Adaptive structures cut down the carbon footprint of buildings

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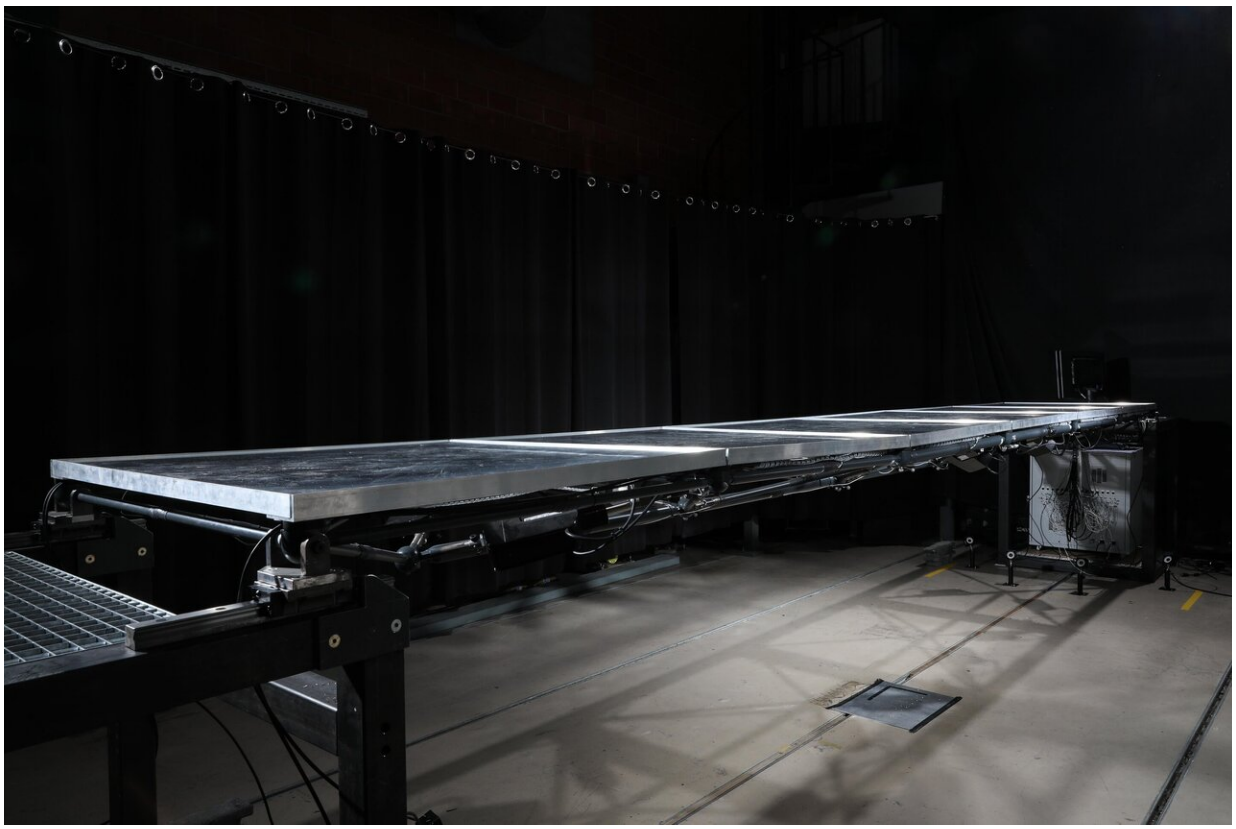


Credit: EPFL / Alain Herzog

Scientists at EPFL have developed new methods to design and control civil structures that are able to automatically adapt to loading. The aim is to reduce the environmental impact of the construction sector.

In order to address current environmental challenges, the construction industry must find new ways of building. "The construction industry is the largest consumer of raw materials and accounts for over a third of global energy demand," says Gennaro Senatore, a scientist at ENAC's Applied Computing and Mechanics Laboratory (IMAC) and lead of the research project. "Built environments are responsible for up to 40-50% of total CO_2 emissions throughout their service life."

That remarkably high figure is partially due to traditional design practices applied to most civil engineering structures. Civil structures are typically designed to withstand worst-case loading events—which in practice occur very rarely: strong winds, earthquakes, snowstorms and large crowds.

A solution lies in adaptive structures, which are able to adapt to ensure that strength and serviceability requirements are met against changing loading conditions. "Adaptive structures can operate closer to design limits, which means they can perform better and in a more sustainable way than conventional passive structures," explains Senatore.

The design criterion adopted in this work is minimization of structures whole-life energy requirement, which includes energy used for operation, such as for sensing, control and actuation during service as well as energy used for materials and construction—known as embodied energy.

Adapting to changing loading conditions through shape control

In order to establish the feasibility of their design method and control-optimization system, IMAC team developed a prototype, which takes the form of a footbridge. It can take an ordinary load passively, and if the load increases above a certain activation threshold, the structure is able to adapt into an optimal configuration through a change of shape.

The control system includes a series of sensors, control units and actuators. "Each structural element is instrumented with a strain sensor and an optical tracking system monitors the structure movement. Machine learning has been employed to improve detection accuracy of the applied load location and intensity," says Arka Prabhata Reksowardojo, a doctoral assistant at IMAC, who successfully defended his Ph.D. thesis related to this project a few days ago. "The control units process information received from the sensors and command the actuators to extend and contract, thereby controlling the structure into an optimal shape that changes as the external load changes."

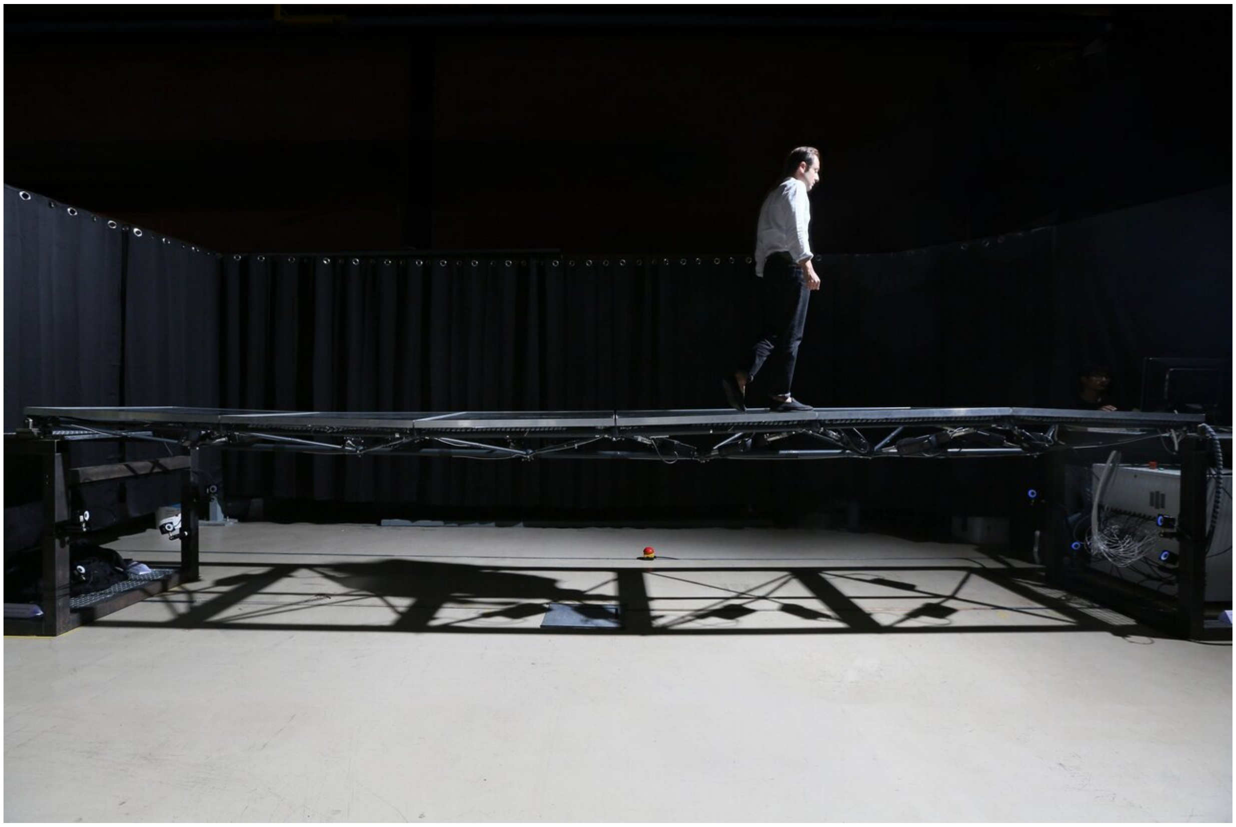
And what if there is a power outage? "The structure would not collapse because it is designed to have sufficient load carrying capacity even without contribution of the active system. However, serviceability limits, such as deflections, are likely to be exceeded," explains Senatore.

Credit: EPFL / Alain Herzog

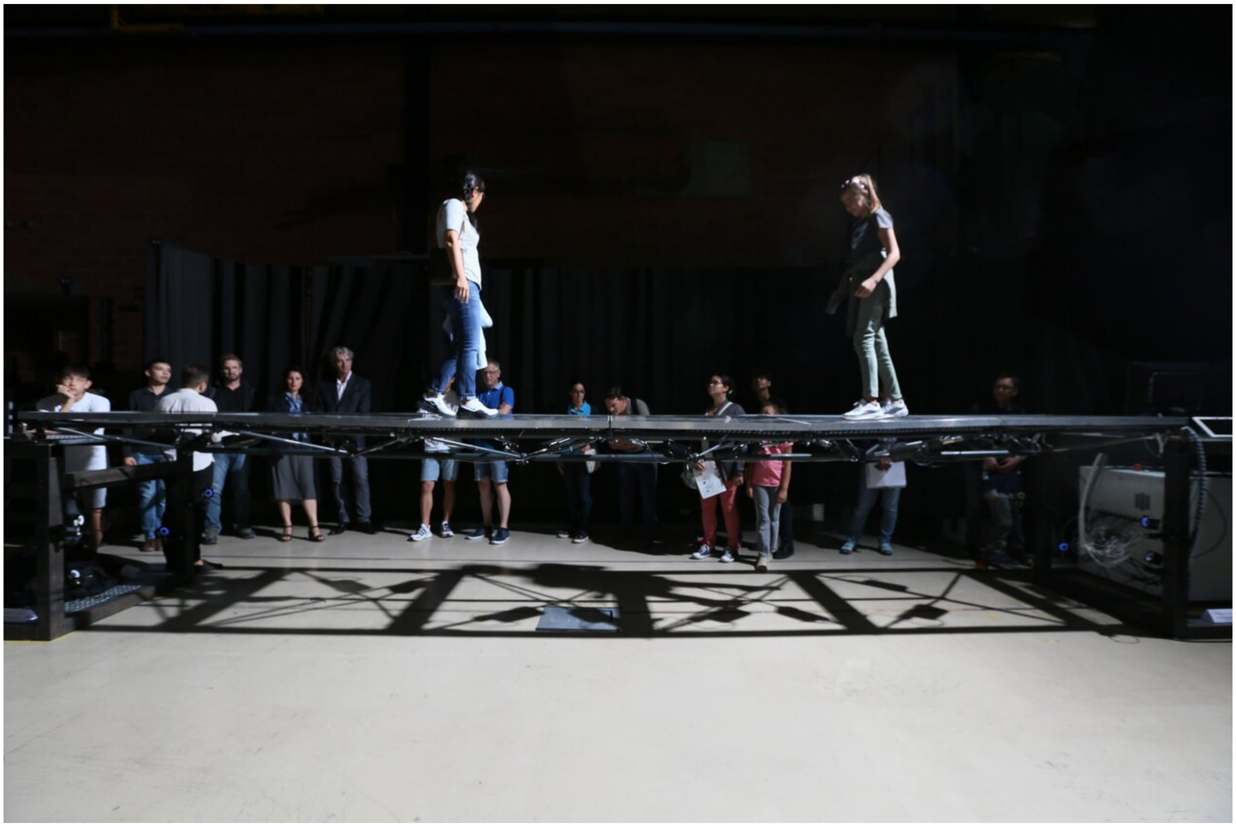
Smaller embodied energy and mass

The footbridge is 6.6 m long, 1 m wide and only 16 cm deep. "It has a very slender configuration with a span-to-depth-ratio that is three times as high as that of conventional structures," says Reksowardojo. This ratio gives an indication of how a passive structure behaves under loading. The higher the ratio, the more the structure will deform—like a plastic ruler that bends in our hands. Instead, the ability to reduce deflections through active control enables new type of structures such as super-slender adaptive buildings and bridges.

"The structure has been designed to be able to counteract the effects of loading through shape control," says Reksowardojo. Part of what makes IMAC structure innovative is that it can adapt to loading through large shape reconfigurations. This kind of structural adaptation leads to a homogenization of stress under strong loading events, with a substantial decrease (up to 37%) in the average stress between non-controlled and controlled states. Thus, the structure requires a smaller mass and embodied energy owing to the capability to change shape under loading.



Credit: EPFL / Alain Herzog



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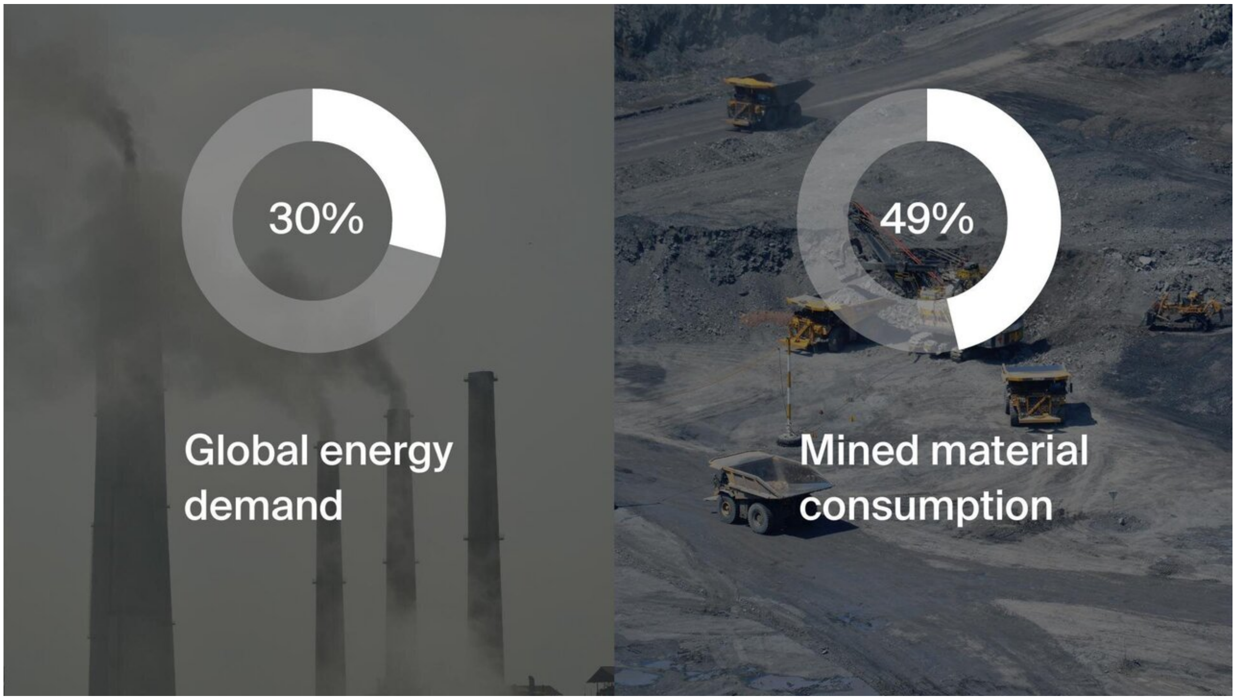
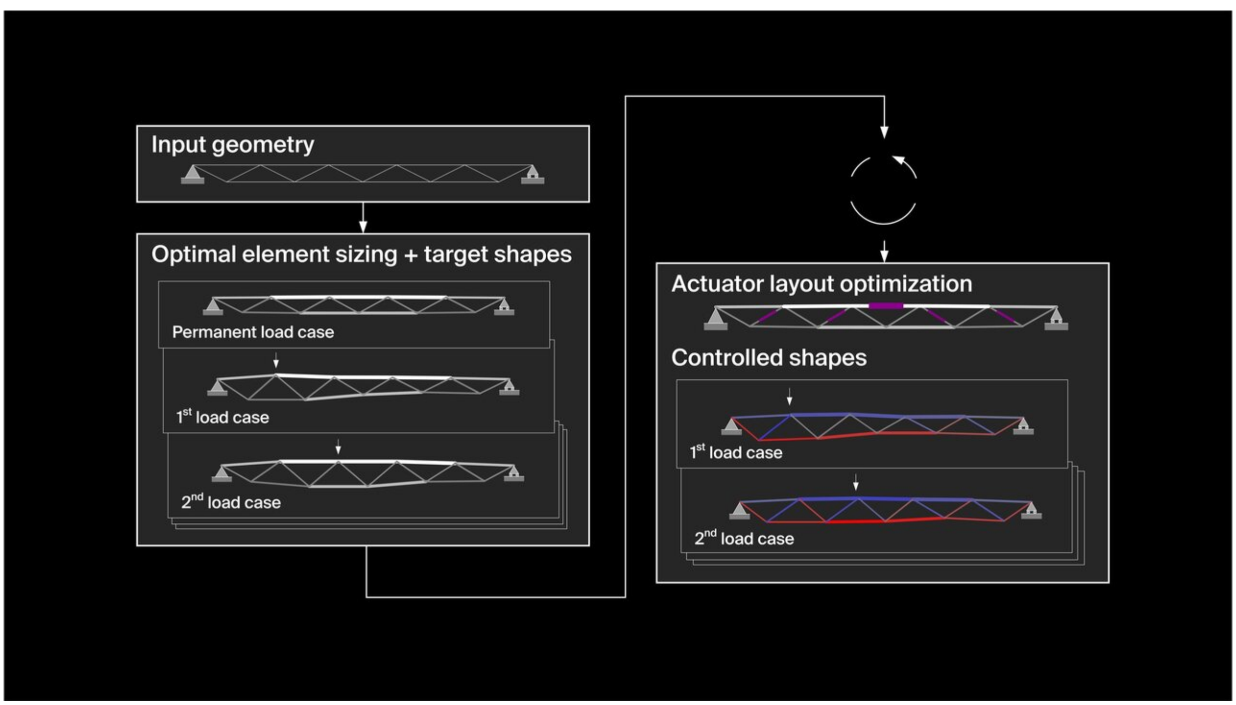
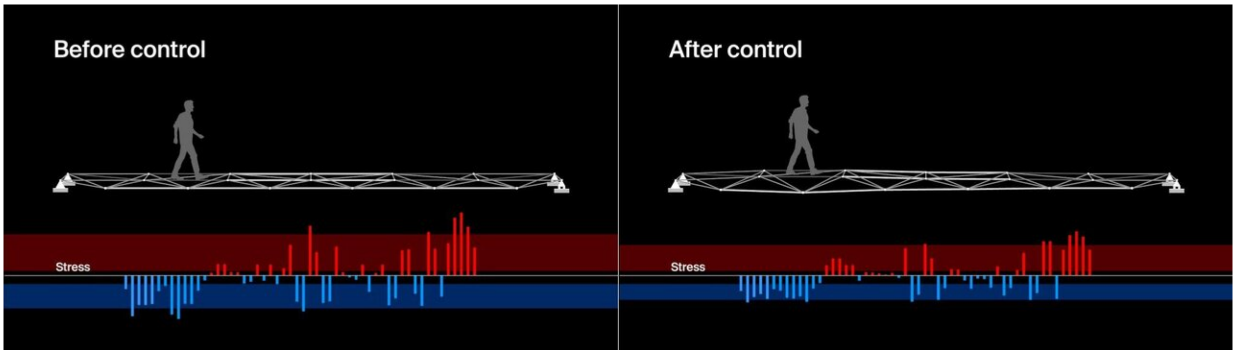


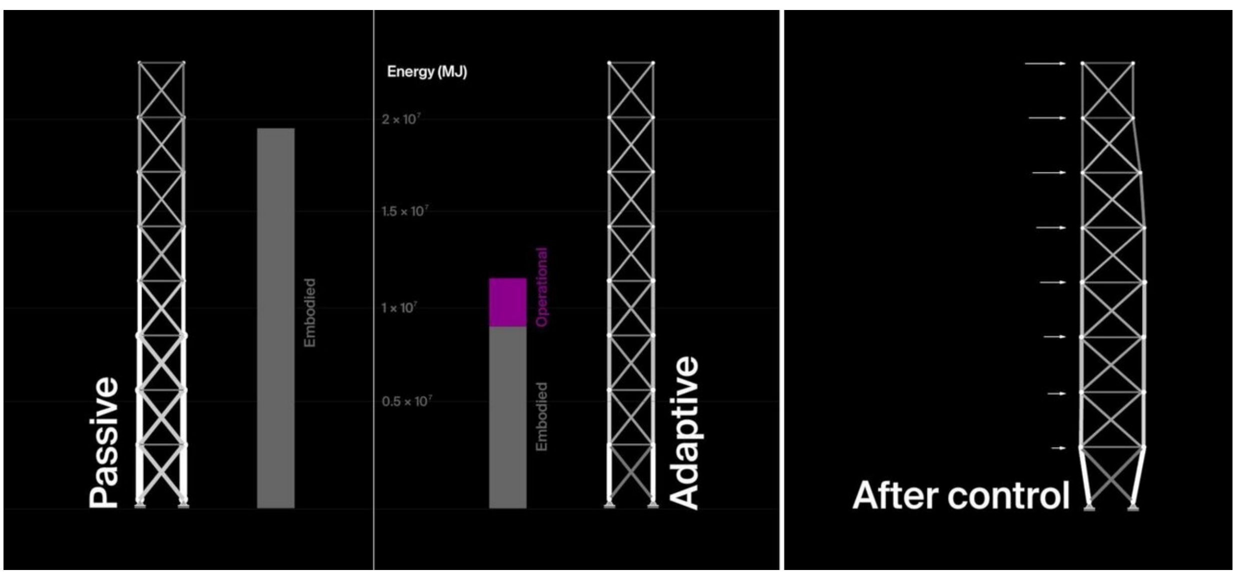
Built environment impacts. Credit: IMAC, EPFL



Adaptive structures design process. Credit: IMAC, EPFL



Stress reduction through shape control. Credit: IMAC



Adaptive tower . Credit: IMAC

A high impact potential

Adaptive structures provide an alternative to stiffness-governed designs for engineering structures. Well-designed adaptive structures require considerably less material and energy resources while meeting safety-critical requirements. Adaptive structures are particularly well suited when the structural design is governed by strong but rare loads such as a wind storm. High-rise and slender buildings could particularly benefit from this approach, providing an attractive option for urban planners to optimize space in high-density cities.

"Studies have shown that structures produced by this method achieve up to 70% embodied energy savings at the expense of a certain amount of operational energy," says Senatore. "The deferral of energy usage obtained by replacing a large embodied share with a smaller operational share helps to reduce greenhouse gas emissions further—because carbon footprint of energy production is likely to decrease in the future owing to technological advancements."

"This combination of low energy requirement and super-slender design is unique in structural engineering, thereby creating high impact potential for the built environment and society as a whole," says Senatore.

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