Digital fabrication to date has typically been blind to context. But this need not be the case – as demonstrated by the experiments of Gramazio Kohler Research, based at ETH Zurich. They have developed systems that employ robotic arms and flying machines with feedback control to adapt the fabrication process as it progresses. From the ballistic projection of clay in a cutting-edge version of adobe, to the interlacing of string to form suspended structures in space, Fabio Gramazio, Matthias Kohler and Hannes Mayer outline some of their inventions here.

New Machines and Techniques for an Era of Computational Contextualism in Architecture
Since 2005 Gramazio Kohler Research has established the robotic arm as a powerful instrument in the toolbox of architecture. Today, robotic arms are common sight at architecture faculties and increasingly used by the building industry to create complex construction tasks. Their versatility has supported a rapid diversification of applications, adding many material processes to the early seminal brick pick-and-place projects. Yet, despite their worldwide success, problems such as their limited workspace remain and call for strategies. The recently inaugurated Robotic Fabrication Laboratory at ETH Zurich developed by Gramazio Kohler pushes these boundaries to a volume of 45 by 17 by 6 metres (148 by 56 by 20 feet) in which four robotic arms suspended from gaurtries can cooperate. A different approach is explored together with ETH’s Agile and Dexterous Robotics Lab: the location-aware mobile in-situ fabricator (2014-18) combines a robotic arm with a base on crawler tracks. In contrast to these projects, which could be described as heavy-handed and industrial, the two Gramazio Kohler Research projects presented in this article: Remote Material Deposition and Aerial Construction – formulate lightweight alternatives with disarming qualities. 

Remote Material Deposition (RMD) was constructed in June 2014 during a student workshop at Sitterwerk, an art foundation near St Gallen, Switzerland. RMD is based on the ancient human insight that throwing increases the reach of an arm. Yet, releasing the firm grip on the building material means challenging one of the core ambitions of digital fabrication: accuracy. Thus, while RMD can be situated within a group of projects that try to expand the work space of digitally controlled building machines – whether robots or 3D printers – to the scale of a building, its process and performative presence cannot be reduced to a purely quantitative and operational goal. RMD has its roots partly in the vernacular and owes its existence not least to an artistic process. It invokes the early work of Swiss artist Roman Signer, who in 1992 synchronously catapulted stools out of the second-floor windows of a vacant hotel in Weissbad, only 25 kilometres (16 miles) away from Sitterwerk. Signer’s work is a peaceful reminder that in the past, from catapults to modern missiles, throwing and launching ‘material’ has resulted in destruction. RMD reverses this process by employing ballistics, the science of calculating and predicting the trajectories of projectiles, for construction: it ‘civilises’ ballistics.

On Neutral Grounds of Architecture

Moreover, RMD reconciles two positions of architecture that have been construed as opposing poles in the architectural discourse of the past years: those advocating digital design and those promoting social design. For the latter camp, earthen buildings designed by architects such as Francis Kéré’s teacher’s housing in Gando, Burkina Faso (2004) or Anna Heringer’s METI school in Rudrapur, Bangladesh (2006) – have acquired a highly symbolic meaning, the latter having featured prominently in manifesto exhibitions such as the New York Museum of Modern Art’s ‘Small Scale Big Change’ (2011). In its search to find an appropriate building material that allows for certain tolerances, RMD adds a digitally controlled new method to the ancient technique of building with rammed earth, thereby bridging the two camps in architecture. At the same time, it reintroduces a material sensuality and self-expression to the digital while also emphasising the performative aspect of the building process.

The Spectacle: From Projectile to Project

Whereas robotic fabrication environments are commonly associated with pristine factory spaces void of employees, RMD literally started off as a dirty endeavour. After months of investigating the behaviour of different clay and loam mixtures with respect to water content, hardening times, deformation and aggregation, 25 tons of clay were ordered from a local pit, mixed with sand and cut into roughly 16,000 150-millimetre (6-inch) long cylindrical projectiles with a diameter of 83 millimetres (3¼ inches). The robotic setup consisted of a pneumatic shooting apparatus and a small robot manufactured by Danish firm Universal Robots that would pan and tilt the launcher. The robot was mounted on a gallery 7 metres (23 feet) above the exhibition space at Sitterwerk and accelerated the clay projectiles to a speed of 7.8 metres (26 feet) per second from its elevated position, which resulted in a circular building area of 11 metres (36 feet) in diameter. A scanner attached to the ceiling constantly monitored the topography of the shot structures, sending feedback to the control of the robot to adaptively determine new target points and to adjust the ballistic curve by recalculating the tilt angle. A 3D-modelling design, based on extruded circles that form undulating walls and topographical ridges, was given as a target input. To improve the building process the design anticipated ‘ballistic shadows’, spatial areas that cannot be accessed due to material deposited earlier in the production process. Such preconceived design was key for ‘civilising’ the ballistic architecture robot and for understanding the principles of ballistic architecture.
Air space had become addressable by coordinates and therefore a part of the rational world, space itself turned into constructible territory by means of digital control.
Compression as Expression

The geometric rigour of the forms made any deviation clearly visible, both when looking at the scans during the process and at the final built structure: the offsets of perfect circles were pushed outwards in shooting directions, leading to a radial stretching of the overall structure with the robot acting as the centre. Following the same logic, walls that ran in ballistic directions would be emphasised in its surprising slenderness. Through the feedback of the constant scanning process, the accuracy of the setup in shooting the design was incrementally improved and allowed for wall heights of up to 2 metres (6 feet 6 inches). The legible overall form emphasised the material expression based on compression and deformation, a frozen state of ballistic impact.

From Autonomous Construction to Autonomous Design

Despite the process’s emphasis on energy, it is controlled by a design agenda that is closer to the Baroque garden with its focus on perfect form and absolute control than to the contemporary understanding of open and dynamic systems with its accent on uncertainty. Thus, in a next step the ballistic potential of RMD in regard to emergent forms – or, more precisely, non-determined structures that are governed by the inherent logic and flows of the process – would need to be explored. What spatial aggregations could be built if the design was not preconceived, but instead fully exploit the material deposition feedback control? How would architects design if they had to translate their typological repertoire into a design system consisting of energy and material? In its first phase, RMD has elevated the hitherto formless heap to a state of architectural significance through remote fabrication of recognisable building elements. In a second phase, RMD could challenge the tectonic architectural conventions and its formative principles using the knowledge gained throughout its first project phase leading to the exhibition at Sitterwerk.

Flying Through Space, Building in Space

In its current state RMD operates best indoors. Without much airflow or turbulence, the ballistic trajectory can be calculated accurately. Such idealised conception of space goes back to the early days of modern architecture when Rudolph Schindler, disciple of Frank Lloyd Wright and one of the founding fathers of Pacific Modernism, introduced space as the medium architecture has to master, highlighting it as ‘a new medium of art distinct from all other arts’. Here, space was understood as the negative to the positive, it was a binary understanding of mass and void. When in 2012 Gramazio Kohler together with Raffaello d’Andrea realised Flight Assembled Architecture at FRAC Centre in Orléans, France, it demonstrated yet another step towards the mastery of architecture’s primary medium. Since airspace had become addressable by coordinates and therefore a part of the rational world, space itself turned into constructible territory by means of digital control. Using ultralight flying machines that have detached themselves from the massive body, firm stand and kinetic restrictions of a robotic arm, it was at this point that architecture’s primary medium – space – stopped being reliant on the ground from where architecture is built up. Flight Assembled Architecture masked this shift due to the sheer presence of the tower being built element by element from bottom to top. Its follow-up research project Aerial Construction (2013–15), discarded such conventions. By continuously unwinding string during flight, the flying machines performed truly spatial operations, gradually densifying and defining, interlacing a suspended structure, in this case a cable bridge.
Based on a dialogue between environment and technology, disarmed machines can move out of the laboratory and venture into open systems, like gliders that gracefully play with airstreams.

Computational Contextualism

Similar in its set-up to RMD, Aerial Construction tasked its flying machines with a predefined design, which proved robust enough to compensate for tolerances due to the material behaviour and the inherent instability of the flying robot. Consequently, Aerial Construction was still about establishing certainty within a medium largely governed by uncertainty. Yet, its development documents the shift from the modern understanding of space as void, to the contemporary perception of it as air that has become digitally tangible due to the comprehension of its dynamics and the improvement of sensorial observations and algorithmic control. With the integration of the latter into the design and fabrication process, the understanding of space and time in architecture enters a new level. At first, this is likely to serve an operational mode to tame the dynamics of the environment and to execute a predefined design without deviations. However, in a second phase the digitally enhanced awareness of and interaction with the environment will lead to a departure from a classical design paradigm that understood digital fabrication as the contextually blind execution of a predefined and pre-calculated design. Local conditions will start to impact on the design decision-making process, turning initially digitally tangible phenomena into physically tangible construction. Propelled by the race for resolution in sensing and control, computational contextualism fully exploits gained control in millimeters and microseconds, as well as further sensorial feedback, by understanding the architectural agency of the dynamic forces acting in the context of disarmed machines. Based on a dialogue between environment and technology, disarmed machines can move out of the laboratory and venture into open systems, like gliders that gracefully play with airstreams.

Notes

A catalogue of nodes that can be flown by quadrocopters, showing the agility of the quadrocopter in a series of diagrams.