benchmarking," Journal of Intelligent Material Systems and Structures, 2025.

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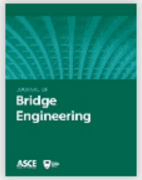

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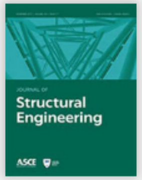

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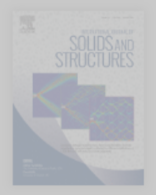

A. P. Reksowardojo, G. Senatore, A. Srivastava, C. Carroll and I. F. C. Smith, "Design and testing of a low-energy and -carbon prototype structure that adapts to loading through shape morphing," *International Journal of Solids and Structures*, vol. 252, p. 111629, 2022.

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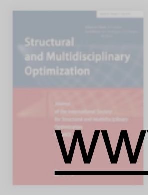

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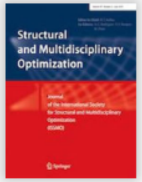

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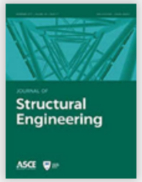

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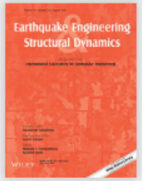

Q. Wang, G. Senatore, K. Jansen, A. Habraken and P. Teuffel, "Seismic Control Performance of a 3-Story Frame Prototype Equipped with Semi-Active Variable Stiffness and Damping Structural Joints," *Earthquake Engineering and Structural Dynamics*, 2021.

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Q. Wang, G. Senatore, K. Jansen, A. Habraken and P. Teuffel, "Multi-Scale Experimental Testing On Variable Stiffness And Damping Components For Semi-Active Structural Control," *Composite Structures*, p. 114976, 2021.

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