Building THE FUTURE COMMISSION
CELEBRATING 180 YEARS

GROWTH THROUGH INNOVATION:
A GUIDE TO TECHNOLOGICAL TRENDS SHAPING CONSTRUCTION'S FUTURE

Contents

Introduction

We have the tools to transform the way we build – now we need the leadership / Thomas Lane

Over the past quarter we have investigated four areas critical for construction's future success – artificial intelligence, digital, modern methods of construction and net zero materials – to assess what impact these can make. These four key elements are an essential part of the drive to find more efficient ways of delivering better buildings that tread more lightly on the planet.

This investigation is part of the Building the Future Commission, a year-long project looking at radical and challenging ideas that could help to transform the built environment. What do these four areas have to offer the industry?

Modern methods of construction (MMC) are an essential part of the drive towards greater efficiency and quality, and also helping to tackle the skills shortage. The industry has no hope of delivering buildings more efficiently using techniques that would not be unfamiliar to our great-grandparents.

Although there have been some high-profile failures, many in the industry are embracing MMC. Platform systems have the potential to get around many of the problems bedevilling MMC, as a kit-of-parts approach can be applied to a range of similar building types. This provides a much bigger market, better economies of scale and greater surety of supply for clients.

Digital twins have the potential to help drive down operational carbon emissions. As the name implies, these are a digital manifestation of a physical building. The twin is linked to that building via sensors feeding it real-time information, enabling it to adjust the HVAC systems for maximum efficiency. The learning acquired by a digital twin over a building's life can also be used to inform the next generation of buildings to iron out any flaws in the original design.

AI is a subset of digital but, given the impact it could have on the industry and the rapid pace at which it is developing, we decided to interrogate it as a standalone topic. Machine learning has been adopted by firms for detecting defects in roads and buildings from videos shot from moving vehicles.

Machine learning is now being used to examine tenders to see which are the most realistic, and project delivery plans to identify unforeseen risks. And machine learning can take a list of client aspirations and project constraints to quickly come up with a shortlist of design options for designers to develop in more detail.

We found that the industry is rising to the net zero challenge. Developers are beginning to refurbish buildings where they can, and designers are experimenting with reusing materials such as structural steel and raised access flooring.

They are also looking at how they can use materials more efficiently, and new start-ups are developing low-carbon cements and other products. And some institutions, such as the British Council for Offices, are revising their guidance to make it easier to deliver lower-carbon buildings.

> “ The industry has no hope of delivering buildings more efficiently using techniques that would not be unfamiliar to our great-grandparents

What would help persuade people to embrace these ideas is evidence. Land Securities is working with Cambridge university to evidence the benefits of platform construction – which it used on its Forge development in Southwark – with some surprising results. It found that platform construction was not sufficient on its own to reduce programme times; good logistics was the key to this.

Building up an evidence base to demonstrate to other clients the benefits of embracing new ways of working is one of the most powerful ways of promoting change. A big challenge is harnessing all the lessons from the work being done by individual firms so that it can be leveraged for wider benefit.

But multiple barriers to the more general adoption of new ways of working remain. Procurement was frequently cited as a barrier to the adoption of MMC and low-carbon materials, and it stands in the way of digital too. Fixed-price contracts mean project teams are reluctant to try anything new because wafer-thin margins mean the slightest hiccup could tip a job into the red.

More collaborative forms of contract would help. Integrated project delivery, a procurement route used in other countries encourages everyone involved in a project to do their best not just for their element of the job, but for those downstream because everyone shares a profit pot at the end.

Everyone we spoke to thought that the introduction of new regulations to drive change was not helpful with the exception of Part Z, a proposed regulation to reduce embodied carbon emissions. What would be better is leading by example.

The government should look at revising its procurement rules to make it less risky for the industry to try out new ways of working. It could take the lessons learned from these initiatives and disseminate them to help promote wider change. This would help to overcome one of the biggest challenges facing the industry – the need to bring the long tail of smaller developers and builders on this journey.

And that journey would be made shorter by that essential but elusive ingredient: strong leadership. And, given the challenges facing the government, which are not going to go away any time soon, that will need to come from the industry.

Thomas Lane is group technical editor for insight and strategy director at Building

WHAT DOES **ARTIFICIAL INTELLIGENCE** MEAN FOR CONSTRUCTION?

Building THE FUTURE COMMISSION CELEBRATING 180 YEARS

A photograph generated by artificial intelligence has won an international photography award. So how far off are we from a building designed by AI winning the Stirling Prize? **Thomas Lane** reports on the opportunities, limits and risks of AI in construction

Last month a photograph generated by artificial intelligence won the creative open category of the prestigious Sony world photography awards. The photographer, Boris Eldagsen, openly admitted the image (shown overleaf) was AI generated and refused to accept the award, saying he had entered it to start a debate over whether an AI-generated image could in fact be a photograph.

The stunt was a response to an explosion in readily accessible AI tools. Last November's launch of ChatGPT was, on the face of it, one of the most momentous technological advances in recent years. A text-based system, ChatGPT can write stories, college essays, job applications and so on in clear, fluent language and, if the user so chooses, in the style of Shakespeare, Donald Trump or Chaucer.

It clocked up more than 100 million users in the first two months after launch, making it the fastest-growing consumer application in history. And, less than four months after ChatGPT hit the headlines, OpenAI, the developer, launched GPT-4, the successor to GPT-3, the artificial intelligence system on which ChatGPT is based.

GPT-4 is a similar leap forward to ChatGPT, as it is capable of writing a novel or passing an American bar exam. It can also recognise images and respond to these. Furthermore, GPT-4 seeks to address some of the criticisms of ChatGPT, namely its propensity to sometimes give spectacularly wrong answers to prompts.

This startling progress prompted more than 1,000 tech leaders including Elon Musk and Apple co-founder Steve Wozniak to warn in an open letter, two weeks after GPT-4's launch, that out-of-control AI development poses profound risks to humanity. The signatories called for a six-month pause in development of systems more powerful than GPT-4 as uncontrolled research could produce tools that outsmart humans, rendering them redundant.

The threat to humanity posed by AI is a moot point, but on the flip side there is no doubt it has the potential to transform how we learn and work. A Goldman Sachs report on the economic impacts of AI, published at the end of March, estimates that tools like GPT-4 could automate 46% of administrative tasks and 44% of those in the legal profession.

Significantly for construction, architecture and engineering are among the professions most likely to be impacted by AI, with the potential to automate 37% of tasks. Could AI be a silver bullet to address industry inefficiencies and skills shortages – or are we all going to be automated onto the end of a very long dole queue?

What is AI and why is it useful?

Artificial intelligence combines computer science and data to deliver human-like thought and actions. This includes the ability to self-learn and make predictions from the dataset on which the system is based.

A system that can mimic the broad range of human abilities does not yet exist; instead current AI technologies, or more accurately machine learning systems, function within a narrowly defined range. These are built around artificial neural networks that mimic the way »

» human neurons in the brain signal to each other. They can be arranged in layers to produce better and more accurate outputs – a system with three or more layers is said to be capable of deep learning.

Machine learning (ML) systems are trained on a dataset and learn to make predictions and produce new responses based on those questions. There are different types of ML – and ChatGPT is a large language model built around text.

DALL-E 2, the system that won the photography prize, is a diffusion model that can generate an image from a series of prompts stating the desired subject matter and style of the output. Training takes time, and human intervention is needed to steer the ML model towards the right responses. Once trained, it can process and interpret vast amounts of data very quickly and produce results that humans would struggle to achieve. This means ML can save companies large amounts of time and let them undertake highly complex tasks that were once unthinkable.

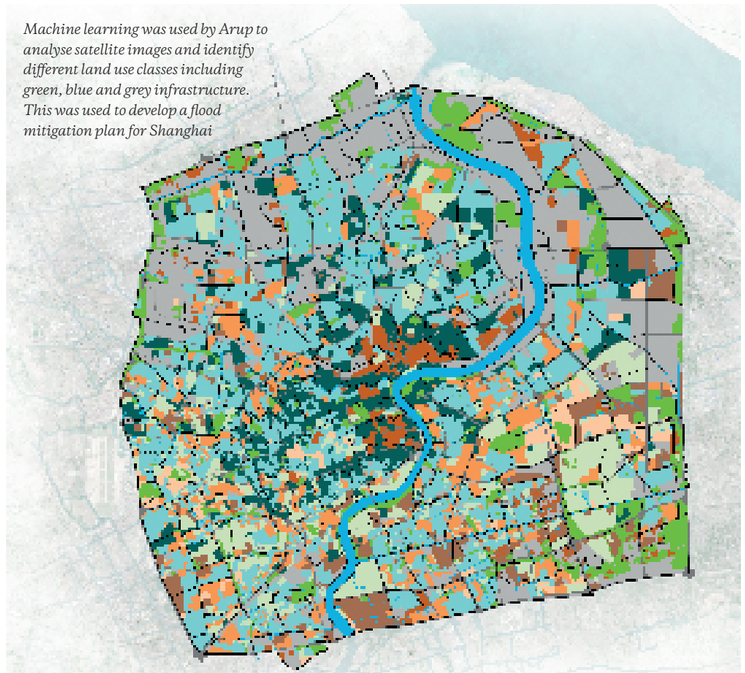
What could it do for the industry?

Systems such as ChatGPT, DALL-E 2 and Google's Bard are generating all the headlines, but in practice they have limited use within construction. Although the industry uses the text and images on which these models are based, much of construction is based on physics and engineering, which is receiving less attention from the AI community. Consequently some industry firms are developing their own machine learning tools specific to their needs and expertise, to enhance their service offering and ultimately to gain competitive advantage.

One firm that is embracing machine learning is Arup. Will Cavendish, Arup's global digital services leader and former strategy lead for the applied team at Google-owned AI research laboratory DeepMind, points to the challenges posed by climate change and the need for the built environment to quickly find new ways to reduce emissions. "We see artificial intelligence and machine learning as a fundamental enabler to allow us to do our work much better, in new ways to solve those fundamental problems," he says. "We are absolutely developing those systems and deploying them safely and effectively where we can."

Arcardis is also investing in machine learning technology. "We've been focusing really hard over the last three to four years on how to exploit these technologies for what they can bring to various client challenges to produce more effective and better solutions more quickly," explains Phillip Brown, a director at Arcadis who is responsible for the firm's automation strategy and implementation in the UK.

Brown points to an image recognition tool the firm has developed that can assess the condition of road surfaces. The model is trained to recognise the patterns and shapes associated with road defects, such as cracks and potholes. A road is assessed by filming it from a moving vehicle, with the footage played back on a computer. The machine learning model can identify the defects with over 95% accuracy and is much faster than interpreting the data manually.



Machine learning was used by Arup to analyse satellite images and identify different land use classes including green, blue and grey infrastructure. This was used to develop a flood mitigation plan for Shanghai

> WE'VE BEEN FOCUSING REALLY HARD OVER THE LAST THREE TO FOUR YEARS ON HOW TO EXPLOIT THESE TECHNOLOGIES FOR WHAT THEY CAN BRING TO VARIOUS CLIENT CHALLENGES
>
> **PHILLIP BROWN, ARCADIS DIRECTOR RESPONSIBLE FOR UK AUTOMATION STRATEGY**

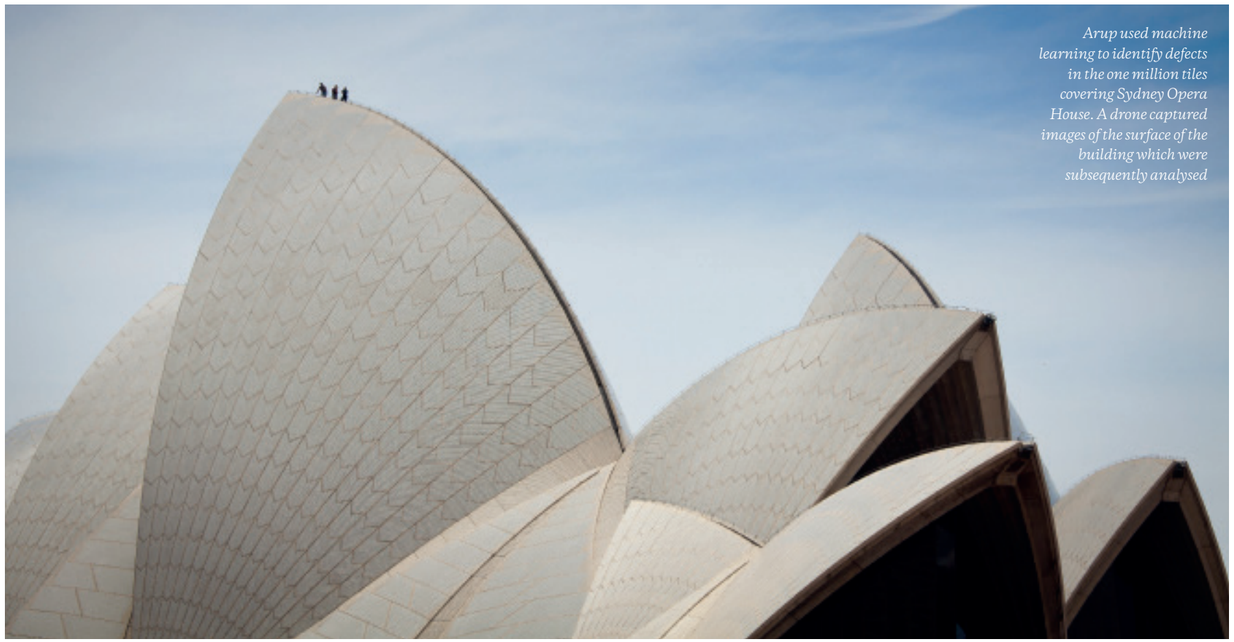
The firm has developed it further so that it can recognise defects in facades and erosion in riverbanks – and even identify wildlife in surveys. The tool is also being used to identify and track landscape elements from satellite images and monitor waste volumes in New York.

Arcadis is also using machine learning for predictive maintenance for the water industry. Based on a water company's asset information including the types of pipe, age and location, the tool can predict the risk of failure of different types of pipes for the next 25 years and help to plan a replacement programme to mitigate risk.

Arup is using similar technology identify grey, blue and green infrastructure areas within cities that could be made more permeable to reduce flooding risk and improve biodiversity. "That allows us a much more detailed and granular understanding of the features of a city or district," Cavendish says. "We couldn't do that previously because we didn't have the detailed intelligence and understanding that AI can now give us using a new data source like satellite data."

Arup is also using drone-mounted cameras and image recognition technology to map over one million tiles covering Sydney Opera House in order to establish which ones are cracked and need replacing. And it is using vibration analysis to understand the response of a structure to stress. This data is fed into a structural model and analysed using machine learning to understand the structural state of a building.

"We think that we are going to be able to safely repurpose and renovate buildings and infrastructure that we wouldn't have been able to do previously, because people would have said



Arup used machine learning to identify defects in the one million tiles covering Sydney Opera House. A drone captured images of the surface of the building which were subsequently analysed

SHUTTERSTOCK

they have reached the end of their design life and need to be knocked down and rebuilt," Cavendish says.

The applied research and development team at architect Foster + Partners specialises in turning the latest technological developments, including machine learning, into practical tools for the firm's architects and engineers. They are developing a range of engineering and design aids, including an in-house search engine for use by the firm's design studios which is based on a natural language model, the same type of technology used for ChatGPT.

The design teams are supported by specialist technical teams who have developed design guidelines based on the firm's 55 years of experience. According to Sherif Tarabishy, an associate partner and design systems analyst who leads on how machine learning can be deployed in the practice, the designers are reluctant to trawl through this documentation.

"What we found is the designers go straight to the expert teams, who bill them for their time to keep answering the same questions over and over again, given that the PDFs are dense documents so no one really bothers to look at them." The team are developing a search engine which will provide answers to specific questions, plus a link to the relevant pages in the PDF documents.

Fosters is also working on a predictive machine learning model to reduce the deviation in the price quoted for a job against how long it actually takes. This is based on historical data for different types of project around the world. The dataset is currently being developed and validated against the manual process used for producing quotations.

Fosters collaborated with software giant Autodesk to develop an engineering focused tool that analyses complicated, non-linear relationships. The architect is experimenting with materials that deform into a different shape when heated, with the idea these could be used for solar shading on buildings.

Layers of thermoactivated and neutral materials are built up into a laminate. By varying the layer makeup, the material will deform in different ways. But working out the correct layering for a desired shape is highly complex, which is where a machine learning process called surrogate modelling comes in.

A surrogate model is given the answers to a selection of known questions and trained to predict answers to other questions posed of it. In this case the process has been flipped – the designer provides the answer first, which is the desired final shape of the material when heated, with the model predicting the initial layering of the material to produce that outcome.

Designers can also save time and produce potentially better solutions using generative design tools. The designer inputs the project constraints including information about the site and desired outcomes, and the software quickly generates a multitude of solutions which it ranks.

The designer can use this ranking to determine which options are worth taking on. This saves time and has the added benefit of generating »

Below: The photographer behind this AI-generated image, Boris Eldagsen, refused to accept the prize it won in the Sony photography awards, as he had entered it only to start a debate over whether an AI-generated image could in fact be a photograph

THE ANSWERS YOU GET BACK [FROM A MACHINE LEARNING SYSTEM] ARE 80% CORRECT, BUT 20% CAN BE VERY WRONG… THERE IS A LOT OF DANGER WITH THAT 80%

MARTHA TSIGKARI, HEAD OF FOSTER + PARTNERS' APPLIED R&D TEAM

» options the designer may not have thought of.

These tools are available right now off the shelf; generative design capabilities are already built into Autodesk's Revit BIM software. This can work out the optimum combination of sightlines and seating capacity in a stadium, the best layout for a hospital to minimise the distance walked by healthcare staff, and the best building shape and floor-to-ceiling heights to maximise natural light in an office.

The downsides of artificial intelligence

The apparent brilliance and promise offered by GPT-4, DALL-E 2 and others is counterbalanced by major flaws which could severely limit their usefulness. Wrong responses to a prompt, or "hallucinations" in the jargon, are a major problem because these cast doubt on all of the information provided by the system.

"The answers you get back [from a ML system] are 80% correct, but 20% can be very wrong," says Martha Tsigkari, head of Fosters' applied R&D team and a Building the Future commissioner. "There is a lot of danger with that 80% because you cannot have a sense of comfort that this is right – as the information you get back might be completely misleading, with that 20% of error."

The problem is that much of the data used by large language models is sourced from the internet, which is awash with misinformation and false narratives. This not only means the information produced by these models can be spectacularly wrong; it can also be politically biased and racist.

ML developers are working to improve the accuracy of these models. OpenAI claims that GPT-4 was in the top 10% of test results for a bar exam whereas the previous version, GPT-3.5, was in the bottom 10%. But even a small margin of error is a problem for construction.

"There will always be a risk [of incorrect answers] and even if it's 1%, it still needs to be considered," Tarabishy says. "At the end of the day you are doing something that people will interact with and there are codes, regulations and liabilities to consider."

The data used by the models being built by firms such as Fosters and Arcadis is proprietary and specific to the tasks they are being asked to perform. This all but eliminates the risk of incorrect input data but, as these tools are self-learning and make predictions for scenarios not necessarily in the original dataset on which the model has been trained, there is still a risk of output errors.

Tarabishy says Fosters will not be relying 100% on its machine learning models "any time soon" because of this risk. For example, answers given by the in-house search engine to the design teams will be cross-checked daily by the expert support teams, with any deviations addressed by more training. "If we need to collect more data about a specific topic to fine-tune the model, we can start doing that," Tarabishy says.

Arcadis readily concedes its automatic defect detection models have an accuracy rate of around 95%. These levels of accuracy are fine if the task in question is not critical, but could this potentially limit the usefulness of such models?

Cavendish says not; Arup is using various strategies to mitigate negative impacts, including training up models to indicate when these are not confident of the right answer, so an engineer can use their experience to make an assessment. He adds that humans are usually involved in the process, which does not negate the point of machine learning.

"The capacity of ML to analyse, diagnose and predict is enormous compared with the human brain. We are talking about ML and humans working together. It is that combination that really works," he says.

The problem of intellectual property

The risks posed by open-source data are compounded by a second issue: intellectual property. If an AI system creates something new based on data that belongs to others, who owns that output? "AI is really pushing the boundaries in terms of the potential legal ramifications of the IP rights of the training inputs," warns Brown. "Cases are starting to emerge, especially in the case of diffusion models and images, of who owns the outputs of these models. Societally and from a policy perspective, we do need to be hyper-aware of what it is that we are presenting as our own."

Brown is right to be concerned. A legal case concerning patent rights is currently grinding its way through the English legal system. An inventor called Stephen Taylor is attempting to patent inventions derived from an ML model and says owners of such systems should be able to name these as inventors on patent applications. The UK intellectual property office disagrees and to date has won cases in the High Court and Court of Appeal. The case was recently heard by the Supreme Court, but the judgment is not expected for some time. Mark Marfe, a patent lawyer at Pinsent Masons, says the case has international significance. "Ultimately, for a machine to be named as an inventor of a patent, patent laws will need to be amended. If the law on this issue is not aligned on an international basis, this would negatively impact companies with global patent strategies," he says.

"As generative AI technologies, such as DALL-E 2, ChatGPT and BioGPT develop further, these questions are becoming increasingly important – and so the eyes of the AI world will be on the UK Supreme Court."

Strict intellectual property rules could mean that the benefits of machine learning are limited to proprietary data. Tsigkari thinks an ethical and legal framework regarding how data is used and shared will emerge. Brown suggest that being open and transparent about the data being used in a project with all the stakeholders is one way forward.

Building a machine learning system

Tsigkari warns that a huge amount of work is needed to populate a machine learning system with the data needed for it to learn on. "For most of the machine learning initiatives in the office, 80% of the time is spent on developing the dataset. Just 20% of the time is spent on testing different algorithms to define the system."

The problem is not a shortage of data – on the contrary, there is too much of it. The problem is that data is mostly stored in a format which cannot be used by a machine learning system without significant intervention. Just one project generates vast quantities of text documents, spreadsheets, emails, drawings, 3D models and visualisations. Someone needs to locate this data, pick out what is relevant, tag it in a consistent manner and export it to a machine learning system. "It is a non-trivial matter to do the simplest of tasks," Tsigkari says.

Tarabishy says it was actually easier to create a so-called synthetic dataset to train a model capable of helping the workspace design team produce optimum floor layouts in real time. This tool analyses a floorplan to calculate how long it takes to walk from one point on a floorplan to every other point and, similarly, how many points on the floorplan can be seen from one point. This helps designers validate design intent – if the designer identifies an area for secluded working, the analysis will quickly confirm this.

Finding the relevant floorplans in Fosters' office and turning these into machine learning friendly formats was too difficult. "We used parametric models to create an array of floorplans of different typologies along with randomly placed furniture," Tarabishy explains. "We created the output using two analyses, and that becomes our curated data set for training the model."

The model is tested by showing it a floorplan that was not part of that training data. "The model is being shown something it hasn't seen before, which measures how well it can generalise, so you are sure it is not just memorising the data," he explains. "We do this test with thousands of floorplans that the model has never seen before during training, and we see over time how close the results become to the output of the actual analysis."

How might machine learning evolve to benefit construction?

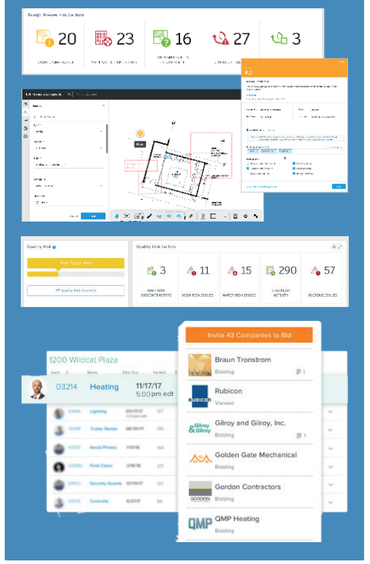
Most of the machine learning tools in construction have been developed by large, well-resourced companies. Tools such as ChatGPT are readily available, so could they be useful to those who do not have the resources to develop their own tools?

Amit Puri, the head of technical solutions for construction in Europe at Autodesk, says that as these tools are relatively new, people are yet to find meaningful uses in construction. He says Autodesk's customers are experimenting with these technologies and have used them to write computer code for new applications to interface with the company's products, such as the ability to put YouTube videos into BIM package Revit.

"The ability that ChatGPT has to give you examples of, and write code for you, is very powerful," he says. He adds that people are only beginning to discover the potential of ChatGPT and speculates it could be useful for tasks such as taking meeting minutes, creating checklists, or specifying formulas for Excel spreadsheets.

"We are only scratching the surface; it is only a matter of time before it becomes a really powerful search engine that everyone is using," he says, adding that future versions of GPT will become less prone to hallucinations.

Brown says Arcadis has been investigating the potential of ChatGPT and other AI tools. »



PROCESS AUTOMATION

Software like Autodesk can be used to automate processes such as design review, quality risk assessment and generating bid recommendations

Above: Machine learning was used to create this image of an art gallery in a modern setting by a river

Left, above and below: Diffusion model generated images of a bridge between Scotland and Northern Ireland and a 50-storey skyscraper in a classical style. Legal issues are starting to emerge around who owns the outputs of such models

SHUTTERSTOCK

MY HOPE IS THAT SAFE AND EFFECTIVE DEPLOYMENT OF AI WILL FINALLY SOLVE THE PRODUCTIVITY PROBLEM THAT HAS BEDEVILLED US FOR 40-50 YEARS

WILL CAVENDISH, ARUP

» "One thing that we are doing – and no doubt every organisation is doing at the moment – is assessing fitness for purpose, creating some framework of engagement with these large language models to figure out what is good that comes out of them, what not to put into them and how to work with them so that they're complementary and don't produce false positives that then gives the wrong result to our clients."

"And in step with that, what shouldn't you do with the technology, given that we're bound by GDPR and data sovereignty? We absolutely cannot be presenting sensitive data into these large language models."

Despite these caveats, Brown says he is excited by the potential of ChatGPT for construction and the firm is asking its employees for suggestions on how to leverage the technology. He thinks it could be a very useful tool for answering general questions, such as getting it to explain the difference between different forms of construction contract or preparing a flow chart outlining the steps needed to take to complete a process, and explaining complex concepts and technical questions in simple language. In other words, a sophisticated search engine.

Arup's Cavendish agrees, saying large language models will enable people to search for and retrieve information more effectively. Diffusion models, which produce images from text prompts, will be handy for quickly generating credible images that could help exemplify a client brief. But he does not think these capabilities are a game-changer for construction.

"This only takes you so far and is relatively superficial in the built environment," he says. "These things will be useful but they won't be profoundly impactful. More important for us is the kind of ML that embodies and deals with the real world; physics and engineering rules."

As with Fosters, this is the area Arup is focusing on because these systems are not readily available as the input data is not freely available in the same way as text or images. "These are going to take some time to develop, but we are determined to be at the forefront of this as we see the potential to reduce carbon and promote nature," Cavendish says. "This is absolutely fundamental for us and we think ML will be a critical part of our ability to do that."

SHUTTERSTOCK

An image of a brick and glass constructed school generated entirely through AI. Diffusion models that produce images like this from text prompts can be used to quickly generate credible images to help exemplify a client brief

Is ML coming for your job?

A recent Deloitte survey of FTSE 100 and 250 chief financial officers found that 75% of them thought UK capital spending on AI would increase significantly over the next five years. The CFOs were split equally over whether this would lead to an increase or decrease in the number of jobs.

The Goldman Sachs report published in March estimates that the widespread adoption of machine learning could raise UK productivity by 1.5% over 10 years. Encouragingly for site workers, and less so in terms of addressing craft skills shortages, the report suggested that only 6% of tasks carried out by site workers could be automated with ML.

And building maintenance workers are at the least risk of all types of workers, with the potential for just 1% of their tasks to be taken over by ML. This contrasts strongly with the potential to automate 37% of tasks performed by architects and engineers.

Automating that 37% of tasks could be a good thing. The tools being developed by the firms we spoke to for this piece all allow labour-intensive tasks to be done much more quickly and, in many cases, take the tedium out of them. This should free people up to focus on their core skills and creativity.

Cavendish sees this as a positive. "My hope is that safe and effective deployment of AI will finally solve the construction productivity problem that has bedevilled us for 40-50 years," he says. "That won't necessarily mean a reduction in employment but a change in the skills of the people working in a sector, because ML is usually about tasks, not jobs. The role will be of augmented human intelligence, not complete replacement."

Tsigkari agrees, using generative design tools as an example. These can analyse site constraints and crunch through millions of permutations to produce a range of design options.

"A building is not only a built asset, but one built in a particular location, to particular codes, with a particular climate, context and cultural significance," she says. "It is an accumulation of many different things that aren't necessarily directly visible when you create a model. How would you include all that metadata if you were training a system on 3D models? There are a lot of interesting discussions around this now; how do you train a system not with just the physical asset but all the contextual data that comes with it?"

She says this challenge could be overcome given the speed at which ML is developing, but for now these tools will not replace designers; rather they will help them. The day an ML tool can generate an architectural design that can respond to all the contextual, cultural and technical constraints of a site and win an award… that is the time to start worrying about the future.

Building THE FUTURE COMMISSION CELEBRATING 180 YEARS

EVERYTHING YOU WANTED TO KNOW ABOUT MMC BUT WERE AFRAID TO ASK

Are modern methods of construction the holy grail of construction efficiency or a technology destined to fail? In the second part of our series in which the Building the Future Commission explores game-changing innovations, **Thomas Lane** surveys the state of the UK's MMC market

Construction has a long way to go before it catches up with the highly sophisticated car production techniques used by vehicle manufacturers. This is car maker Skoda's factory in the Czech Republic

The recent decision by investment and pensions giant Legal & General to wind down its modular housing factory comes as a significant blow for confidence in the future of offsite manufacturing. Modular construction has had its fair share of problems recently; failures include Caledonian Modular in March and House by Urban Splash in May last year.

The L&G decision is particularly significant because the company manages £1.3tn of assets, more than the UK government spends in a year, and as a pension provider it favours long-term investment. It is fair to assume that L&G, which has lost £174m on the venture over seven years, did not see any prospect of long-term returns.

On the flip side, some companies such as Tide Construction/Vision Modular have made it work. There is a queue of investors including insurance company Aviva and housebuilder Persimmon lining up to pour money into modular housebuilder TopHat. And offsite manufacturing has become the default for building services and cladding specialists.

Modern methods of construction (MMC) have been touted as the saviour for construction's poor productivity and quality for decades now and as the answer to skills shortages, and yet the road has proved long, hard and bumpy. In the second in our series in which the Building the Future Commission zeroes in on game-changing innovations, we look at the state of the UK MMC market and examine its long-term prospects.

The downsides of MMC

The reason why MMC struggles to get much traction is because the factors conducive to efficient factory production match up poorly against construction. For starters, clients and architects want bespoke buildings but MMC is more suited to standardised products. Designers and contractors are used to working on designs in parallel with construction, whereas MMC requires these to be fully developed in advance of construction, then "frozen" for manufacture, imposing a different discipline on project teams. This also makes it difficult – and expensive – to accommodate late client changes. The refurbishment market is growing rapidly in a bid to meet net zero targets, a market where the opportunities for MMC are more limited. And refurbishing an MMC-constructed building, in particular modular, will be more challenging than one built traditionally.

There are other factors that militate against MMC – for example, many public sector clients want contractors to use local labour as part of social value agreements, something that is difficult if the factory is 100 miles away.

One of the biggest barriers to greater adoption, and a big challenge for modular manufacturers, is that factories require significant upfront investment, which is tough for an industry operating on low margins. The more sophisticated the factory, with potential for even greater efficiency, the greater the investment.

Factories need to operate close to maximum capacity to generate a reasonable return, which does not suit the unpredictable construction industry market. And the speed gains of MMC, particularly for housing, are of debatable value in an industry constrained by a glacial planning system and where build-out rates are dictated by the need to avoid depressing local house prices rather than the need to build quickly.

Then there are the risks that face all manufacturers, including regulatory change, as L&G found out when it had to develop a concrete and steel hybrid apartment rather than CLT for tall buildings after regulations governing combustible cladding were introduced.

> IT IS ALWAYS A LOT EASIER TO DRIVE AN MMC SOLUTION WITH HIGH-RISE BECAUSE IT'S USUALLY REPEATABLE. THAT'S WHERE WE CAN GET THE TRUE BENEFITS OF COST, PROGRAMME, SAFETY AND QUALITY
>
> **GARETH LEWIS, CEO FOR CONSTRUCTION, MACE**

Where MMC is being used successfully

Despite these constraints, the uptake of MMC is increasing as there are plenty of scenarios where it makes sense. Modular is well suited to repetitive building types such as student accommodation or build to rent.

Tide Construction/Vision Modular, a modular manufacturer, also acts as its own main contractor and has successfully built some of the world's tallest modular buildings. High-rise buildings are an ideal candidate for MMC because of the high degree of repeatability.

This is where Mace is concentrating its efforts. "It is always a lot easier to drive an MMC solution with high-rise because it's usually repeatable," says Gareth Lewis, Mace's CEO for construction. "That's where we can get the true benefits of cost, programme, safety and quality."

A range of different MMC systems are typically used on a high-rise. Bathroom pods are common in residential schemes; Lewis describes the quality of these as second to none. "That's one example where it's worked really, really well for the industry," he says. Unitised cladding systems, or precast panel-based systems, and building service modules are the default on high-rises these days. Lewis says Mace is now on the sixth generation of modularised services, having first used these for the construction of The Shard.

Structural panellised systems are suitable for many other applications, including housing and other low-rise buildings. For example, CLT has displaced insitu reinforced concrete in many situations because the speed benefits outweigh the increased cost of the panels.

MMC is also commonly used for applications where disruption needs to be minimised or access is difficult. In addition to work taking place within existing facilities such as schools and hospitals, prefabricated footbridges and other structures are ideal for transport infrastructure such as roads, railways or airports where work needs to take place at night.

Evidence is needed to show the benefits

According to Professor Campbell Middleton, who heads the Laing O'Rourke Centre for Construction Engineering and Technology at the University of Cambridge, a big barrier to MMC uptake is a lack of clear, consistent evidence that demonstrates a compelling business case for »

WHAT IS MMC?

Modern methods of construction covers a broad range of different systems. The government commissioned Mark Farmer, CEO at Cast, to come up with a definition in 2019.

The MMC definition framework includes seven different types, ranging from pre-manufactured 3D primary structural systems such as modular, pre-manufactured 2D primary structural systems which include panellised systems and pre-manufactured non-structural assemblies and sub-assemblies which include bathroom pods and service modules. The definition also includes additive manufacturing, the 3D printing of parts or even whole buildings and site-based process improvement.

The benefits of MMC

The guiding principle behind MMC is simple: it is better to produce building elements in a warm, dry factory than on a site in a muddy field in the pouring rain.

A factory production process can be optimised for efficiency using repeatable processes and components and can make use of tools such as jigs and computer numerically controlled machines that would be impractical on a construction site.

The standardised nature of factory production means lower-skilled workers can be employed, which helps with costs and at a time of skills shortage. Sophisticated factories could use robotic assembly techniques, reducing operating costs further.

There are numerous advantages to this approach. Construction time is drastically reduced, by up to 50%, because the work has been done in a factory. It is safer because fewer site workers are needed. There is less waste because factory production, with its predictable processes, can use materials more efficiently and offcuts are more easily recycled.

Quality is improved, which means more airtight buildings and greater energy efficiency, and post-construction snagging is reduced. There is less disruption from site works; modular, in particular, is ideally suited for constrained sites such as operational hospitals.

SHUTTERSTOCK

» offsite to clients. One of the centre's objectives is to establish a consistent methodology for measuring construction performance.

As part of this research the university studied the construction performance of 46 new schools. "There were exemplars where it was clearly advantageous to use offsite methods. But there were others which got extremely good performance from conventional construction."

The problem is that in "no two organisations, and even within the same organisation" was performance measured the same way, Middleton says. He adds that some performance outcomes such as quality are very difficult to measure. "Some measure the amount of reward, some the amount of major rework by cost, others the amount of rework by the number of incidences."

Working with research and best practice body CIRIA, the university developed a methodology to measure offsite construction performance based on what it learnt from the schools research project. This includes measuring wider impacts such as workforce wellbeing and the degree of disruption caused by construction work.

It is now applying this methodology to measure the performance of offsite projects, notably The Forge, a Landsec office development in Southwark, south London, that was built using platform construction. The results of this research will be published by the Construction Productivity Taskforce, with the idea being that other projects will be monitored to establish the performance of other offsite methodologies and ultimately benchmarks will be produced to help clients and others make decisions about which methodology to adopt for specific projects.

Design for manufacture and assembly

Designing a building to be constructed traditionally then changing to a factory-based approach is guaranteed to add complexity and cost without realising the full potential of MMC. Instead, projects must be designed from the beginning with a view to factory production, a discipline called design for manufacture and assembly (DfMA).

DfMA includes standardising repetitive elements and, if a project is designed with a specific system in mind, the project is designed around it. As the name suggests, designers must also consider the construction process including site logistics to ensure that the benefits of factory production are fully realised on site. All this information should be captured digitally so the design can be used to directly drive factory production including the subsequent site process.

Laing O'Rourke uses what it calls an integrated delivery model, where the whole job pivots around the product. The job is planned element by element so its Explore offsite factory knows when each component needs to be manufactured and when it needs to be dispatched to site.

The site team know when components are arriving and need to be installed. Mace applies a similar process to all its projects, calling it construction to production. "You bring all the decision-making forward, you find problems earlier, you rinse them out earlier and you get a much more cohesive design into the factory and out the other end," Lewis says.

Crucially, it reduces risk, making it much less likely that the firm will get stung on a problem job. "This will give us long-term efficiencies and better programme consistency, something which the industry is desperately searching for."

The role of logistics

The work done by the University of Cambridge brings home the role played by logistics. Danny Murguia, the research associate monitoring The Forge, says measuring productivity by dividing the total cost of a project by the number of hours worked is a crude metric. Instead, he has been monitoring progress by work package, including the frame, the cladding and MEP modules.

The activity level of each package is assessed against other work packages to see how they work as a system. "You can measure how long it takes to lift a service module, install it and move onto the next one. This gives a sense of how quickly you can do the installation," Murguia says.

"In reality, productivity is much more than that. You can have very fast installation of individual components but, when you see the overall performance of the whole activity, there are several gaps between installations."

The research showed that 10 modules could be installed on a good day, but there were days when none were installed. "Platforms require enhanced site logistics to ensure the skilled workers are doing it continuously," he says. "We found they were moving their own materials or receiving deliveries in the morning, which affected their productivity for the day."

Flow line analysis – which shows periods of activity and inactivity – of the primary steel erection revealed that there was inactivity for 32% of the time. If a dedicated logistics crew were employed to unload deliveries and get these to where they were needed, and workers within teams were trained to be able to install all elements of a work package, then productivity could be dramatically improved.

Murguia says it is better to have a constant rate of activity than peaks and troughs. Modelling shows that, if the teams achieved 75% of the maximum possible speed of installation consistently, a massive 40% could be sliced off the programme.

Avoid building a factory

The differences between construction and manufacturing coupled with the capital needed for product development and production facilities

Top right: The frame of The Forge under construction using a platform system

Bottom right: CLT has displaced concrete from many residential schemes as the programme benefits outweigh the additional cost of the panels

Left: Tide Construction and sister company Vision Modular have made a success of delivering build-to-rent and student accommodation, such as Ten Degrees, two build-to-rent conjoined towers located next to East Croydon station. The architect was HTA Design

> [INTEGRATED DELIVERY] WILL GIVE US LONG-TERM EFFICIENCIES AND BETTER PROGRAMME CONSISTENCY, SOMETHING WHICH THE INDUSTRY IS DESPERATELY SEARCHING FOR
>
> **GARETH LEWIS, CEO FOR CONSTRUCTION, MACE**

people struggle with; they don't have the pipeline to keep the cost of the factory running or to even justify the cost of the factory before they even got into a solution, which in most cases is over-engineered," he says.

Companies such as TopHat and Ilke Homes have opted for a business model with greater potential for success in that they are manufacturers first and developers second. The business model of these firms is primarily supplying third parties such as housebuilders and housing associations, as this is the only way to get the economies of scale needed to support the factories. Yet both firms have yet to turn a profit, and Ilke Homes has reportedly just been put up for sale in a bid to raise more finance.

Clowe says the reason why these firms are more likely to succeed is because they have stuck to a limited number of housing typologies that appeal to their target market. Persimmon, for example, has recently invested £25m into TopHat, the first time that a FTSE 100 housebuilder has invested in a third-party modular manufacturer.

"They [Ilke and TopHat] have put a lot of effort into the design and manufacturing process to get it right. As a result, they have got a product that can compete in the marketplace and which they can manufacture to pipeline."

For some firms, setting up their own facilities makes sense; the MEP sector has embraced offsite manufacturing because it stacks up financially. "Most MEP companies have now got their own variation on pre-manufacturing," Hyams says. "Another reason is because they are struggling for labour. This alleviates the problem as they need fewer people to do the work on site."

And Mace, rather than investing in its own factory like Laing O'Rourke, is using third-party suppliers for its prefabricated high-rise solutions product. The firm worked with Australian prefabricated high-rise construction specialist Hickory to develop a solution that combines a precast concrete slab and a facade section. This is delivered and installed as one unit and can be varied in size according to the specifics of the application.

The product is made by offsite superstructure and facade specialist PCE and precast hollowcore flooring specialist Oranmore, with the product assembled in Oranmore's factory in Brandon, Suffolk. "We do not just use one supplier," Lewis explains. "As we grow, we need a sophisticated supply chain that can adapt themselves to our demand. We do not want to be a factory owner, but have a facility where we can assemble things. We are a designer, a design and build contractor that construction manages, assembles and builds."

This model is widely used; many companies design products in their home countries but get them manufactured and assembled in cheaper places such as China by third parties. Automotive manufacturers design and assemble their products but rely on a complex web of third-party suppliers. Clowe thinks this is the way forward for construction too. He cites the example of Core Haus, a small modular manufacturer based in County Durham, which developed its own product but outsourced all the components. "They created a small, local supply chain, with one making the floor cassettes for them, another the walls, one making the internal bits, one making the bathroom and one making the roof. They haven't turned their factory into a production line but a little assembly hub," he says.

The tendency for modular manufacturers to design and build all the elements needed for a building has another big downside – there are too many different systems on the market. Clowe cites the example of a Ministry of Justice (MoJ) initiative to develop a rapid deployment cell, a 4.5m x 2.5m box that includes a door, window, desk and small ensuite bathroom. The idea is these can be deployed across seven prison sites and the units can be placed in stacks to help manage overspill. The MoJ needs 3,000 units and went to four suppliers. "Every single one has come up with a different design and none of them are interoperable," Clowe says. "Not one of them. They can't sit next to each other, they can't stack on top of each other, you can't line up the rainwater pipes… nothing."

This lack of interoperability and standardisation is a risk for clients; if a manufacturer goes bust halfway through a job it is nigh on impossible for another company to pick the job up.

The case for platforms

Platform systems aim to address these challenges. In essence a platform is a standardised chassis – in other words, a frame to which other components can be attached. These other »

JAMES D EVANS / ARCHOPTICAL

THE MORE PEOPLE USE JUST ONE PLATFORM SYSTEM, THE GREATER ECONOMIES OF SCALE AND THE GREATER THE BENEFITS

JAIMIE JOHNSTON, HEAD OF GLOBAL SYSTEMS, BRYDEN WOOD

Right: Manufacturers such as Ilke Homes primarily supply third parties such as housing associations in a bid to get the economies of scale to support their factories

Below: Rather than build its own factory, Mace sources the elements for its prefabricated products from third-party suppliers

The Grange, a new hospital in Wales, was built by Laing O'Rourke and delivered four months early thanks to DfMA

» components allow for a degree of customisation. They are widely used in manufacturing – for example, in the car industry. Volkswagen Group spent billions developing its MQB platform, which is now on its second iteration and used for a wide range of smaller models across its four brands.

A report by Mott MacDonald for the Construction Innovation Hub takes the definition further by describing a platform as a set of standardised, repeatable components and a standardised, repeatable process. This includes people and relationships, in the sense that long-term relationships drive innovation including the economic advantages of repetition.

According to the report, platforms have the potential to reduce construction costs by up to 31% as well as the usual MMC advantages of improving safety, reducing the need for skilled labour and cutting carbon emissions.

The advantage that platforms have over other forms of MMC is the potential for different manufacturers to make components for a standard platform system, which increases competition and reduces the risk to clients if a manufacturer goes bust.

The Seismic consortium, which developed a standardised lightweight steel frame based around a connection node, uses components from two different manufacturers, Algeco and McAvoy, with other manufacturers, including Tata, making components such as cladding and roof cassettes that bolt onto the frame. Components can be delivered to site individually or, in the case of Algeco, assembled into fitted out modules.

The government is throwing its weight behind platforms with a vision of mass adoption by 2030 because, as construction's biggest client, it stands to save a lot of money. A core policy of the Construction Playbook is to accelerate and promote the use of platforms, and the Infrastructure and Projects Authority publication Transforming Infrastructure Performance: Roadmap to 2030 talks of mandating platforms.

Platforms undoubtedly have many advantages compared with other MMC systems, but they are subject to some of the same problems; namely different consortiums developing proprietary systems that are incompatible with the others.

"My concern is too many people are saying they need to develop their own platform design," says Jaimie Johnston, head of global systems at engineer and architect Bryden Wood, which has been instrumental in developing and promoting platforms including for the MoJ, The Forge and Seismic. "The more people use just one system, the greater economies of scale and the greater the benefits. You need to make it ubiquitous so the barrier to entry just disappears."

Bryden Wood has developed its own, open-source platform system and wants it to be adopted by the industry at large so it becomes as ubiquitous as scaffolding, in that all the parts are readily available, simple and cheap and everyone knows how to put it together. This system offers flexibility in that the column and beam lengths can be easily varied to suit the application.

"That was always our idea, that people would use our solution," Johnston says, adding that there is room for variations on a theme, such as a system based on timber. He says a platform should be a carrier frame for other components, giving architects plenty of design flexibility.

The government is waking up to the need for systems interoperability. The Department for Levelling Up, Housing and Communities (DLUHC) recently appointed MMC consultancy Akerlof to lead a research project investigating the feasibility and benefits of standardisation for key MMC components, connections and sub-assemblies to facilitate interoperability between different MMC systems in housing. This work includes identifying the structural components in housing suitable for standardisation and investigating platform systems to see if an open-source kit of parts could facilitate interoperability between them.

Jamie Hillier, a partner at Akerlof, says greater construction efficiency is more than just a set of standardised components. He cites Akerlof research investigating NHS Trust-commissioned construction work since 2010 to see the difference that platforms could make to future spending, including on the New Hospital Programme.

The research discovered that just 10 firms were involved in the delivery of 75% of the investment.

"If you can get those parties to work together more collaboratively, you could start to get some real progress," Hillier says. "Some of the principles around platforms might actually be manifest in different ways. It might not be around product, but more around process, people and relationships as well."

The role of procurement

Everyone to whom Building spoke for this piece agreed that a favourable procurement route was one of the key ingredients needed for MMC to succeed. The MoJ worked with Bryden Wood to develop a platform system for its prison estate transformation programme. Johnston says this did not work out because the contractors had been appointed to a framework some years ago with projects delivered on a lump sum basis.

"The reason why this fell down was the procurement couldn't work as the contractors said they didn't sign up to deliver buildings using platforms. They said they were being asked to do a completely new thing with a potentially new supply chain where the risk is uncertain, and it all sits with them," he says.

Cambridge university's Middleton concurs. "The challenge is, unless the whole supply chain – from clients through to design through to the delivery – are geared up, and have the capacity, the will and the incentivisation to do it, it's very hard to make it work." He says the whole supply chain needs to buy into the concept, including the client, who has the power and incentive to drive adoption and controls the procurement route.

Landsec chose construction management for The Forge as this took the risk away from the contractors and enabled it to get closer to the supply chain. Specialists were engaged under pre-construction service agreements so that they could contribute their expertise to the MMC process at an early stage.

Johnston says that while construction management worked on The Forge, it is not the ideal form of procurement. Some later processes such as cladding installation rely on earlier packages to be executed to a high standard to enable that later process to take place smoothly. But the teams executing the early stage packages do not get the benefits enjoyed by the subsequent teams so have no incentive to go the extra mile.

And it does not incentivise the construction manager either as they have no reason to deliver the project more quickly. Johnston says that integrated project delivery (IPD), a procurement route used in other countries, is a good solution. "The way IPD works is everyone declares their overheads and management fees and then there is a shared profit pot. It is everyone's job to make that profit pot as big as possible.

"IPD incentivises everyone to do the best they can for the sake of the project and for the sake of all the other teams. And that's quite different to how we normally procure, where we just buy package by package and where everyone is focused on just delivering their package."

Could the government help drive change?

The government has thrown its weight behind MMC, and platforms in particular, but how is it driving that change? It needs to reform its procurement to break down the barriers. For example, public sector procurement rules seek to obtain so-called best value, which is predicated on a competitive tendering process. The Grange, a £350m hospital in Cwmbran, Wales, was built by Laing O'Rourke and delivered under budget and four months early thanks to DfMA. Competitive tendering was not going to work given the need for close collaboration between all the suppliers. It took a lot of work to convince the Welsh government to switch away from competitive tendering and sign the more collaborative NEC contract, which meant it shared the risk – and rewards – of the job.

The success of this project saw Laing O'Rourke invited for a meeting with the Cabinet Office to discuss how the lessons learnt could help deliver the New Hospital Programme (NHP) – the government ambition to build 40 hospitals in less than 10 years. The NHP leadership say that standardised and modular designs will be used on the programme in a bid to deliver the hospitals 20% cheaper and 25% faster. A programme delivery partner is to be appointed by September. But the big question is, will the NHP procure this work using an alliancing or IPD approach? "The opportunity for the NHP to crack this is there because it's a new programme and because it's got potentially some new terms of reference," Johnston says. "We are watching this with interest because, if they do it and prove it at scale on healthcare, then that's it – you have transformed social infrastructure delivery forever."

Could the government give the industry a push by mandating MMC, as it did with BIM in 2016? The Infrastructure and Projects Authority's Roadmap to 2030 suggests as much. It stated that it would mandate the use of platforms over the next two years for social infrastructure. That two years will be up in September, which makes it look unlikely.

Johnston reckons the government was hoping the industry would embrace platforms without being pushed, as the benefits were so great that it would do it anyway. He says the industry may well recognise the benefits, but this means it will need to change its business models to make this work, which it is reluctant to do unless it is convinced that enough work is coming down the pipe to justify it. And the government is cautious about how much it spends unless it knows it is getting better value for money.

Johnston says the government and industry should meet halfway, as they did with the BIM mandate. The government could publish standards for MMC and help resolve issues such as who is liable if a standardised design goes wrong, and who owns the intellectual property of those designs.

The DLUHC is already making moves in that direction; it recently commissioned the British Standards Institution to develop a standard for offsite homes. The department says this will help with access to product warranties, insurance and mortgages and promote the takeup of MMC. Although there are many issues to overcome, there is a sense that things are moving in the right direction. Rigorous research is being undertaken to decisively prove the benefits of MMC, a process that is also revealing how the operation could be made much more efficient.

Meanwhile, in the background, despite the failure of firms such as L&G, many within the industry are quietly getting on with changing how they build for the better.

MACE. MICHAEL WHITESTONE PHOTOGRAPHY

DIGITAL CONSTRUCTION ARE WE NEARLY THERE YET?

Many industries, including manufacturing and retail, are using data to gain new market insights and improve their services. In the third in our series on innovations with the potential to transform construction, **Thomas Lane** asks what it will take for the industry to catch up

My local supermarket is at the forefront of making food shopping quicker, cheaper and easier. It is one of a handful of UK supermarkets where customers walk in, put their purchases straight into carrier bags and leave without fear of being chased down the street by security guards. An app is used to enter the store, cameras monitor everything bought and an itemised receipt is emailed shortly afterwards.

The system identifies purchases with amazing accuracy, and the experience is quick and convenient. And because it make it impossible to steal anything, this approach should lead to lower prices – since the store is unlikely to fall victim to the £1.76bn annual cost of retail crime which everyone is paying for in higher prices.

There are no security guards; instead there are staff dedicated to helping customers. Critics will say camera-monitored shopping is very "Big Brother", but anyone who thinks they are not being captured on CCTV when they go into a supermarket is under a delusion. True, the system excludes people without smartphones or bank accounts, but there is another supermarket less than 50m away – complete with a bank of self-service checkouts, which seem to attract more complaints than ones without.

This story demonstrates how other sectors are already embracing sophisticated digital technology to provide a better, more convenient customer experience and reduce costs too. Construction, on the other hand, has been rather slower to embrace the full benefits of digital technology, which is hampering efforts to overcome its low productivity, high costs and project overrun problems.

In the third in our series on how innovations could transform construction, we look at how far construction has come down the technology road – and how much further it still has to go to catch up with the likes of the big supermarkets.

What is the extent of digital adoption?

The use of technology in construction has come a long way since the days when 2D CAD was regarded with suspicion by those who thought it would never replace the drawing board. Building information modelling was another leap forward as it enabled designers to attach attributes to objects in a model that could be shared by others in a project team and used for project costing and planning, and for building operation by clients.

Initially slow to adopt BIM, the industry was given a big helping hand by the 2016 BIM mandate which required anyone working on public sector projects to use the technology. The mandate was backed by the BIM Task Group which supported the industry with guidance and standards to make adoption easier and more consistent.

There are multiple other technology tools available today to improve efficiency; project collaboration platforms where teams can share information securely online, project planning tools and, more recently, virtual reality where teams can rehearse project delivery in a realistic, 3D environment. Virtual reality is also useful for enabling clients to experience what their building will look like and the effect of design variations.

There are many other tools, such as point cloud scanners for capturing as-built information for refurbishment projects, snagging software and lone worker monitoring systems which allow workers to send alerts in case of an emergency.

Building THE FUTURE COMMISSION CELEBRATING 180 YEARS

> THE NOTION OF GETTING ORGANISATIONS TO SHARE INFORMATION, METHODS AND DATA FREELY WHILE THEY ARE IN COMPETITION IS, IN ANY OTHER WORLD, JUST BONKERS
>
> **MARK BEW, CEO, COHESIVE**

Firms use sophisticated information management systems for internal processes, with more and more turning to the cloud as this allows people to work from anywhere with an internet connection, particularly useful for construction.

Machine learning is making inroads too. Generative design tools can quickly crunch through a list of client needs and project constraints to produce a shortlist of design options from which a team can develop in detail. Machine learning tools can scrutinise images of building facades, roads and so on and quickly identify defects. There are tools such as nPlan which use machine learning to examine tenders to see which are the most realistic, and project delivery plans to identify unforeseen risks.

Mark Enzer, the former director of the Centre for Digital Built Britain and strategic adviser on digital transformation at Mott MacDonald, says there are plenty of excellent examples of digital adoption in the industry, but these are happening in relative isolation. "There is everything from digital surveying techniques, the automation of plant, digital delivery processes using artificial intelligence in all sorts of interesting ways including using it to spot problems on programmes, to using data and digital processes to improve health and safety onsite," he says.

"There are plenty of good examples, but they're not evenly distributed across the industry. It is hard to see how they could scale up, because an awful lot of the good examples are clearly within the bounds of an individual project or organisation and it is very hard to see how those can actually be shared across the whole industry."

Mark Bew, former chair of the BIM Task Force and now CEO of digital solutions specialist Cohesive, says industry firms have embraced digital technologies for internally facing processes more readily than those that facilitate information-sharing and collaboration between external teams. "The adoption of organisational tech has always been ahead because people are trying »

SHUTTERSTOCK

HMP Five Wells in Wellingborough is a fully digital construction and building operation scheme. Kier adopted a digital first approach to enable it to monitor, manage and communicate across the wider team

» to gain competitive advantage," he says. "I'm seeing companies really getting into corporate data and improving their internal businesses."

He adds that manufacturing-focused firms have been particularly good at automating processes, whereas the teams within cost consulting and project management firms have been poor at sharing their data with others. There is a new trend of these firms putting information into central libraries to better analyse cost and programme performance.

Construction projects bring together multiple companies which need to collaborate and share information for effective delivery. BIM is a central part of that collaboration process, which is why it was mandated for public sector work in 2016. But this is where the industry underperforms compared with the adoption of internally facing digital tools.

The NBS digital construction report – an industry survey of digital technology adoption last carried out in 2021 – showed that 71% of respondents had adopted BIM. This has fluctuated between 69% and 73% since 2018, suggesting that BIM adoption had reached or was close to saturation point. BIM adoption covers a broad spread of ,uses ranging from internal facing use as a 3D design tool to sharing data for external collaboration with other members of a team.

The latter application is where Bew reckons the industry is still lagging because its underlying structure militates against greater collaboration. "The old problems that we've always had are still there," he says. "We take businesses through a process of competition to select them and then ask them to collaborate. The notion of getting organisations to share information, methods and data freely while they're in competition is, in any other world, just bonkers."

The potential of digital twins

To improve industry productivity, the ideal is for project teams to use digital tools and processes collaboratively to design high-performing, attractive buildings and deliver them efficiently. Clients take some of that digital information to operate and maintain the building efficiently and sustainably. The 2016 BIM mandate, so-called level 2, was designed to facilitate digital collaboration by setting out how data should be classified, and included information exchange methods to enable collaboration between teams for design and delivery.

Firms created their own models and combined as a federated version to protect their intellectual property. The primary focus of the 2016 mandate was design and construction. There was a nod to the operational benefits of BIM as it included the so-called COBie protocol for handing as-built information over to clients ready for them to populate facilities management software tools.

Level 2 was seen as a stepping stone to level 3, where firms shared information in the form of intelligent objects – the 3D building elements in a model combined with data describing attributes such as cost, the make, service intervals and so on – in a common data environment rather than using federated models.

Since then, the notion of BIM level 3 has been replaced by the digital twin. As its name suggests, this is a digital manifestation of a physical building, including an as-built 3D model complete with comprehensive information about the physical assets making up that building. This is linked to the building's systems to facilitate more effective operation and maintenance.

Bew, whose company Cohesive helps create digital twin strategies for clients including HS2 and manages these on their behalf, says the real benefits of digital twins are gained during the post-completion building operation and maintenance phase, particularly in terms of reducing operational carbon emissions. The other big benefit is that knowledge gained from that operational phase can be used to improve the design and delivery of subsequent projects.

Indeed, the digital twin process operates as a kind of virtuous loop, which starts off with client requirements that inform the building design which is done digitally. The design goes through a testing process to make sure it meets client and all regulatory requirements before construction work starts. Bew says not enough attention is paid by clients, particularly the public sector, to this stage. "This should be part of the green book [public sector appraisal and evaluation] and investment process, so that there's a digital assurance and pathway in the business case before you start spending money on concrete and steel," he says. "That would dramatically change the way that we provide assets in the future."

The digital twin is updated as necessary to reflect the completed building. It is linked to building systems via an array of sensors that monitor how different building elements such as a pump or a lift are performing. The digital twin is used to optimise operational energy efficiency and can detect via the sensors when something is not operating as it should, enabling an intervention before the item fails.

This aspect of a digital twin helps to ensure buildings are operated and maintained optimally. Performance is measured against the initial requirements. If the building doesn't measure up, this information is captured and used to inform the next project so the issues that contributed to subpar performance are not allowed to recur.

The Centre for Digital Built Britain, a partnership between Cambridge University and the Department for Business, Energy and Industrial Strategy that ran between 2018 and 2022, established the national digital twin programme – which, as the name suggests, is an ecosystem of connected digital twins that enables data to be shared between organisations, leading to better-performing assets.

There is a long way to go to realise this vision. Bew says very few clients are leveraging the full potential of digital twins, let alone sharing these with other organisations. "We have seven to 10 clients globally and not many are in the UK."

HS2 and Highways England have digital twin strategies – both organisations have a lot to gain as these can be used to operate and maintain their rail and road networks respectively. Bew is not concerned about the low rates of digital twin adoption, saying that three London developers are close to achieving digital twin maturity, with another three on the rung below. He adds »

> IF YOU TOOK A QS FROM 1890 AND TIME TRAVELLED THEM TO NOW, I RECKON, WITH A COUPLE OF WEEKS' TRAINING ON EXCEL AND SOME TIME TO GET OVER THE CULTURE SHOCK, THEY WOULD STILL BE ABLE TO FUNCTION AS A QS
>
> **JAMES GARNER, GLOBAL HEAD OF DATA AND INTELLIGENCE, GLEEDS**

Big infrastructure providers, including HS2, want to use digital twins to run their networks more efficiently

TIME TO EMBRACE A STEP CHANGE

All the experts to whom Building spoke for this piece emphasised the need for an industry step change by moving to a more open, collaborative model of information sharing. Cohesive's Bew says if information were more transparent – for example, knowing how buildings are performing – this would open up new ways of demonstrating value rather than lowest price. He says other industries have managed to drive out huge chunks of cost and waste by the effective use of data.

"The retail market completely reversed the whole value chain, and until recently we've enjoyed much cheaper food than if we had stayed in the old model," he says. "Amazon has completely transformed the retail supply chain; small organisations can compete on the same basis as big organisations without anyone knowing."

For Garner, artificial intelligence will be the catalyst for major change. "The big paradigm shift that's happening is not just doing things digitally, but totally reinventing how we do things," he says.

"AI is important because it is allowing us to… do things totally differently. So instead of taking a process such as tendering and asking how can we do that digitally, what we need to ask is: why are we doing it like this in the first place and what would it look like if we were to invent it from scratch? If a big tech company was to come in and start from scratch, would they do it the same way? Probably not."

Garner says the industry is vulnerable to a big company coming in and doing exactly that by inventing new, more effective ways of doing things, then selling this back to the industry. He cites the example of the music industry, where artists receive tiny amounts of the money generated from streaming.

"If we don't take control of the situation as an industry, then my fear is that the big tech companies will – because that's exactly what they've done in other industries," he says. "If you take the music industry, you can see how that's been decimated and totally transformed by the advent of streaming. This wasn't because music was digitised but because streaming totally changed the way that people consume and interact with music."

Garner says companies need to become much more protective of their data, for example when signing licence agreements for software products. He says: "The industry needs to come together and put some rules and governance in place. Yes, let's embrace these tools – but we don't have to just sign away our knowledge to the big tech companies."

Enzer describes the transformation the industry needs to go through in terms of three horizons. The first is business as usual, which is difficult to break out of because there are so many pressing issues such as energy and material prices to focus on. The second horizon is a stepping stone such as reforming procurement to facilitate the third. The third horizon is a much more connected industry where there are common approaches to a whole raft of processes, including data management. This will not only make the industry more productive and efficient but also help it tackle big issues such as climate change.

"We are getting to the end of the road of doing what we've always done and not making a change," he says. "We will find that climate resilience is a systems-based thing, and we've got to embrace joined-up thinking because you can't solve a big systemic challenge in silos."

IF WE DON'T TAKE CONTROL OF THE SITUATION AS AN INDUSTRY, MY FEAR IS THAT THE BIG TECH COMPANIES WILL – BECAUSE THAT IS EXACTLY WHAT THEY'VE DONE IN OTHER INDUSTRIES

JAMES GARNER, GLOBAL HEAD OF DATA AND INTELLIGENCE, GLEEDS

» they have realised that creating and managing digital twins is not part of their core business so Cohesive does it for them – a model that could become more common for smaller businesses which stand to benefit from digital twins but do not have the specialised expertise to build and run them.

The data management challenge

Data is the building block of digital technologies, and the way it is stored, organised and accessed is fundamental to success. Machine learning, in particular, relies on high-quality, consistent data. Unfortunately, construction suffers from poor-quality data and information management, which is a major barrier to more effective collaboration.

Construction lags behind other industries as it has a habit of taking paper-based processes and digitising them – the classic example is a pdf document – rather than making direct use of the data. "If you took a QS from 1890 and time travelled them to now, I reckon, with a couple of weeks' training on Excel and some time to get over the culture shock, they would still be able to function as a QS," says James Garner, the global head of data and intelligence at Gleeds.

Bew says there are signs that industry firms are beginning to move away from a paper-based mentality where firms, or even departments within firms, operate in silos and are unable to effectively share information. "Every other high-performing industry is routinely sharing data, not files. We need to stop sharing electronic paper or indeed actual paper and move to a place where we routinely share objects and proper atomic data," he says.

"And that is happening; we are starting to see products come on to the market that enable object-level sharing, and we're starting to see a few big projects like HS2 and Highways England beginning be able to cope with data. It is progressing." While that is a good sign, Bew says creating systems to integrate data so it can be used for high-value purposes such as digital twins is expensive and that the systems tend to be bespoke to each organisation, which precludes wider data exchange.

Above: Supermarkets such as Aldi are trialling checkout-free shopping using sophisticated technology, including artificial intelligence

Right: Terminal 5 at Heathrow was the first major project to use a common data environment for design and construction

"That integration strategy is expensive and not repeatable as each one is bespoke to the client because each one has its own requirements, language and processes. There is some good functionality emerging, and there is some good understanding of data quality and driving that up. But the standardisation of object-based data is missing and so the ability to be able to share that on a widespread basis is missing."

Enzer agrees. For him the industry is being held back by being unable to share best digital practice. "There are examples of clients who crack how to get the supply chain to provide excellent services on a project. But that supply chain is broken down and reformed in a completely different shape for another client on another project. Because they can't share that across the whole industry, you end up with a frustrating picture of excellent examples in lots of different places that just don't connect," he says.

Promoting better information-sharing

There are some established open data standards used by the industry, such as Industry Foundation Classes (IFCs). The IFC schema describes the names and attributes of objects which can be used for how an asset is designed, built and operated. It is described by an international standard and is designed to be easily used across a wide range of platforms and devices.

Contractor Kier used IFCs as the primary information exchange for the design and construction of HMP Five Wells for the Ministry of Justice and for providing data to the MOJ for building operation. It is also developing a digital twin using IFCs for the design and construction of HMP Millside for the MOJ and intends to develop these in the future for operation too.

IFCs are useful for exchanging data, but they do not describe how information or processes should be organised. Enzer says the industry needs to agree how data should be shared consistently across a variety of processes so project teams can use the same approaches on multiple projects for multiple clients. This would need to transcend sectors for the national digital twin programme too.

Aware of this issue, the Centre for Digital Built Britain created an information management framework setting out a high-level approach for managing data so it could be used by multiple parties, used consistent definitions for assets, was consistently structured, and could be trusted. "The information management framework goes into the space of digital twins and connected digital twins," Enzer says.

"Data isn't just being shared around a project, but being shared between organisations, say between a client organisation and a regulator, or between one regulator and another, or between energy and transport. It is a much bigger ambition for secure and resilient information flow. The benefit to the country would be absolutely enormous if we could get our act together and make that happen."

The Centre for Digital Built Britain has now been disbanded but Enzer says there are multiple organisations continuing the national digital twin agenda, including the Digital Twin Hub where over a hundred people meet on a call each week to share best practice. There are other initiatives, including a digital twin demonstrator on the Isle of Wight which is being led by the Department for Business, Energy and Industrial Strategy. And there is the Apollo Protocol, a mechanism for formalising cross-sector digital twin interfaces which is being promoted by the Institution for Engineering and Technology.

Enzer praises these initiatives but cites them as another example of industry fragmentation. He says this is why the industry needs to find a way of connecting and co-ordinating these and other digital initiatives to come up with an agreed, coherent set of standards that everyone could adopt.

The role of government

The success of the 2016 BIM mandate backed by the support of the BIM Task Group begs an obvious question: should the government stage another intervention to drive the step change that is needed to create a 21st-century digital construction industry?

Bew, the former chair of the BIM Task Group, says that although this might sound appealing, he considers it a "blunt instrument".

"To raise awareness and get people to move the game forward to get very high value, you need to create competition and create an environment rather than a policy," he says.

The mandate covered the use and exchange of data. Most of the BIM Task Group's work focused on protocols and methods of data exchange which were not mandated.

"What that did is it allowed competition to happen on both sides and allow people to communicate," he says. "For the data journey we need to look at what it is we are trying to achieve and what is the minimum touch we could do. It's a very thoughtful, careful minimum intervention backed up by policy and a long-term commitment to the supply chain."

Garner says the industry cannot sit around waiting for government intervention but must take the lead. "We cannot afford to go at the pace of government, because they can't keep up with the pace of technology. We will be lucky if we get some regulations on ChatGPT by the time we're on to the next iteration of AI," he says.

"The government will look to the industry bodies for guidance, and there is a role for government in terms of enacting it."

Enzer dismisses the idea of government intervention, partly because it does not have the money, which was the reason why the Centre for Digital Built Britain was disbanded, and because he thinks a top-down, command-and-control approach will not work. Instead, the industry needs some visionary leaders, who want to change things for the better, to bring people together to develop a vision for construction.

"I don't think that an over-centralised approach is what we want. What we need is an approach to leadership that brings people together and, in my experience, this works really well."

Bew points to Paul Morrell, who proposed the BIM mandate during his stint as chief construction adviser to the government. "Paul Morrell was just an absolute genius at supporting us [the BIM Task Group]," he says. "His relationship with ministers and the political scene and aligning that was the power of what we did."

Unfortunately, Bew does not think there is anyone in government or industry with the ability to progress the digital agenda, because of covid, government ructions and now inflation and the cost-of-living crisis. "Let's recognise that and spend some time over the next couple of years getting clarity on what the intervention should be," he says.

"So that, when an administration does come in that has the bandwidth and time, the industry is ready rather than rocking up with a half-baked idea then wondering why it doesn't get traction. We should be developing that idea now ready to be submitted in two years' time."

The message is clear: the industry needs to come together to develop a digital strategy on its own terms – before someone else does it instead.

SHUTTERSTOCK

This deep green refurbishment of an old office building for the Cambridge Institute for Sustainability Leadership could be an exemplar for the future. The existing structure was retained and the raised access flooring carefully removed at the beginning of the job, cleaned up and reinstated. Some of the light fittings were removed from a London office and inspected and warranted by manufacturer Phillips

Building THE FUTURE COMMISSION CELEBRATING 180 YEARS

WHAT TO DO ABOUT CONSTRUCTION'S CARBON PROBLEM?

With new construction responsible for some 11% of global carbon emissions, the problem is clear enough. But what's the solution? In the last of our four features on industry-changing innovations, we look at how the industry can mitigate the upfront embodied carbon impacts of construction. **Thomas Lane** reports

Last month's decision by Michael Gove to refuse Marks & Spencer permission to demolish and rebuild its flagship store on Oxford Street marked a turning point for the industry. For the first time ever, a planning application was rejected on the grounds that a new-build would emit far more carbon emissions than a refurbishment unless the electricity grid was decarbonised.

M&S had argued that a new-build would have lower whole-life carbon emissions than a refurbishment, but the Department for Levelling Up, Housing and Communities decided that, if the development were delayed until the grid was decarbonised, the upfront carbon of a new store would be "much lower or eliminated".

In a year of record high temperatures on land and in the sea, and extreme heat and wildfires in Europe, the time for urgent action on climate change is very much here and now. New construction is responsible for some 11% of global carbon emissions so the industry must act to reduce those emissions and, as the M&S decision demonstrates, is likely to be forced to do so via the planning system. So, how can the industry mitigate the upfront embodied carbon impacts of construction?

Reusing buildings

The most effective way to reduce upfront embodied carbon emissions is to not build anything. But given that the built environment has to respond to changing societal needs – and old buildings must be periodically refurbished to keep them up to date and efficient – some construction work is inevitable.

The big London-based developers have already taken this on board and are making efforts to retain the frames of buildings where these have sufficient floor-to-ceiling heights and structural capacity and are also in good condition, as the frame often includes 50% or more of the total embodied carbon.

Ideally other elements should be retained where possible – for example, up to 15% of embodied carbon is in the facade. British Land chose to carefully remove, refurbish and reinstall the 20-year-old facade of its 1 Triton Square office in central London rather than replacing it. Keeping the 3,000m² facade saved 2,400 tonnes of carbon and 66% of the cost of a new facade. Replacing the double-glazed units ensured that the building was energy efficient too.

Occupier demand for low-carbon space and government moves to require all non-domestic buildings to have a minimum EPC B rating before being rented out by 2030 are driving the retrofit and refurbishment of existing buildings.

Simon Wyatt, sustainability partner at multidisciplinary consultant Cundall, says replacing the lighting and fans and improving the energy efficiency of mechanical systems will pay the upfront carbon back in a reasonable space of time, but he questions whether it is worth upgrading the building fabric. "In order to get the best energy performance, you need to start doing work to the fabric of the building. And this is where – going forward – there is going to be a bit of uncertainty over the next five to 10 years, as the embodied carbon of doing the works to improve the operational energy may not pay back in carbon terms," he says.

The uncertainty comes from not knowing how quickly the grid will decarbonise as carbon is being expended now on materials to save energy over 20 years, and the carbon impacts of that energy depend on how it is generated. This calculation is complicated by the fact that current grid decarbonisation assumptions include energy efficiency improvements being made to buildings and, if people hold back on the grounds that the carbon payback does not stack up because the grid is decarbonising, the process will take longer.

> IN ORDER TO GET THE BEST ENERGY PERFORMANCE, YOU NEED TO START DOING WORK TO THE FABRIC OF THE BUILDING – AND THIS IS WHERE THERE IS GOING TO BE A BIT OF UNCERTAINTY OVER THE NEXT FIVE TO 10 YEARS
>
> **SIMON WYATT, SUSTAINABILITY PARTNER, CUNDALL**

Reusing materials

If the case for demolishing a building is overwhelming, the next-best option is to reuse the materials as this is less carbon intensive than reprocessing these into new products. Some building materials, such as London stock bricks and hard landscaping products, have been reclaimed for many years as these were easy to reclaim with a high value, making the exercise worthwhile.

There is growing interest in reusing a much wider range of materials, such as raised access flooring and structural steel. Recently several London developers, including Grosvenor and Great Portland Estates, have experimented with reclaimed structural steel for new-build projects. Because this is a nascent industry, sourcing the steel can be a challenge. Both Grosvenor and GPE reclaimed their steel from existing buildings within their portfolios which were due for demolition.

Audrey McIver, a director at multidisciplinary consultant WSP, sources reclaimed steel from a big scrap dealer called EMR and stockholder Cleveland Steel & Tubes; both suppliers certify the steel for reuse. McIver's team have to match the section sizes in the design against the suppliers' stock list. The available steel sections are unlikely to exactly match the design, so it is a case of establishing a best-case match. Working out that best-case match for all the steel in a building is a fiendishly complex task, so WSP has developed a parametric modelling tool to simplify this job.

Another complication is that, by the time the building gets to site, the reused steel sections identified at the design stage may no longer be available. McIver says this is not necessarily an issue. "The stockholders do have visibility of what is coming as they know their market and what is coming up for demolition. So we have a sense of what is more risky in terms of »

SOLK PHOTOGRAPHY / ARCHITYPE FIELDEN MAWSON

» section size than others," she says. "And what is the worst that could happen? We would have to use some new steel, which is what we would have had to do anyway."

McIver adds that, in carbon terms, it is not worth using significantly heavier steel sections than called for by the design. "If the one that is available is 20% heavier than the most efficient new section, you are probably better off giving someone else a chance to use that beam, or sending it off to be recycled in the normal way, because the recycling is a very mature and efficient process," she says.

David Watson, AKT II's technical director and climate change lead, reckons reclaimed steel is a transitional phenomenon as steel production decarbonises. This is because old steel sections can be completely recycled into new ones.

"The carbon cost of reprocessing steel is going to come down to the point where any small amount of wastage when reusing steel is going to be difficult to justify," he says. McIver adds that, as more buildings are refurbished rather than demolished, the supply could dry up.

Concrete is much more difficult to reuse than steel; the default is to crush it for aggregates. Gerry O'Brien, AKT II's design director, says there is a trend toward cutting out whole pieces of floor slab for reuse because planners see this as a good thing. "When you put in a circularity submission for a planning application, they don't like the idea that you will reprocess the material. They would rather have it used as close to how it exists at present," he says.

O'Brien thinks this approach is problematic as crushed concrete is much more versatile than chunks of floor slab, which have to be transported and stored until the right use can be found. And aggregate for new concrete needs to come from somewhere. "Thirty percent of the aggregates that we use in the UK every year comes from reprocessed aggregates," he says. "If this wasn't available, we would be digging 30% more out of the ground." Innovation could come to the rescue as the cement paste binding the aggregates could be reclaimed by extracting the unactivated cement in the concrete and reactivating the hardened paste.

What about the materials used for the fit-out and services? Wyatt cites reclaimed access flooring as a exemplar for these elements.

"This shows it has to be done professionally," he says. "Suppliers take the flooring away, clean it up and make it good, and provide a warranty. Agents are quite happy to point to a scuffed-up floor and say it has been recycled. Isn't that a great story? That has been really positive, and we need to see that across the wider industry."

Wyatt questions why elements such as ductwork and cable trays are scrapped when they could be easily reused. "Ductwork and cable trays are generally melted down and recycled, but why are we wasting that energy and that carbon to do that when they're perfectly functional as they are?" he asks.

Left: Developer Grosvenor used reclaimed steel for the rooftop extension of its Holbein Gardens refurbishment

Below: Seratech, a mix of silica and cement, is effectively carbon neutral thanks to the CO_2 sequestered by the silica

Right: Marks & Spencer was refused permission to demolish and rebuild its Oxford Street store on sustainability grounds

> DUCTWORK AND CABLE TRAYS ARE GENERALLY MELTED DOWN AND RECYCLED, BUT WHY ARE WE WASTING THAT ENERGY AND THAT CARBON TO DO THAT WHEN THEY'RE PERFECTLY FUNCTIONAL AS THEY ARE?
>
> **SIMON WYATT, SUSTAINABILITY PARTNER, CUNDALL**

Wyatt reckons that fan-coil units could be reused too. "An office could have several hundred fan-coil units. When there is a new fit-out, they are put in a skip and taken away. Some 80% to 90% of the embodied carbon is associated with the shell; the only thing that needs to be replaced is the controls, motors and the fan because these are much more efficient now. The rest of the fan-coil unit can be retained.

"What we need to do is work with the MEP industry in the same way as the raised access flooring industry, so these are taken away by the suppliers, made good and reused."

Wyatt adds that this could apply to lighting and other services too. Material passports could make this process easier in the future as these would provide details of the components in a building, rather than needing to find out via surveys which are time-consuming and expensive.

Use materials more efficiently.

As materials are cheap and labour is expensive, many structures use material extravagantly to save time. For example, the flat slab is the default choice for concrete frames because these are quick to construct and the flat soffit simplifies the services installation.

Waffle and ribbed slabs were popular 50 years ago and used concrete more efficiently because these dispensed with concrete on the underside of the slab which was not contributing anything structurally. This can reduce embodied carbon by 20%-30% but take longer to build and complicate the services installation.

The same is true of steel frames. Arup designed every structural element used on 8 Bishopsgate, a 50-storey office tower in central London, for its individual load, which reduced steel weight by 25%. Avoiding long spans and irregular grids also makes a big difference.

"We've been able to get the embodied carbon of a number of steel buildings that we have been working on recently from over 1000kg/CO_2/m^2 down to 600kg/m^2/CO_2 just by looking at the efficiency of the steel frame," Wyatt says. "It's making sure the structure is regular, the spans aren't too long, and the depths are right. This reduces material and drives down cost."

Ensuring that the structure is not overdesigned for the loads it will carry also saves carbon. This applies to services too. More rigorous building performance analysis of building designs helps here – for example, using the NABERS design for performance process in addition to Part L.

Peter Fisher, the architect on Timber Square, an office building in Southwark, says the NABERS modelling enabled the team to reduce the number of heat pumps needed on the scheme. "On the first round of NABERS, we found the air-source heat pumps would be operating at 20% of capacity at peak, whereas these should be operating closer to 60% [for maximum efficiency]. We were able to remove some of the air-source heat pumps because they were never going to be used."

Organisations that set performance standards for buildings are revising them to reduce the carbon impacts; the British Council for Offices published an update to its Guide to Specification this year which included adding smaller spans to the recommended range to help reduce carbon. Wyatt says the Chartered Institution of Building Services Engineers is also working on guidance to reduce the oversizing of services and maximise performance.

Opting for low carbon over high-carbon material seems an obvious thing to do, but O'Brien adds a note of caution. "If you look at carbon intensity per tonne, the carbon intensity of timber is really low, the carbon intensity of steel is really high and concrete is in the middle. If you do it against the Young's modulus [the material stiffness] then they would all be on the same line."

In practice this means the carbon impact of a structure could be the same regardless of the choice of material, because less high-carbon material is needed for the same performance. Distribution centre developer Prologis has focused on delivering low-carbon buildings for many years and has found a steel portal frame has less embodied carbon than a glulam structure and has the additional advantage that the steel can be easily recycled if the frame cannot be reused at the end of a building's life.

Watson says architects are starting to think along these lines too. "Some architects are starting to look at embodied carbon per square metre of finish. Not per tonne of material, but per unit of performance. As structural engineers, we should be doing the same; choosing materials for strength and stiffness and durability."

O'Brien says that all materials, including timber, should be used in the most appropriate and least wasteful way. Timber, for example, is ideal for housing as the spans are relatively short.

Reducing the embodied carbon of familiar materials

The substitution of cement with ground-granulated blast furnace slag (GGBS) and fly ash has become the default for many new developments, particularly on groundworks, where the slower curing times are less of an issue. Half of the cement in a mix is regularly substituted with GGBS, with up to 85% possible.

The downside of these materials is that GGBS is a byproduct of carbon-intensive steel production, and fly ash of coal-fired power stations, which have been all but phased out in Britain. If the steel industry can move away from blast furnace production, the supply of these materials will eventually dry up.

A lot of work is focusing on finding alternative ways to reduce the carbon impact of concrete. Because cement production releases carbon dioxide regardless of how the kiln is heated, the cement industry is looking at carbon capture and storage (CCS) as a solution. Heidelberg Cement has started building the world's first industrial-scale CCS cement facility in Norway. Others are investigating alternative ways of reducing the carbon impacts.

The National Graphene Centre at Manchester University researches practical applications for graphene, and sister organisation the Graphene Engineering Innovation Centre commercialises these. They are working on a graphene-enhanced cement called Concretene which can potentially use 30% less material for the same performance.

"You potentially can get a product that is cheaper and has lower CO_2 emissions, but also has very good performance. Not only do you get the mechanical strength, it cures more quickly, it doesn't crack and there is no need for expansion joints," explains James Baker, chief executive of the Manchester graphene centres.

He says that, if the graphene is properly »

SOPHIA EDWARDS; HELENE SANDBERG; MATTHEW ANDREWS

Left: Waffle slabs were used extensively in the 1960s, including on the National Theatre as these used less concrete for the same performance as a flat slab

Right: The structure of the UCL Student Centre includes 100% recycled aggregates, with beam and floor slabs made from 50% GGBS to reduce the embodied carbon content of the concrete

» dispersed throughout the mix, less than 0.1% of it is needed. A big challenge is dispersing such a small amount of graphene evenly throughout large volumes of concrete. Baker says the secret of Concretene is an additive which disperses the graphene evenly through the mix and gives consistently good results. The cost of graphene is coming down, and Baker points out that while Concretene will cost more than standard concrete, it should work out cheaper because up to 30% less material is needed.

As part of the process of getting the product certified, it has been used on projects including a layby, a gymnasium and a housing development. Baker concedes that getting the right approvals will take time and envisages it being used initially for simple structures such as roads, pavements and single-storey buildings.

Watson and O'Brien are particularly excited by a product called Seratech, which came out of work done by Imperial College London. This takes magnesium silicate and combines it with CO_2 to produce silica and magnesium carbonate.

"Silica is chemically very similar to fly ash and the like, so you put that in your concrete to replace a proportion of the Portland cement. It is a really familiar chemistry and gives you a concrete with good strength and durability properties," explains Sam Draper, chief executive and co-founder of Seratech. The magnesium carbonate can be used to produce a low-strength concrete for block or board manufacture.

> IF YOU WANT TO EXTRACT MATERIALS FROM BUILDINGS AND REUSE AND REPURPOSE THESE, THERE IS A LOT MORE LABOUR INVOLVED
>
> **DAVID WATSON, TECHNICAL DIRECTOR, AKT II**

The beauty of this process is that the silica manufacture balances out the CO_2 from the cement production. "The process used to produce the silica sequesters CO_2," Draper says.

"A mix that is 65% Portland cement and 35% silica is in line with standards for using fly ash. All the emissions from making that Portland cement is being sequestered to produce the silica, which means the mix is nominally net zero."

Draper says the testing done to date shows that the product has better early strength than concretes made using fly ash or GGBS.

The big advantage Seratech has over similar products is that it meets the chemical definition of a pozzolan, that is to say a material that does not have any cement content but behaves like one when mixed with water and Portland cement. The only difference is that the silica is an engineered product, so Draper is in conversations with the Mineral Products Association and British Standards Institution to get their approval.

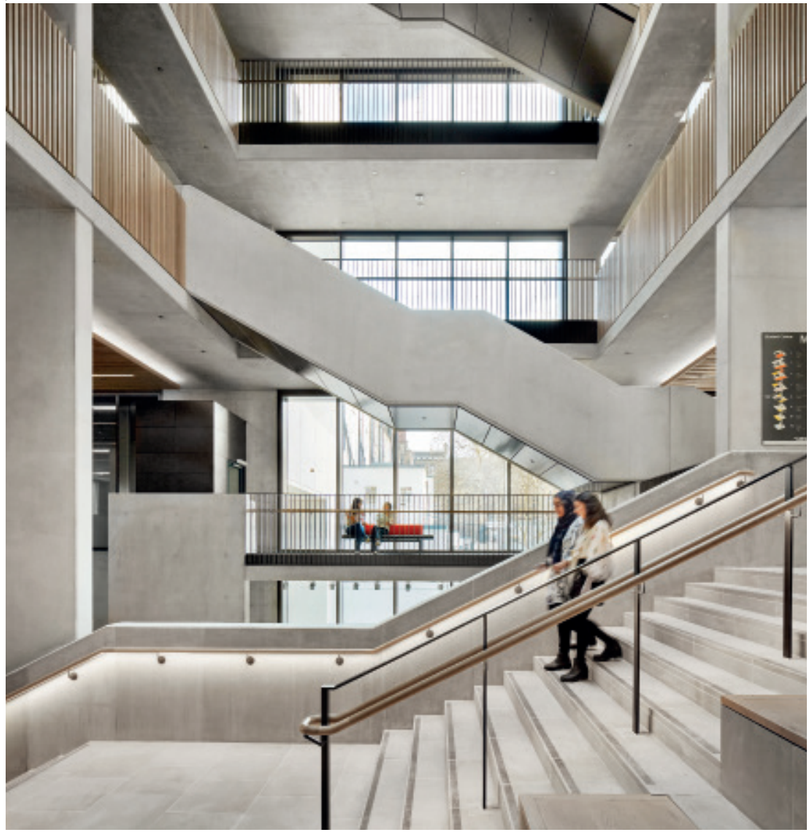
"Hopefully, we will get a green light from them, which means it is already approved as an existing cementitious material." And it can be used in the same way as existing concretes using the same equipment. Draper says it should cost the same or be slightly cheaper than current products as the raw materials are abundant and cheap.

The next stage is to prove the product in pilot projects with which AKT II is helping. Draper says that, once Seratech has been proven, it will put the business in a better position for getting the interest of cement manufacturers who could provide the CO_2 for the process and reduce their carbon footprint.

Draper says the CO_2 produced from brick kilns would also be a good source. He adds that the product could be available as early as 2026, although more realistically it will be 2027.

The steel industry is experimenting with direct reduced iron, a refined iron ore for making steel using an electric arc furnace that can be powered using renewable energy. The problem is the direct reduced iron is produced using natural gas, which means the process is not much lower-carbon than simply using iron ore in a blast furnace.

Tata is experimenting with using hydrogen in place of gas to produce the direct reduced iron, and a company called H2 Green Steel is building a plant in Boden, north Sweden, which it says will produce 95% less carbon emissions compared with conventional steel, with a production target of five million tonnes of steel a year by 2030.



Building THE FUTURE COMMISSION CELEBRATING 180 YEARS

What would help drive change?

There are plenty of ways of reducing the carbon impact of construction materials, including some promising innovations. But the construction industry is slow to embrace change, and time is running out. So, what would speed things up?

Regulation is one answer. A group of industry experts including Simon Sturgis, an architect and specialist in whole-life carbon, have created a new building regulation called Part Z to regulate embodied and whole-life carbon.

It proposes that all buildings over 1,000m², or housing schemes with more than 10 units, submit mandatory whole-life carbon assessments and upfront embodied carbon calculations. Initially there would not be limits for whole-life carbon, but upfront embodied carbon would be subject to limits.

The proposal enjoys widespread support including from investors, developers, architects and contractors. The Greater London Authority already requires whole-life carbon assessments of major schemes, so it seems inevitable that this will extend nationally over the next few years through building regulations. The big unknown is what limits would be set by the government – it is likely the limits would be initially relatively generous to allow smaller, regional clients and contractors to adapt to the new rules.

Much of the drive towards net zero is being led by financial institutions. "The financial sector is leading, occupiers and other organisations are following, and the government is trailing behind," says Wyatt.

As financial institutions widen the scope of their carbon reporting, they include the impacts of so-called scope three emissions: indirect emissions not directly controlled by that institution. This will impact directly on the development and construction industry as financial institutions seek to reduce their scope three emissions.

This could include the embodied carbon impacts of the buildings financed and occupied by those institutions. In time this could mean financial institutions favouring refurbishments over new buildings or buildings with demonstrably low upfront embodied carbon.

Taxation is another lever. "Taxation on materials is generally quite low, which drives us towards primary material use," Watson says. "If you want to extract materials from buildings and reuse and repurpose these, there is a lot more labour involved. Labour taxation is proportionately higher than on materials."

Although adjusting this dynamic sounds logical, it could be challenging as it could push up prices of items considered essential by many, which would impact those on low incomes who proportionately do not pay much income tax. A carbon tax would also be controversial as it would inevitably mean bumping up the price of gas and motor fuel, something which past experience shows would be deeply unpopular with the electorate.

A less controversial move could include adjusting taxes such as VAT to provide financial incentives to favour refurbished products or buildings. This taxation lever could also be used to promote the use of goods as a service rather than outright purchase. Suppliers could lease products as a service rather than selling them outright, which would incentivise them to refurbish rather than renew because this would make financial sense.

According to O'Brien, lump sum procurement stifles change. Designing out carbon involves more upfront work, which adds cost and does not sit well with a lowest-cost mindset. And transitioning to lower embodied carbon inevitably involves a degree of risk as it involves doing things differently.

By the time a contractor is appointed on a project, the scope of work and price are fixed, so the contractor understandably wants to use tried and tested forms of construction using a supply chain they are familiar with. O'Brien cites the example of the UK Bloomberg HQ in the City.

"It isn't accidental that on Bloomberg, which was construction management with the client making the decisions continuously throughout the process, there were bucketloads of patents because they had proper opportunities to embed innovation throughout the project," O'Brien says. "That is frequently made inaccessible because of the procurement route and that discussion around risk."

Despite this, there is an inexorable drive towards lower-carbon construction. Many developers are already prioritising refurbishment over new-build, and the M&S decision – whatever the motivations behind Gove's announcement – will only accelerate that. Regulations and pressure from the investment community mean the construction industry will have to respond and negotiate a path towards lower-embodied-carbon buildings.

There is high demand for reclaimed steel and raised-access flooring to the extent these products command a price premium, which will prompt other sectors to follow. The challenge will be extending the work done by the big London developers and enlightened clients to the wider industry. Although this will take some time, the path blazed by those industry leaders should make the job easier.

PHILIP VILE; ALAN WILLIAMS


Building
THE FUTURE
COMMISSION
CELEBRATING 180 YEARS