Caitlin Mueller

MIT professor Caitlin Mueller gave the keynote presentation at the IStructE Digital Design and Computation conference in May. Here, she tells Jackie Whitelaw how computer tools she's developing will help structural engineers design for zero carbon.

AS THE URGENCY FOR NET-ZERO CARBON becomes ever greater, the challenge of minimising embodied carbon in the built environment is going to be one of the biggest facing structural engineers in the years ahead. Can, for instance, society's demand for up-to-date buildings be met in part through reuse of existing structures so all that carbon already emitted can expand its value?

How useful, then, would be a free computer program that helps engineers incorporate sections of old buildings in a new facility, a program that would allow a designer to envisage how an old structure could be taken apart and the jigsaw of elements put together in a structurally sound way to be part of a brand-new building?

Caitlin Mueller, associate professor in building technology at MIT in the USA, is working on just such a program.

'Material reuse is a super important component of sustainability,' she says. 'I'm looking at algorithms for using found material in design, how you can reassign all those irregular shapes and come up with a structure that responds to the material you already have,' she explains **(Figure 1)**. 'There is something very pleasing about the idea of taking a pile of stuff and turning it into a building.

'Material reuse has a long history – I have a colleague, Brandon Clifford, who calls it material cannibalism. My interest is how to do it at scale, using computation in a systematic way.'

Developing sustainability tools

Mueller and her Digital Structures team at MIT are also focusing on how to measure the impact of city planning and policy decisions on carbon in the urban environment. 'We are all deeply concerned about climate change and are focused on coming up with new tools and methods for designing buildings that combine sustainable performance with good design,' she says.

The Digital Structures research group has a track record in developing such innovative and exciting tools. Its stated aim is 'to contribute new knowledge to empower the design and fabrication of innovative, creative and performative architectural structures'.

Its first interactive design tool was structureFIT, a free, web-based platform for exploring the structural design of planar trusses that allows designers to link geometric design variables with structural performance and then test design alternatives that assess structural material volume, stress and buckling.

At the moment, among many other things, the group is looking at an automatic path planning framework for robotic construction to overcome the issue of professionals working in the parametric design environment having to manually 'plan' for the robot – generating guiding curves for the robot to follow that avoid collisions with other objects on site. The project will overcome these limitations through an automated robotic path-planning software layer linking design geometry to robotic telepath code that will design out potential collisions and other issues.

Carbon-efficient designs

In her keynote presentation at the Institution of Structural Engineers Digital Design and Computation conference in May, Mueller shared some of this expertise, demonstrating how computational tools that have been developed for early-stage or conceptual design can allow buildings to be built efficiently and practically by optimising their geometry **(Figure 2)** and by digital planning for fabrication. And throughout, low carbon should be top priority **(Figure 3)**.

'Climate change should be the overriding priority for designers,' Mueller says. 'I would love engineers and architects to be creative in how we respond. It shouldn't be just decarbonise the energy in a building and carry on as normal.

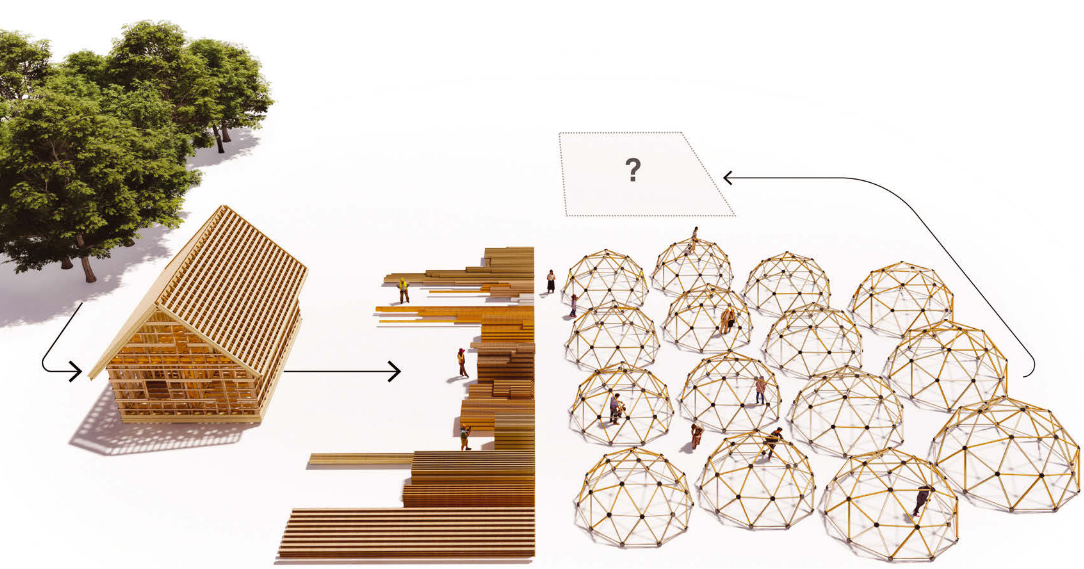

FIGURE 1: Mueller is developing algorithms to allow designers to reuse material from a structure in new designs (with Yijiang Huang, Latifa Alkhayat and Catherine De Wolf)

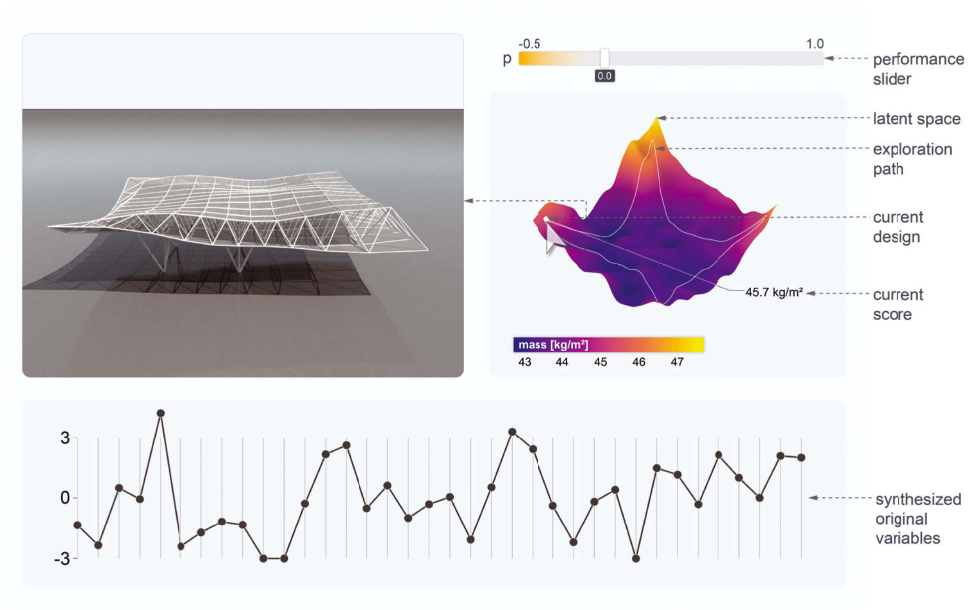

FIGURE 2: Efficient designs can be achieved through optimisation of geometry (with Renaud Danhaive)

'There is decadence in the way we use material, and we need to be more responsive in the way we design to stop that. My students all understand the urgency, but when they go into work they run into the economics of construction. It's still cheaper to do things in the old ways.

'Change is going to require incentives and regulation but also a concerted voice from architects and engineers encouraging clients to put carbon reduction first. We can make the tools to help the argument.'

Perhaps surprisingly to some, Mueller thinks engineers are at a disadvantage in the field of computer design compared with architects. 'I think architects are more computer literate than engineers, especially in geometry. Architects are using powerful tools for exuberant design, tools the engineers don't have. In my experience, engineers are mainly focused on analysis – even though that can be really complex – and need to catch up in terms of tools they use and their influence on geometry. That is the key to a structure, where the efficiencies including carbon are to be found.'

Designing for modular construction

This will become increasingly important as modular design for manufacture and assembly (DfMA) techniques take hold. And it is where engineers and architects need to work together to avoid the trap of limited components. 'I see no reason why DfMA means we should limit ourselves in terms of how we express ourselves in architecture,' Mueller says. 'The idea that it is too complex if all the parts are not the same is overblown. Contractors are not overwhelmed by

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difficulty. DfMA decentralises the process of construction so different people can make things in different places using different moulds, but that can still be planned for modular assembly using the right computer programmes.'

DfMA will oblige engineers, architects and contractors to emerge from their design silos, Mueller believes. 'At the moment, designers design and contractors work out how to build.

FIGURE 3: Low-carbon design needs to be a priority, e.g. low-carbon slabs (with Mohamed Ismail, Eduardo Gascon Alvarez and Leslie Norford)

This limits the ability of engineers and architects to use their design skills to think about the process of construction. But as fabrication processes develop, e.g. 3D printing, designers are going to need to understand the mechanics.'

Mueller can see tools being developed soon to allow for lightning-fast sketch iterations that could be converted into a quick shop drawing to test which option is best for manufacture and assembly. 'That collapsing of design has a lot of potential,' she says. 'This wouldn't be something fully automated, you'd still need all various professional skills to get things correct and you would still require the hand calculation skills to verify the soundness of design, but there is an opportunity for quick checks on ideas so you get to the most efficient solution.'

For the last two years, Mueller herself has been working on a programme that would link sketching and computer assessment of the drawn idea. 'Basically, a designer would produce a sketch and the computer could read it, work out how it would perform in reality and suggest alternatives (**Figure 4**). I'm at the very early stages using narrow structural types such as trusses, blocks and curved frames, and the initial results are very exciting. But as with all our artificial intelligence tools, this needs data to learn on. We need to test on real-world problems.'

Real-world applications

To that end, Mueller and the Digital Structures team work with major practices to validate their more mature computer tools. They collaborated with SOM on a hotel tower to maximise the number of rooms in a tapering shape, for example.

'I like the idea of working at the cutting edge with new ideas and then at a later stage taking them into an actual project,' she says.

This is not surprising. Mueller trained first as an architect and then as a structural engineer and worked in practice for a couple of years. 'I started during the 2008 recession and learned a huge amount working on some not hugely important buildings. But it was a very influential time for me.

'I was surprised how brittle the system was. I'd assumed we'd have all these modern tools, yet everyone was doing what was done 20, 30, 40 years ago. The need to develop new tools led me to MIT.'

Mueller's main motivation is advancing knowledge and the MIT ethos is very philanthropic. 'There is a strong belief in open source, we believe in ideas development and commercialising them might limit access.' Some of her PhD students have gone on to join start-up

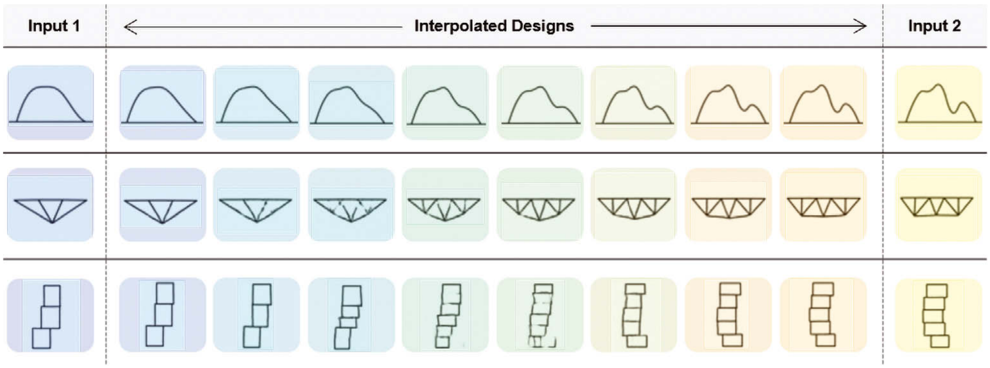

FIGURE 4: Computer assessment of sketches could lead to more efficient alternatives (with Bryan Ong)

companies that have been acquired by mainstream suppliers, nevertheless.

She has a warning about reliance on computer design, however. 'Computers, you could say, pose a problem because they enable designers to understand the building less – you can't draw it and you can't always explain how it works with hand calculations. On one hand, that is very exciting, but it is also part of the reason we see some destructiveness in terms of the cost of carbon in the built environment, because structures that seem impossible become possible even though they may not be the most sustainable.

'There is a risk that computing can be embraced just for expanding possibilities rather than understanding constraints. We have to use them with constraints in mind, especially the impact on carbon and the climate.'

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