THE RISE OF THE ROBOTS

Robot-augmented design and finishing is now striding on from where ecosystems and nature's solutions led, resulting in architecture schools seizing and further developing the opportunities offered by technology and robotics, with research departments in Stuttgart, Zurich and Cambridge (Massachusetts) leading the way

Words Oliver Lowenstein

Deep in the Dorset woodlands the quieter end of a pretty noisy revolution has just notched up a first. The latest graduates from the Architectural Association's Hooke Park annual Design & Make Masters have completed the Woodchip Barn. The barn is large and long and a strange looking beast. In that sense it fits in with the projects that instigated the one-time cult Parnham furniture school's ambition to grow buildings from its immediate 350 hectares of trees. These included two Frei Otto experiments, which turned out to be the only buildings he completed in Britain. Woodchip Barn, designed collectively by the year's five-person intake, differs from Otto in that technology is at its heart, from 3D scanning to construction by robot.

A genuine team effort, the D&M students worked with Hooke Park's tutors, led by programme director Martin Self, using a recently purchased robotic arm to fashion a seemingly impossible structural system to hang the barn's roof on. Analysing the structural properties of the wood's tree trunks and, specifically, the forking branch junctions, enabled them to optimise each split trunk to build an eerily organic truss frame for the more conventionally designed roof.

That the robots have arrived in Hooke Park's formerly very traditional neck of the woods, is one indication of just how far-reaching what is often now termed the Fourth Industrial Revolution – shortened to 4.0 by some – is. Robotics is of course one tool in digital fabrication's kit bag that also includes now-familiar laser and plasma cutters, and CNC mills and routers. The emergence of 3D-printed buildings with DUS Architects' Canal House in Holland and Zhuoda in China, as examples, has particularly excited the taste buds of the mainstream media, as has the emergence of drones in construction and their more nefarious uses. And then there's regenerative architecture and biomimicry, which has given this tech-dominated scene a connection to the realm of nature. Here ecosystems and nature's solutions lead and inspire, allowing machine-augmented design to follow and finish.

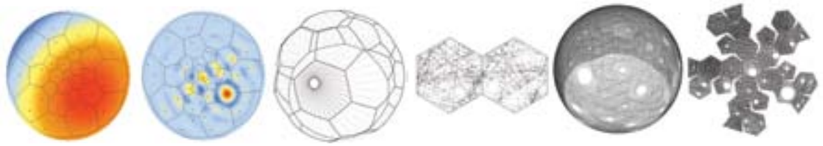
All over Europe and North America, indeed all over the richer parts world, architecture schools have been jumping on the tech and robotics bandwagon, or should that be landspeeder. You can find niche research activities all across European university departments, from Aarhus – researching concrete formwork – to Gaudí-inspired Barcelona, focused on vaulting catenary masonry arches. As well as the machines, tech conferences are multiplying. Melbourne recently hosted Rob/Arch2016, positioning the city's architecture department as the robo-hub in Australia, in comparable manner to how the previous conference underlined the University of Michigan's robotics faculty's place on this emergent tech-architecture map.

What is also evident however is that the pioneering centres of early digital fabrication and robotics activity emerged where they did for a reason – money. Stuttgart, Zurich and Cambridge, Massachussets (MIT and Harvard), were the three earliest and most influential research departments, and are some of the best financially and hence technically resourced and equipped research hubs in the world.

London, Europe's current financial centre (Brexit may have a future role to play here), has also incubated some of the key players who've helped pioneer and explore the technological parameters, not least the fertile collaboration between Arup Advanced Geometry Unit, under Cecil Balmond, and the AA's experimental summer pavilions, run by Charles Walker and Self (2005 and 2009). The Bartlett has been gradually building up its robotics and digital fabrication capacity as well, initiated by Bob Sheil, Emmanuel Vercruysse and Ruairi Glynn. Sheil and Glynn successfully launched the Fabricate conference in 2009, and Glynn's work has hived off into the Interactive Architecture Lab, while Hooke Park's Martin Self, joined by Vercruysse, is now in the throes of launching the AA's first specialist robotics masters.

Returning to the pioneering centres, Zurich, Stuttgart and Boston, there are clear affinities between the three. At Zurich ETH, probably the best-known technical and engineering powerhouse in Europe, digital fabricators Fabio Gramazio and Mathias Kohler are in the midst of the kind of work many researchers dream of (though the story isn't quite so straightforward: see Robot Pioneers: Gramazio Kohler page 87)

This image and below – **From the Robotic Barn, Hooke Park**



Likewise MIT and Harvard Design School in Cambridge, MA, including Neri Oxman's Material Ecology, have been leading American research in the field.

Meanwhile, in Stuttgart, the Institute of Computational Design (ICD) is not only in one of Germany's leading technical cities but is also the spiritual home of Frei Otto's Institute of Lightweight Structures. It is also the home of two world class companies which are extremely well-versed in robotic manufacturing – Mercedes-Benz and Porsche. Now Stuttgart's ICD has come to London, with the Victoria & Albert Museum launching its first engineering season with a robotically manufactured summer pavilion in its central courtyard. Called the Elytra Filament Pavilion, it was designed by ICD, led by ex-AA graduate, Achim Menges, a pioneer and a key player in the robotic edge of digital fabrication (see page 91). The structure is robotically spun from composite carbon fibre. Elytra refers to the lightweight filament structure of the forewing shells (elytra) of flying beetles, which inspired Menges, along with long-term engineering partner Jan Knippers, head of the Institute of Building Structures and Structural Design (ITKE) and biologists from the University of Tübingen.

This is tech-informed-biomimetics at work and is further augmented with sensors allowing it to respond to visitors' behaviour patterns, which will enhance the pavilion's design.

Compared to the organicism of the Stuttgart school, the practice Gramazio Kohler comes across as almost old-school Swiss-German modernists. Gramazio acknowledges the Swiss-German immersion in materiality and the physical explores what it characterises as 'additive design' through a series of projects mixing, brick, timber and composite materials used across a spectrum of projects such as the collaboration with Graubunden's Bearth & Deplazes on the Gantenbein Winery. This building used the adjacent farmhouse as the vernacular basis for the design. The robotically constructed walls demonstrated a materiality that was almost dizzying in the optical effects it created. The exact positioning of the bricks also highlighted the infallibility of robotic precision, especially when compared to the imperfection of the human hand. GK was also an early-adopter of drones, with it's Flight Assembled Architecture structure at FRAC Centre Orléans in 2012 (See Blueprint 312).

Different again to both Menges and Gramazio Kohler is Neri Oxman, and her MIT Materials Ecology agenda. Oxman, whose Israeli architect parents Rivka and Robert Oxman are also significant in this tech story, has been engaged in interdisciplinary research for two decades with the interface of ecology of materials – where 'material is interpreted merely as any physical entity which corresponds to its environment'. Known for taking environmental constraints and feeding them into computational software then letting the computer generate the form, the results are etremely biomorphic – think the interior of the alien spaceship in the film Alien. More recently Oxman and team's current research hub, Mediated Matter, includes projects like CNSilk – robotic interaction with silkworms (above and right) to produce a skin of silk thread around a geodesic dome. What is striking, are the entirely different intellectual traditions on each side of the Atlantic. In the USA, MIT's Media Lab, founded by Nicholas Negroponte, is an influential lode point, while research can often be traced to American General Systems Theory and Cybernetics traditions that lie at the root of the origins of computers around mid-20th century figures including Heinz von Foerster, Ludwig von Bertalanffy, Gordon Pask and Warren McCullough. In Europe, the ICD's organicism, and the materiality of Gramazio Kohler are striking contrasts, a contrast highlighted by Theo Spyropoulos, director of the AA's Design Research Lab, which he feels is one of the few labs looking to Negroponte and the East Coast Systems on this side of the Atlantic.

Menges and Gramazio Kohler, as much as Oxman, and indeed so much of what is happening at this robotics-meets-architecture edge, remain oddities – outside the discourse of the architectural mainframe. Yet at the same time a steady stream of architects either use or reference different aspects of digital fabrication, for what appears PR opportunism look no further than stories last year about Google's Californian HQ, at the time jointly being designed by Thomas Heatherwick and Bjarke Ingels Group using drones. Gramazio, with his drone research background, voices scepticism about Google's research being anywhere near this level of development any time soon, while also noting how difficult it is to tell for sure given the supremely secretive nature of Google's research culture. Gramazio does however believe that students and an increasing number of architects, who have been through robotics-related study and training, are now beginning to influence the mainstream. He cites ex-ETHZ students now working on Shigeru Ban's SWATCH campus in Bienne, Switzerland as an example.

For all its interdisciplinarity, both the digital fabrication scene and the wider architectural world seem reticent to engage with the wider cultural issues regarding robotics and the current 4.0 zeitgeist, expressed through a rising chorus of commentators, competing to discuss the social consequences of these technological shifts. While Martin Ford's 2015 book Rise of the Robots sparked a level of general interest and debate, architectural discussion of the book's themes has been conspicuous by its absence. The profession seems too busy keeping its head down to engage in meaningful ways with Ford's key controversial claim, that 50 per cent-plus of jobs will be replaced by non-humans within 30 years or so. Apart from how the industry itself will be changed, there's also a dearth of discussion regarding the prospect of how architects should react to the needs and dreams of a robot-dominated, leisure-rich future.

Below left – **Gramazio Kohler construction:research images**

Bottom right – **Detail for Gramazio Kohler's Federal Court in Bellinzona, Switzerland**

Robot pioneers: Gramazio Kohler

If you'd asked me three years ago,' says Fabio Gramazio, 'I would have said the labour question was crap.' We are talking over Skype and the discussion has reached the tricky, wider public debate about robotics, and specifically the prospective redundancy or otherwise of humans, including human architects. 'Our view was that having more powerful tools meant that humans can become more powerful craftsmen.'

Gramazio should know, as one half of the Swiss digital architecture practice Gramazio Kohler, the acknowledged first to introduce robots into its work, back in 2005. Gramazio and partner Matthias Kohler have pursued an archetypally Schweizer-Deutch agenda, one which they soon titled Digital Materiality. As mid-Nineties' students at the height of the virtual blob-tecture frenzy – Kohler worked as an assistant to pioneering digital architect Greg Lynn – the pair had grown frustrated at the total absence of physicality of the virtual universes on the other side of the computer screen. With the Gantenbein winery completed very early on, the series of subsequent projects, which honed in on the materiality of brick and wood, the young studio burnished an impressive research portfolio.

Three years on though, and Gramazio's position on the calibration of robotics, skill, labour and the future, has moved on: 'Now I recognise that there is a change in quality in the technical context, but it is at the level of artificial intelligence rather than that of robotics, and it is progressing at a fantastic speed.' That rate of change may provide partial explanation for the practice's latest big news – it is leading a research project to create the NCCR Digital Fabrication Centre, a national centre of competence in research. The NCCR Digital Fabrication Centre will be woven around a new building on ETHZ's campus, which is to provide a large ground-floor lab and two equally sizeable open-plan office spaces for a diverse interdisciplinary team the two digital architects have brought together. Gramazio describes the historical ETHZ as a difficult if not dysfunctional warren of cellular rooms, built to militate against collaboration and the different disciplines talking, let alone working, with each other. Gramazio reminds me of a first visit in 2008, when he and Kohler described their outsider status, and how on the technical, science-based ETHZ campus there wasn't really much interest in what they were up to with their three-tonne robo. The only people who were intrigued were other architects.

'In the beginning we were alone. We thought of ourselves as bricoleurs, programming with no experience of architectural engineering. When we thought "we want to do this", we went and did it.' This included finding the space for the robot in one of the engineering department's workshops, which came about by chance but had long-term consequences: 'The engineers, started to become really interested in what we were doing.' Various relationships began to blossom, spreading across and into a mixture of departments and this became the seed for the new interdisciplinary lab, focused on two core issues: the future of prefabrication, and what might be described as the smart construction site, introducing digital intelligence as a part of

Opposite page – **The Gantenbein winery, by Gramazio Kohler**

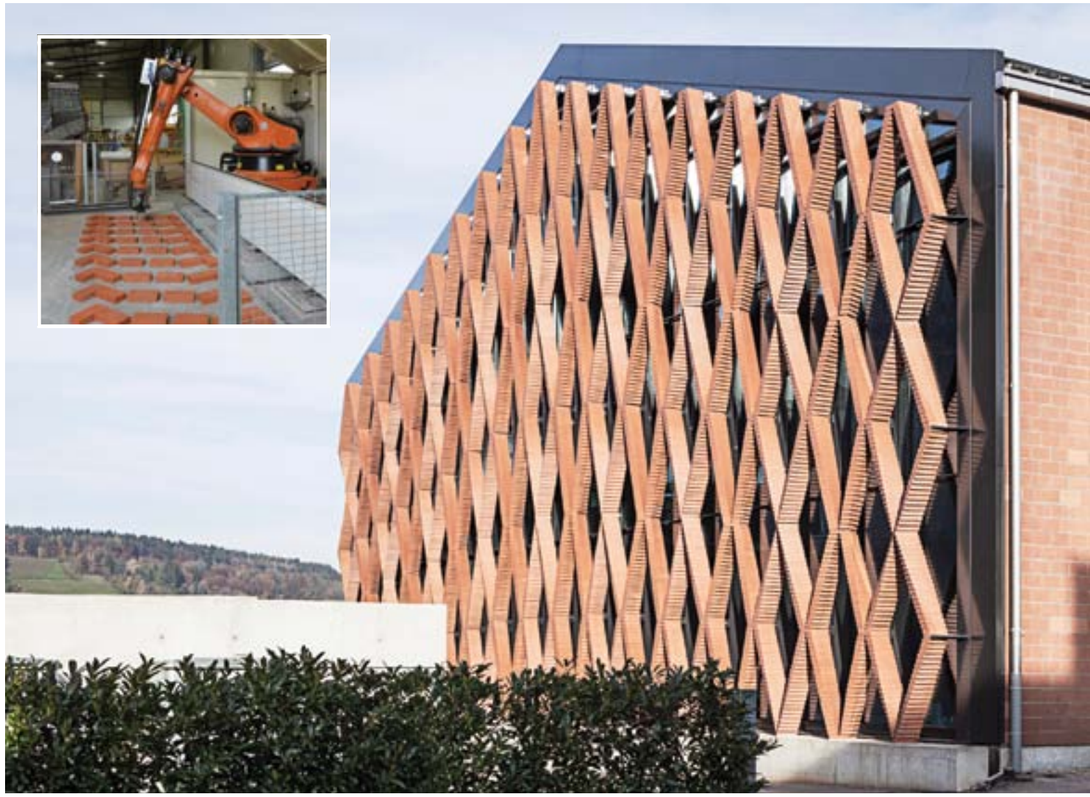
Centre – **Construction images from Gramazio Kohler projects**

Bottom – **Gramazio Kohler's HQ for Keller, with a twisting brick facade**

fine-tuning the build process. 'If everything is prefabricated, it still has to be transported and assembled on site. What happens with joints, for instance?' And so what happens when adapting robots to real, live, building sites? To this end the new ground-floor lab will have an extra-high roof, and multiple, mobile robots to start testing these research questions.

Divided into three four-year phases, Gramazio and Kohler have drawn together several layers of interdisciplinary teams for the NCCR Digital Fabrication Centre research, with the first-phase completion of the research building by the end of the year.

That Gramazio and Kohler has arrived at this point within the ten years of the Gantenbein winery project, speaks significant volumes about the speed at which this part of the technologies tree is moving. When Gramazio hints at a rethink regarding the level of change happening, pondering the advances in artificial intelligence, he may not necessarily be alluding to what the true techno believers call the singularity, or techno-rapture, the point where silicon intelligence surpasses our carbon-based mind-matter, but it'll be interesting to go back to him another 10 years down the line, and ask how his thinking has upgraded in the interim. ▶



Below – Views of the Woodchip Barn, created at Hooke Park, now owned by the AA

Woodchip Barn, Hooke Park, Dorset

Hooke Park is a place with something of a mythic reputation. Sitting in 350 hectares of low-value woodland in the hills above the Dorset village of Beaminster, Hooke Park was the dream child of entrepreneurial furniture maker John Makepeace. Makepeace already had a well-developed reputation, having founded Parnham College, the specialist wood-focused furniture design school in Beaminster in 1976. Hooke Park was an early-Eighties next step, with the radical idea of creating a new site for the furniture-school campus in the woods, and using those same woods as the source of material to grow its buildings. As we mentioned in the introduction, this is the scenario that brought Frei Otto, working with Ahrend's Burton Koralek Architects and Buro Happold, to design his only British projects, the furniture workshop (1989) and the refectory (1987) from the immediate round-wood thinnings. Otto's two buildings were followed by Edward Cullinan Architects' Westminster Lodge, which went up as students built, made and crafted in the woods. But Hooke Park as an organised commune unravelled, the economics and grants drying up, and it closed shop in the late Nineties. The site stood silent over the next years, with Makepeace transferring ownership of his woodland creation to the Architectural Association in the early 2000s and the AA trying to decide what to do with its new campus in the country, before commissioning Rural Studio's Andrew Freear to draw-up a new master plan in the mid Noughties. Freear's plan called for a building to be designed and built by an annual intake of students, which is eventually pretty much what has happened. In 2011 the AA launched a 16-month Design & Make course, initially run by that most visible of Invisible Studio Architects, Piers Taylor and master carpenter Charley Brentnall, and led by AA tutor Martin Self.

What, you may be asking, does this have to do with robots? Last year Self, along with colleague Emmanuel Vercruysse, decided to buy a six-axis robot arm, which has been since begun to be put through its paces by the most recently completed Design & Make student cohort. Five students were tasked with the next project on the list, a woodchip store, and came up with the bright idea of scanning tree trunks from the Hooke woodland, analysing their structural and physical properties, and identifying the integrity, strengths and weaknesses of each trunk. The trees were then felled, and milled into shape by the robotic arm for a truss. Not only this, but the chosen trunks all had forking branches, so that the trunks joined to create a long, bridging structural-truss-frame designed to carry the barn's roof.

The resulting Woodchip Barn is a surreal piece of work sitting on a piece of cleared land in the woodland. Yet there's also something recognisable in the arching truss's bare branching trunks, which has particularly animated Self. 'The robotic barn is taking the buildings here in a more interesting direction. We've been defining ourselves by what we're not, existing in a hybrid space, but now with this round-wood barn, we've found a path where round-wood architecture has a future. It also connects back to Otto's round-wood experiment with the furniture school building. It no longer has to be a backward, rustic move. It feels like there's potential for a new attitude to using local and characterful wood. There's a clear affinity between Otto's round-wood furniture hall and that of the new algorithmically engineered robotic barn.

While a definite team effort, a significant contribution was made by a young Canadian architect, Zac Mollica, who'd spent time jobbing as a carpenter in Ontario before coming to Europe. Mollica put in many hours working on computer 3D modelling and resolving what became the truss geometry over the course of last summer. From there the robot began the bespoke fabrication and milling on each forking trunk. 'There were some crazy-looking trees,' says Mollica, 'from which we made this hybrid robotic crafted structure and, we didn't lose control to the algorithm.'

The whole team, including both students and staff seem to have all been through quite a trip with the project, coming out of it changed people. Self's sense of mission regarding Hooke Park's new-found direction is palpable.

For Jez Ralph, the estate manager, Hooke's larger story is all about rurality, and rurality's future. While the diversity reflects the almost blasphemous possibilities that are being tried out amid this rural studio's experimental test bed, it's pertinent to ask how much do these projects speak to rural futures in the longer term? If the next few student-cohort cycles that roll round add to and build on the lineage of radical round-wood exploration, the Woodchip Barn could mark a turning point in bringing round wood back into the 21st-century's future. ▶

Below – Synchronised robots in filament winding

Bottom – The 2016 Elytra Filament Pavilion, in the V&A's central courtyard, is the latest in a series of robotically made summer pavilions

Elytra Filament Pavilion at the V&A, London

The Victoria & Albert Museum's Elytra Filament Summer Pavilion is a first for the august institution, but for creator, Stuttgart's Institute of Computational Design (ICD) and Achim Menges, the robotically built structure is only the latest in an increasingly long production line of experimental pavilions completed over the past six years.

The first pavilion was exhibited in Stuttgart in 2010. Kicking off a series of timber pavilions, it set the investigatory scene for what robotically augmented design could bring to the research lab, which was otherwise impossible. The first two pavilions were early fruit of Achim Menges' long immersion in evolutionary, morphogenetic and biomimetic-related architectural research, while a student and then tutor at the AA's Emergence & Design unit. While the 2010 pavilion played with the geometric properties that emerged out of the research analysis of ultra-thin plywood when exposed to bending, biomimetics was at the heart of the second pavilion, with the design based on the sea urchin's plate structure.

That these intensely biomorphic forms, seemingly fusing this and other worlds, were happening in Stuttgart is hardly incidental. First off, there is the long German organic tradition, traceable back to philosopher Leibniz, continuing with the

Opposite page – **The ICD:ITKE 2016 Elytra Filament Pavilion, at the V&A, London**

Below – **The 2012 ICD:ITKE Hygroscope Paviiion**

Bottom – **Images of the ICD:ITKE pavilion 2011 iteration**

science of ecology's founder, Ernst Haeckel, and experiencing its most vital structural expression in the engineer-architectural visionary, Frei Otto, who made Stuttgart his research base, and which in considerable respects Menges and ICD are heirs to. Like Otto, Menges is tapping into Stuttgart's hi-tech networks, particularly the automobile industry – with Mercedes head-quartered in the regional capital (another German car giant, Volkswagen is the main Elytra Pavilion sponsor – with its 40-year history of robots on car production lines. Yet counter-balancing this hi-tech sheen, Menges says in Stuttgart, and across Southern Germany, 'there's an incredible respect for nature', pointing to the profusion of organic and biological projects.

'Otto had a broader vision of biology,' says a clearly admiring Menges, before inviting me to consider Otto's famous soap-bubble experiments. 'They're examples of "natural construction", which didn't, as many interpreted it, refer to something "natural" that happens in nature,' Menges underlines. 'Rather, natural construction is what happens when you inflate a bubble. It inflates naturally.'

Although through its lifetime Stuttgart's Institute for Lightweight Structures drew some of the best and the brightest engineers and architects, including Ted Happold and the other founding fathers of Buro Happold, and Shigeru Ban, the sheer radical nature of Otto's ILS team's investigations into the principles of how nature works was never accepted in Stuttgart's academic or architectural circles, let alone Germany's. A somewhat difficult character, it has only been in the aftermath of the Pritzker Prize being bestowed on Otto last year, days before he died, that there has been renewed interest rippling in from

this honour. It's also been a 'fantastically good thing' for Menges and the whole Stuttgart biological engineering sub-culture that encompasses ILS, ICD and The Institute of Building Structure and Structural Design (ITKE).

Not that Menges is exactly reticent in his critique of architectural conventions. Speaking at the recent Association of Architectural Educators conference hosted by The Bartlett this spring, he again returned to rehearsing his conviction that, 'truly computational design… is not an extension of established design techniques, but the beginning of a different way of designing'. Materials are no longer a passive receptor of a predesigned shape, underlining how radical a departure materials actively generating form is from modernism's hoary old 'truth to materials' chestnut.

When the materials' focus shifted, with the 2012 ICD/ITKE pavilion inaugurating research into synthetic glass and fibre composites, the form finding also changed. So the Elytra Pavilion, the latest iteration of these spun-composite web-like structures, has been generated from different algorithmic starting points to the plywood pavilions. Working in collaboration with biologists from the University of Tübingen, the first of these explicitly biomimetic pavilions applied the morphology of a lobster's exoskeleton, with the size, thickness and other structural and geometric properties determining the form, and from there, the programming that sets the bright orange Kuka robot arm spinning.

At the V&A, Menges' IKTE partner, engineer Jan Knippers, said the next step was bio-composites. Knippers and Menges also framed their experiments within the Victorian engineering tradition of Joseph Paxton, and his experimental greenhouses. Standing in the courtyard I could see the connection, although it felt as if the pavilion also evoked suitably Gothic atmospheres; organicism almost overlaid with a vestige of steam-punk. I wondered, what would Paxton have made of this future? ■

Below – **The ICD:ITKE 2013 Hygroskin Pavilion inaugurated research into synthetic glass and fibre composites**