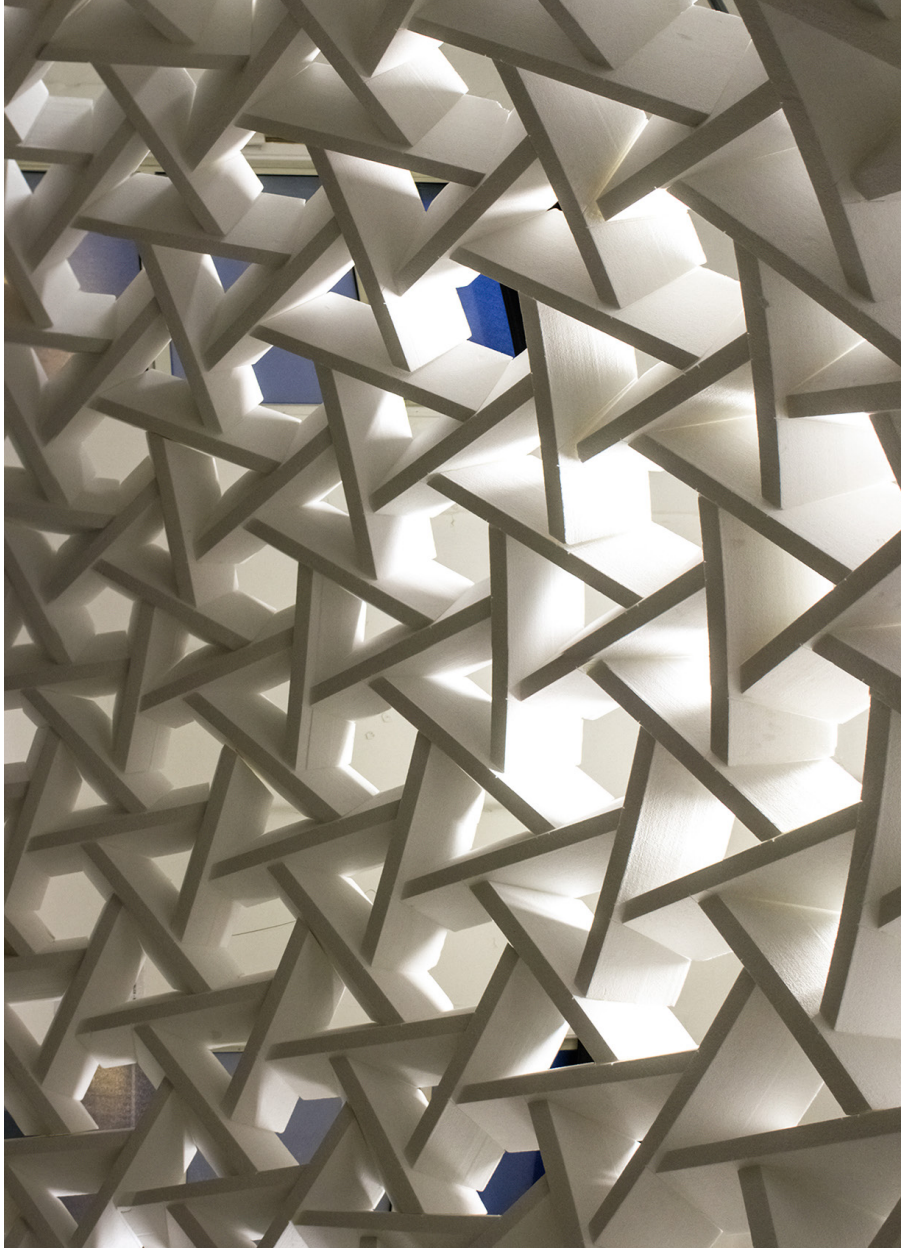
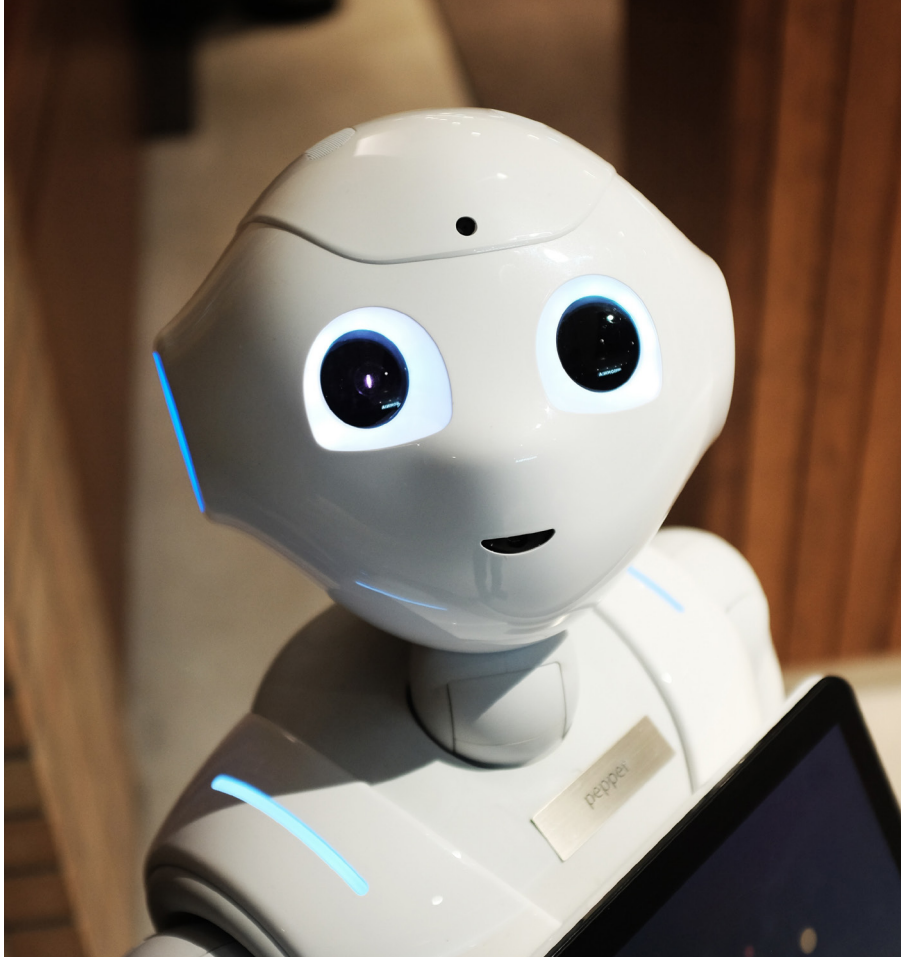


KNAUF

Robots in Construction

Build for the world we live in



✱ These images are courtesy of HAL Robotics © HAL Robotics.

Contents

Introduction

The construction industry must modernise or die.

That was the conclusion of Mark Farmer's 2016 review of the UK construction labour model. It is not difficult to understand how he reached that conclusion given the construction industry's ageing workforce and looming skills shortage as well as poor levels of productivity.

One way to transform the industry could be robotics. Robots have transformed the automotive industry, reforming both quality and productivity; could they hold the key to the transformation of construction? To find out Knauf, the UK's leading manufacturer of lightweight building materials and systems, hosted Robotics in Architecture.

The event, which took place in London on 31 January 2019, at Knauf's Clerkenwell showroom, brought together leaders from the robotics and technology community with experts from the architecture and construction industry to discuss the applications and implications of robotics in architecture and construction.

The speakers were:

Sebastian Andraos

Co-founder and VP of Human-Machine Interactions at HAL Robotics

Eva Magnisali

Founding Director of Dataform Lab

Dale Sinclair

Director of Technical Practice at AECOM

This case study is an illustrative summary of the key themes to have emerged from the event.

Background to architecture and construction

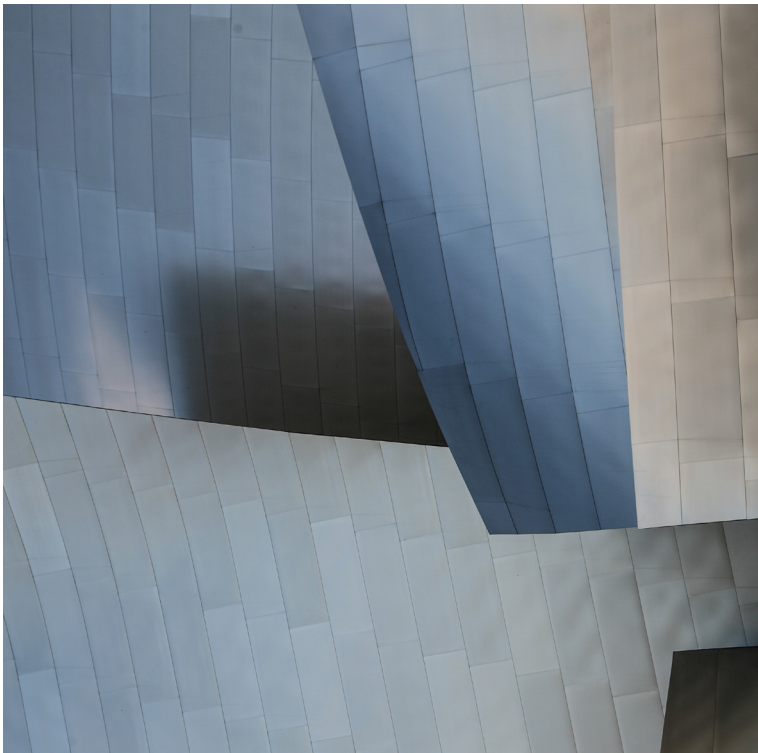
The value of construction work in Great Britain at current prices is £113 billion. According to the Office for National Statistics over 300,000 firms are involved in construction, employing 2.4 million people.

A major challenge for the sector is its ageing workforce. In his 2016 Review of the UK Construction Labour Model, Mark Farmer said: "The real ticking 'time bomb' is that of the industry's workforce size and demographic". In the document he warned that the age of the existing workforce and current levels of new entrants could result in "a 20-25% decline in the available labour force within a decade".

Such a reduction in the workforce would lead to a significant reduction in capacity with the potential to "undermine the UK's ability to deliver critical social and physical infrastructure, homes and built assets required by other industries to perform their core functions". Add to this the uncertainty created by the UK's vote to leave the EU and the impact this might have on the availability of migrant labour in the future and it's not difficult to understand how Farmer reached the conclusion that the construction industry must "Modernise or Die".

Construction is a big industry, it is also a very conservative one. While technological change and innovation are proceeding at a phenomenal pace in wider society, there are concerns that unless the industry starts to embrace innovative ways of working, it will miss the greatest single opportunity to improve productivity and offset the implications of its shrinking workforce. Failing to embrace change will also further marginalise the industry by making it less attractive to a new generation of workers who will have grown up in a digital world.

"The way we construct buildings hasn't fundamentally changed in the past 2000 years," said Dale Sinclair, Director of Technical Practice at AECOM. "There has only been two paradigm shifts in construction since the Romans built the Coliseum: the first was when Leon Battista Alberti's invention of architectural design made the jump away from site-based design; the second was the Industrial Revolution which disconnected craftsman from the process of making so that now we have mass production and materials being turned into products. The crucial thing for me is that we're about to encounter two massive paradigm shifts: first in the way that we design and the second is in the way we make buildings. I think the crucial thing is that we're going to see some serious disruption including Robotics in the next 3-5 years".



Drivers for change

The government is also keen for the industry to evolve in order to deliver better value for money and to speed the time taken to deliver its assets. Its strategy for construction was set out in the document Construction 2025, which includes the aims for construction to deliver:

33% reduction in both the initial cost of construction and the whole life cost of assets (from 2010 levels).

50% reduction in the overall time from inception to completion for new build and refurbished assets (based on 2013 standards).

Current technological advancements that could be rolled out at scale to modernise construction include: offsite (modular) manufacture, robotics, and additive manufacturing (3D printing of components). These technologies could help to deliver more resource-efficient buildings quicker and cheaper while helping the industry overcome a declining workforce and a widening skills gap by needing less skilled workers.

As an incentive to drive change in construction the UK Government is using its purchasing power to drive change; it has said that it will favour bidders for government work that adopt prefabrication. The autumn 2017 budget stated: "Building on progress made to date, the Department for Transport, the Department of Health, the Department for Education, the Ministry of Justice, and the Ministry of Defence will adopt a presumption in favour of offsite construction by 2019 across suitable capital programmes, where it represents best value for money".

To make construction more accurate, efficient and collaborative, designers will need to establish close digital links between their designs, manufacturers and installers.

Digitisation of architecture

In July 2018, the RIBA and Microsoft produced the report: Digital Transformation in Architecture. One of the key findings from this research is that the way architectural organisations operate has changed significantly in the last few years with digital technologies transforming the way that they work. According to this document, most architectural practices have already embarked on a digital journey by embedding BIM into their culture and processes. The same journey is occurring in large engineering consultancies and major contracting organisations.

Not every organisation in construction is embracing digital technologies to the same extent as architects. Sub contractors in particular were singled out by Eva Magnisali, Founding Director of Dataform Lab:

"We are losing a fair bit of data when designers pass their files to sub contractors because most of them don't support data in BIM so data has to be translated from digital to analogue."

Robots on construction sites

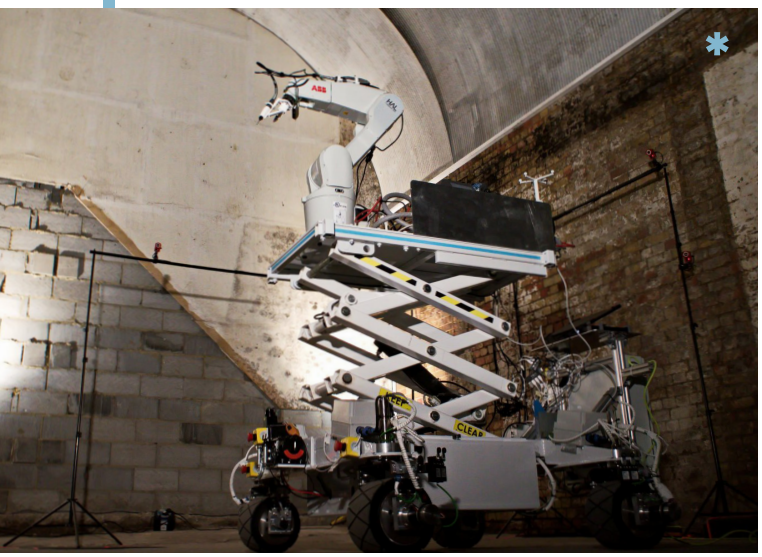
One reason often cited for construction's failure to modernise, usually by those in construction, is that 'every building is unique'. It is not; while its form may be unique it will almost certainly be assembled from a series of components and products, such as bricks or tiles, that are common to many other 'unique' schemes. It is this commonality that makes the use of robots on construction sites a possibility.

Currently, there are very few robots used on construction sites. However, there are robots that have been developed for brick-laying and masonry. These robots are claimed to dramatically improve the speed and quality of construction work. Robots are also starting to be used in demolition because they are unmanned and therefore safer when it comes to demolishing concrete and structural elements of a building at the end of its lifecycle. In addition, remote controlled or autonomous heavy vehicles, using similar technology for self-driving cars, are already being used where large sites are being remediated, excavated or graded.

"The first things that need to be automated are the dirty, dangerous and repetitive jobs that people should not be doing. We're currently working on a project to automate drilling into soffits – a process that currently involves standing on a ladder with a drill in your hand pushing yourself towards the floor – that should be a robot's job," said Sebastian Andraos, Co-founder and VP of Human-Machine Interactions at HAL Robotics.

One challenge with automating construction sites is the large number of different activities needed to build a building. Many of these tasks involved are complex, such as brick laying, and require knowledge and experience to complete successfully.

Proof of concept mobile robotic arm, automatically programmed from BIM data, for drilling and marking soffits on construction sites



"Some construction methods, such as brick laying have not changed significantly since Roman times," said Dale Sinclair, Director of Technical Practice at AECOM. "Currently we have robots that can lay bricks and other traditional materials, our view is that we should be re-examining those materials and looking at the brick that is best fitted to the robots that will be making buildings in the future. What I see from robotics [onsite] drives me absolutely bonkers: robots laying bricks is the wrong answer to the wrong problem; we should not be using a robot to take a material designed for the human hand to make a wall, we should be reinventing the brick. What would the brick of the future look like if it was designed for a robot rather than the human hand?" he asked.

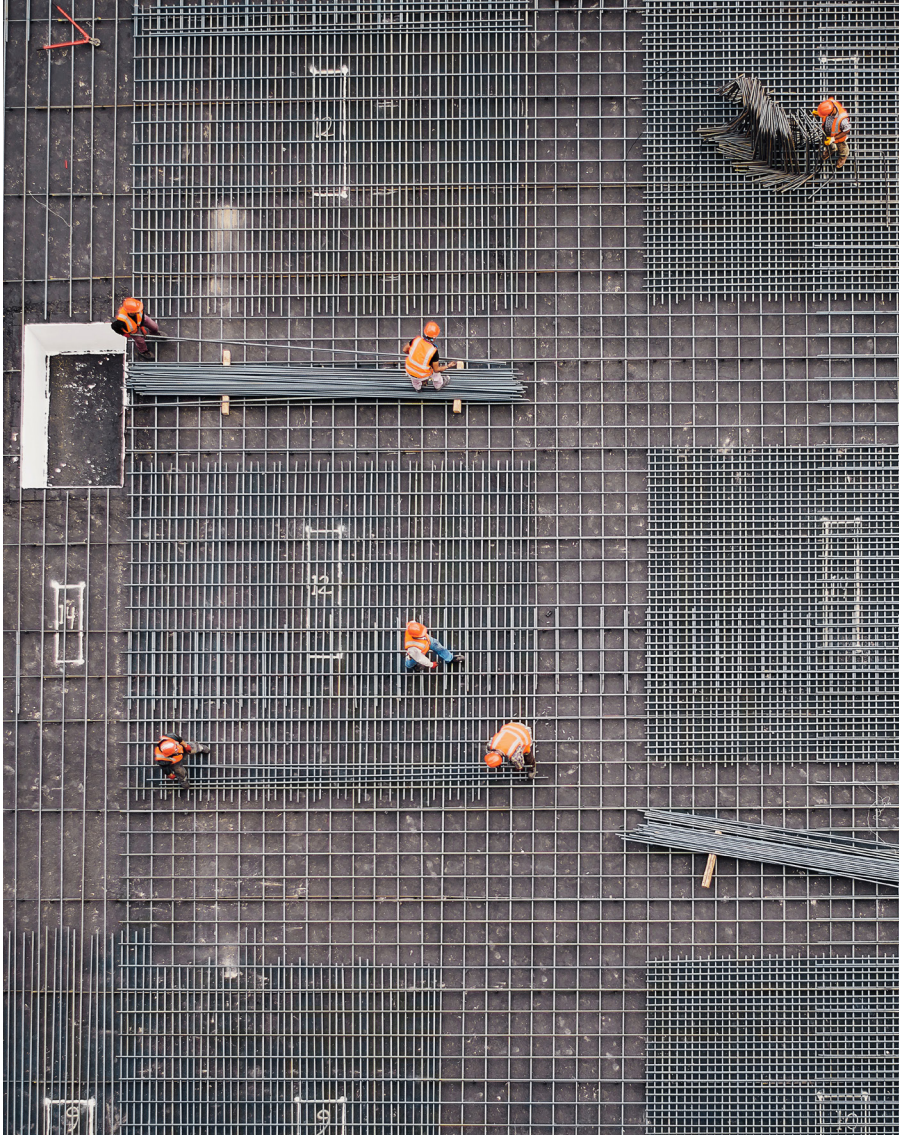
Dale expects that in the next 3 to 5 years "we will begin to see the sort of disruption that has major impacts on the industry and starts to drive significant change in the way that we design and make buildings".

Eva Magnisali agreed with Dale, she said that while the industry is starting to embrace digital technology, it is often doing so by digitising current ways of working and rather than using digital technology to drive transformation in the design and construction process. "The good news is that more and more people are getting involved and working in the Fourth Industrial Revolution so we hear more and more about robotics, smart materials and immersive environments," she said. "The bad news is that the construction industry is a very big machine, and a very slow one, so instead of using new technologies in order to reinvent the construction process most of the time we use them to substitute already known processes like brick laying and, in so doing, we don't take advantage of their full potential," she warned.

It may seem odd that the construction industry utilises so few robots, but there's a good reason for this: construction tasks are notoriously difficult to automate.

The construction worksite is the primary obstacle to robotic automation.

Multi-robot steam bending of timber elements with 6-IR camera-based real-time trajectory compensation



Construction sites are hostile places and are not set up for robots. Sites are often exposed to everything the weather can throw at them. They are full of obstacles. And, because of the nature of construction, sites are relatively dynamic and evolve as construction advances so workers have to be able to move around and perform a variety of tasks. Construction projects happen in unstructured, outdoor environments, and worksites are always changing. This presents difficulties for industrial robots, which excel at repetitive, predictable tasks. A construction robot would have to be mobile and be able to respond to variables in its operating environment. "The challenge of using robots on site is in keeping them stable because they have to install components to millimetre precision," said Dale Sinclair. "Also, robots are difficult to move about a construction site because they tend to be quite heavy," he added.

This would imply that in order to use robots effectively in practice, on actual work sites, they would have to be portable, perhaps even able to move themselves around with a certain degree of intelligence while avoiding obstacles; they would also have to be capable of sensing their environment, processing the information received and, based on all the information available, then perform the task. Robots need to be able to adapt to real-time variability in their environment with little or no reprogramming in order to be profitable and productive. They would also have to be capable of working in all weathers and, potentially, be able to cope with impacts from materials or from falling from height. While current robot technology could overcome each of these difficulties, the resulting robot would not be economically viable, even if major changes were made to building sites.

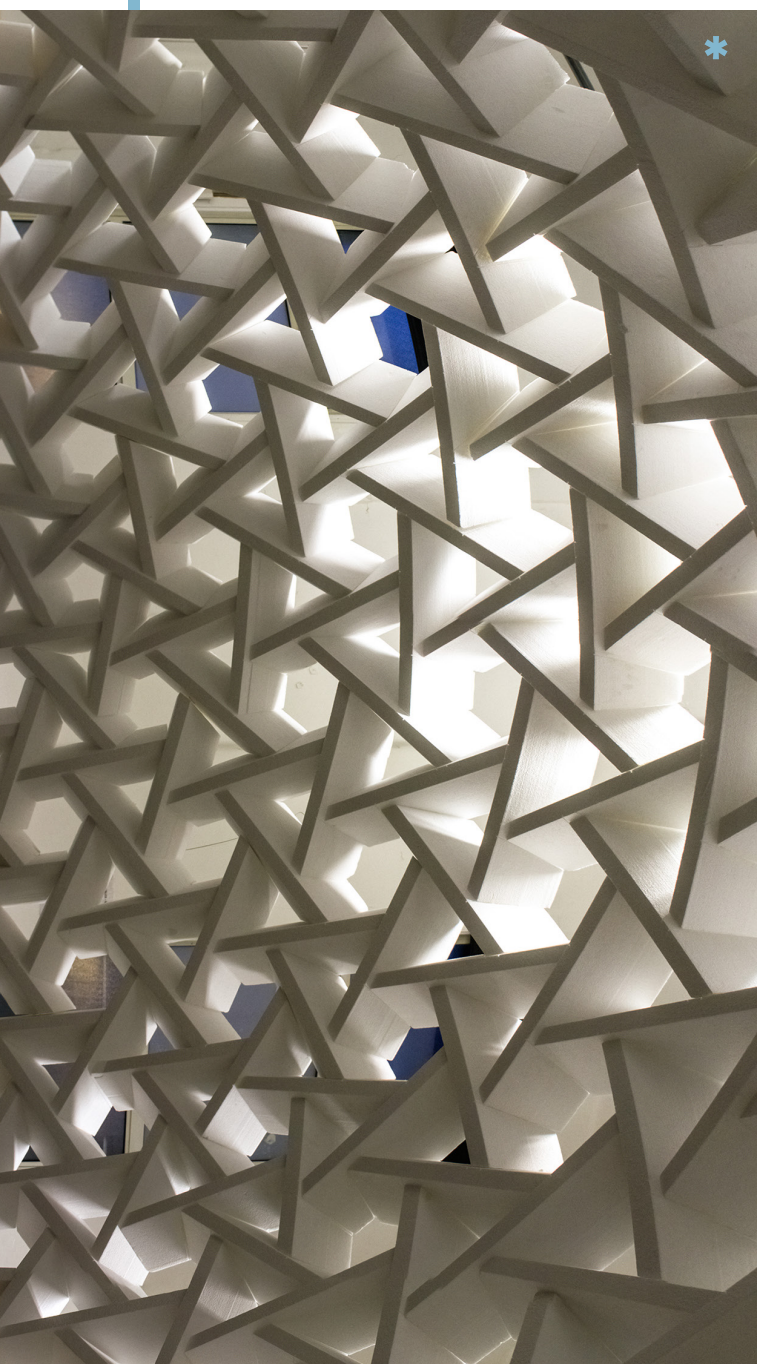
"I believe that right now most of the robots we see in construction are trying to remake an already well-known process whether its bricklaying or putting plaster on to walls," said Eva Magnisali. "We shouldn't have to ask if the robot is doing a task better, but instead, we should be asking whether it should it be doing it at all," she added.

One type of construction robot that has changed an established process is a 3D-printing robot that is capable of printing buildings from concrete on demand. It uses a mobile robotic arm controls a 3D-printer, and with a set of preprogrammed instructions, this system 3D prints an entire structurally-safe building. This technology is also beginning to be used for building bridges, with the first ever 3D printed bridge recently being built in the Netherlands. This combination of 3D printing and industrial robots is, potentially, one of the most promising ways in which construction sites can be automated.

Design for manufacture

Robots excel at repetitive tasks in a controlled environment. Most industrial environments in which robots operate in are stable, predictable and indoors. Typically, robots operate in spaces like warehouses or assembly lines, often confined within their own stationary work cell. Robots are ideally suited to carrying out repetitive tasks in factory environments, where there is no need to move around – which is why the automotive industry in particular uses them. For robots to be used in construction, the construction process itself needs to change.

6-axis hot wire cutting of a 3.4m Abeille vault (reciprocal structure)



"I think it is easier for someone to use a new technology for something they already know, but what is actually needed is to redesign the whole process from scratch, to try to re-imagine the construction process and the design that leads to it," said Eva Magnisali. "I don't think we need to construct with robots on site when we can prefabricate whole bits of buildings and then have only the assembly job to do outside, which is much simpler and it needs less skills on site," she added.

To benefit from robotics, designers would have to adapt the way buildings are put together so that they use pre-assembled groups of components provided by prefabrication. On site construction would then increasingly become an assembly task. "I strongly believe in design for manufacture and assembly, it is more efficient and quality is much better if you design and fabricate everything offsite and then assemble most of it onsite – that's why I'm skeptical about using robots onsite," said Eva Magnisali.

Software such as CAD and BIM have effectively digitised the building design process, making it relatively straightforward move to robotic offsite manufacture.

Sebastian Andraos, Co-founder and VP of Human-Machine Interactions at HAL Robotics said it was critical to ensure that when you are designing things to be produced by a machine you need to be sure that they can actually be manufactured by talking to a specialist. "We would hope to give you extra information like how long production will take, how much wastage there is, where you might have the most wastage and other information that should help you make the most of your plant," he said.

Eva Magnisali said whilst some residential housebuilders have embracing volumetric, most modular construction is effectively a construction site in a factory and not true design for manufacture. "In due course we will see residential start to use more and larger components or industrialised construction where robots play a much bigger role," she said.

Part of the process of moving to industrialised construction, is thinking about the manufacturing process. "We will need to move to the language of the manufacturer," said Dale Sinclair.

He says a major impact for construction of the transformation of design into a making process will be the time it takes to complete a building. "It currently takes roughly 12 months to design a building and roughly 12 months to construct a medium-sized building. Start to think about the disruption that will happen when the construction process happens in a month and not in years".

Learning from other industries

"As soon as you link robots and machines to computers you get the ability to optimise your design for performance and for manufacturing constraints, such as the time for each component to be manufactured and the material limitations," said Sebastian Andraos. "When you link machines and computers together you get the ability to mass customise by reprogramming the machines; that means that it will not cost you any more to produce a million different parts than it does to produce a million parts that are the same. You'll also get the benefits of precision because machines are infinitely more precise than humans."

Sebastian Andraos said that the most appropriate parallel with automating construction is the shipbuilding industry. "It has taken processes out of the car factory and rewritten them for a larger scale. Construction can learn from shipbuilding, where projects of a similar scale are being implemented using automation. Although, in shipbuilding, processes tend to be mono-procedural – the ship is pretty much all bits of metal so you're basically only riveting or welding – whereas, as soon as you have to start putting in acoustic insulation and concrete and metal it gets a little bit more complex, but that comes back to having to design for automation," he said.

"At the moment there is not as much robotics in the construction sector as you might imagine, but robotics is starting to appear in the supply chain. For example, steel fabrication is starting to see a big increase in automation; eventually that will trickle through to assembly and maybe onto construction sites," Sebastian Andraos said.

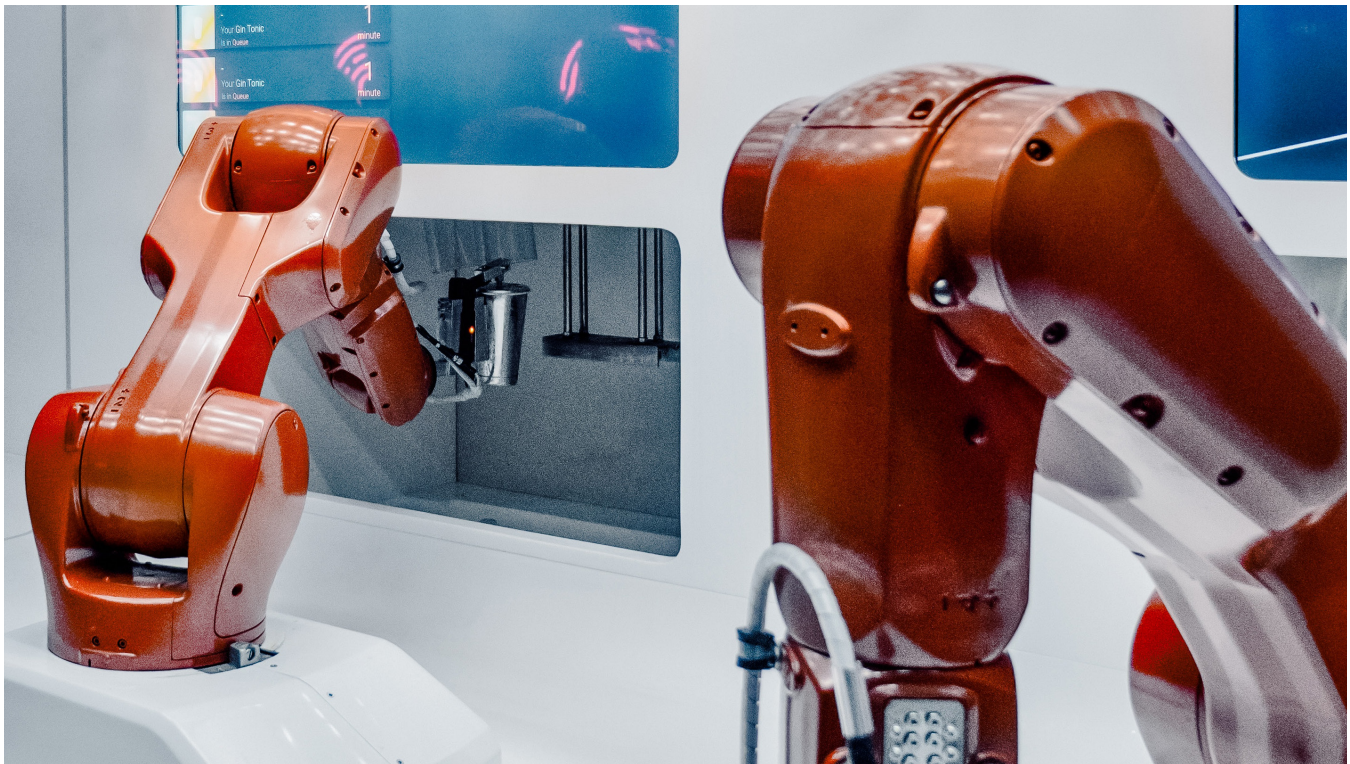
Prototypes too will become an essential part of the design process. "It is important is to test design ideas at a very early stage in the design, when it is quick, easy and low cost in order to understand if something is able to be manufactured or not," said Eva Magnisali.

"I think we'll see increasing use of automation in the construction process, starting with prefabrication and eventually moving to site," said Sebastian Andraos. However, he does not expect every job to become automated: "Even in the automotive industry companies like Tesla and BMW are reintroducing people into their manufacturing plants because there are some jobs that are just more efficient when done by humans," he said.

Eva Magnisali agreed:

> "Robots are like any machine, they come with limitations and possibilities and are not the solution to every problem we have".

The economic implications of manufacturing assemblies to be assembled onsite means that construction will become more and more reliant on the upstream industry. The viability of these firms will depend on sales volume which, in turn, would be critically dependent on the popularity of their products and the capacity of the company to produce them at a cost that justified the change in technology.

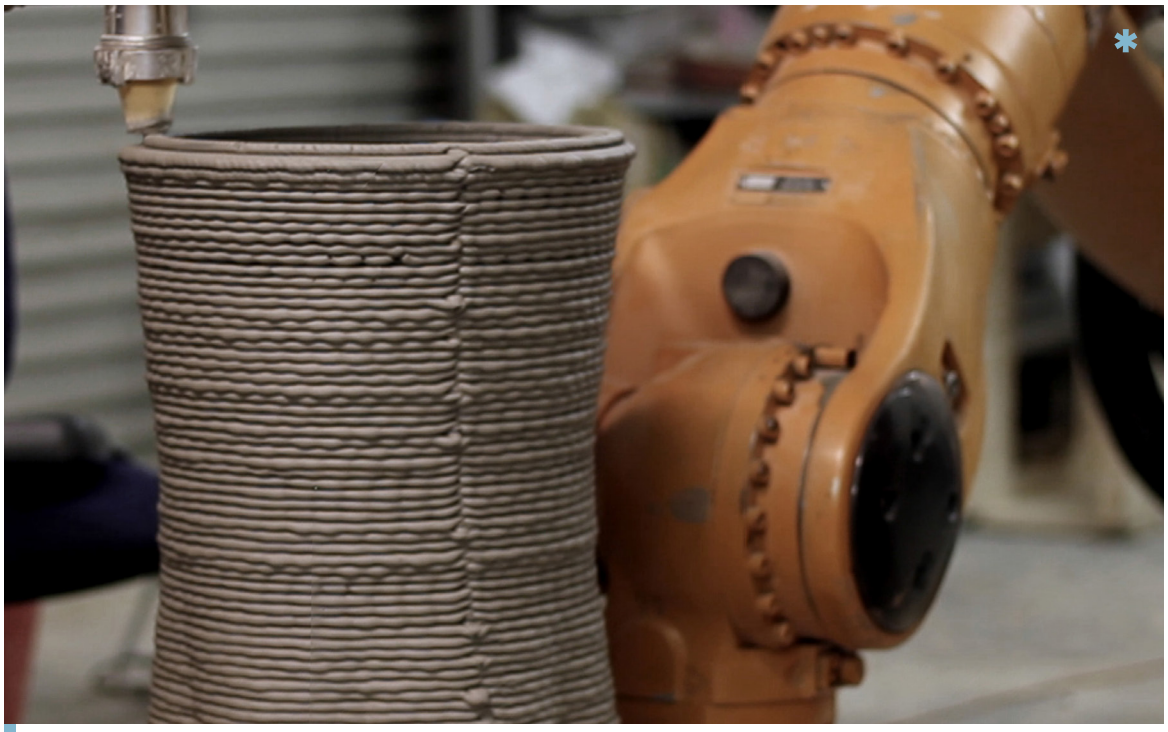


3D printing

"Construction products are probably not going to be 3D printed because mass production is still an extremely efficient way of making things, when the making is being done at scale," said Dale Sinclair. "I think we need to think critically about the adoption of 3D printing because there are so many other techniques out there. 3D printing only really makes sense when other techniques don't, for example 3D printing can be used to augment products produced in another way, such as adding different motifs to a light fitting."

Dale Sinclair: "3D printing will be a solution for the longer-term because there are a lot of QA issues that we need to unlock before we will see 3D printing at scale. For example, if we are going to print a façade using a 3D printer, we'll need to look at the sort of materials we use, how we calibrate the printer properly, and how do we know the materials that we're printing with have been mixed correctly? You see 3D printing of concrete used for housing, but you don't see it used for the hard bits, for example to print the lintels and put services into the homes".

Sebastian Andraos agreed with Sinclair: "I see 3D printing being used for certain elements, but I'm not entirely convinced about 3D printing entire buildings – I think there are some processes that are much more efficient for large scale mass production, but with 3D printing then used to customise the mass-produced elements".



Multi-robot steam bending of timber elements with 6-IR camera-based real-time trajectory compensation

Conclusion

The introduction of new robots in architecture will change the distribution of jobs in the sector, but not necessarily to the detriment of all workers: many jobs in construction are dirty and dangerous, and often dull too. Robots could free up workers to be retrained for more challenging, complex or creative jobs. The design, manufacture and commissioning, and supervision and maintenance of robots will create a new industry.