IN-SI FABRIC MOBILE ROB CONSTRU CTI

Volker Helm

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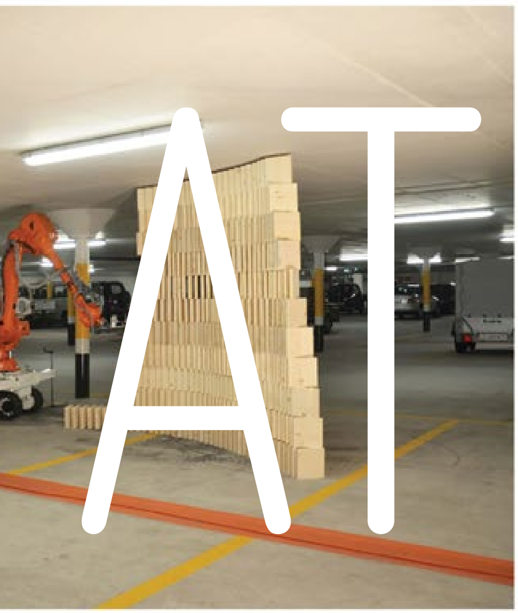
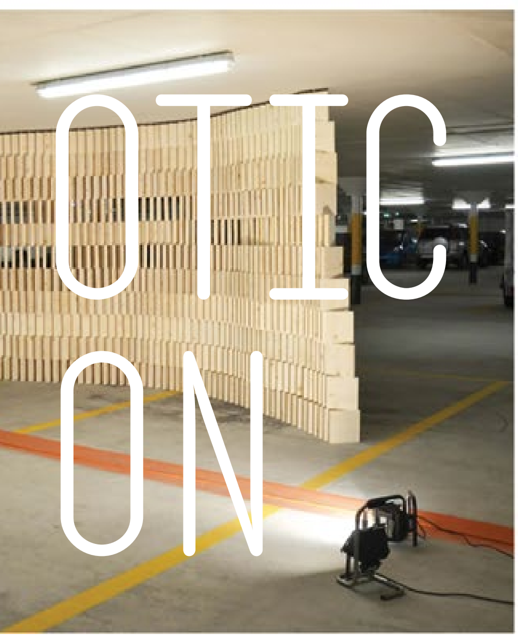





Fabio Gramazio and Matthias Kohler, In-Situ Fabrication, Architecture and Digital Fabrication, ETH Zurich, 2012
previous spread: Robotic positioning sequence.

Fabio Gramazio and Matthias Kohler, In-Situ Fabrication, Architecture and Digital Fabrication, ETH Zurich, 2011
below: An 8-metre (26-foot) long modular wall, digitally fabricated in the parking garage of the Department of Architecture at ETH Zurich using an additive assembly method, for which the robot had to reposition itself several times.

Enabling the robotic fabrication of building elements directly on a construction site, in-situ fabrication is a radical and novel approach to the application of digital fabrication in architecture. **Volker Helm** of ETH Zurich describes how an on-site unit, developed with Fabio Gramazio and Matthias Kohler in the Architecture and Digital Fabrication department at the university, offers the first-ever generic robot with applications in a wide range of processes, providing the means of investigating the requirements and capacities involved in non-standardised fabrication.

In-situ fabrication – as opposed to prefabrication on stationary machines – enables the robotic fabrication of building elements directly on a construction site. The application of mobile robotic systems allows for the 'continuous production' and erection of large-format or even complex construction systems over the course of an open-ended, on-site building process. This approach avoids the conventional industrial method of assembling prefabricated elements produced in advance on stationary equipment at off-site or on-site field factories. It also eliminates the need for the often laborious and costly transportation of larger building components to the construction site.

In-situ fabrication requires the employment of an automatic mobile robotic unit that can navigate an unstructured, dynamic construction site, continually detecting and adapting to the surrounding building equipment and components, as well as any material tolerances, imprecision or deviations. A critical necessity is the deployment of a closed-loop system that interconnects the robotic digital fabrication, sensor-driven cognitive skills, and human-machine interaction. This ensures the direct integration of incoming information into the logic and articulation of the building components as well as real-time input that enhances the interlinking of digital data and the concrete material.

In-situ fabrication is a radical and novel approach to the application of digital fabrication in architecture. The robotic unit developed for these purposes with Fabio Gramazio and Matthias Kohler and ETH Zurich, where they share the Chair of Architecture and Digital Fabrication, is the first-ever generic robot with applications in a wide range of processes. Since 2011, it has served as the apparatus by which the requirements and capacities involved in non-standardised fabrication on a construction site are investigated at ETH Zurich.

ON-SITE MACHINES

Since the 1980s, several attempts have been made to employ mobile robotic units on construction sites. Various efforts to develop specialised construction robots were aimed at the semi-, fully automated or remote control of separate construction processes.[1] The most advanced of these were probably the mobile robotic systems ROCCO[2] and BRONCO[3] designed for automated on-site masonry fabrication developed in the 1990s. Architectural considerations were not the prime concern of these early attempts, which were aimed foremost at increasing productivity and economically optimising building processes.[4]

Most of the mobile robotic systems never quite managed the leap from prototype or research to application. This was due in part to the dynamic and unstructured nature of construction sites in comparison to laboratory settings. It can also be attributed to the fact that at that time, technologies were not yet advanced enough to handle the complexity required to develop automated machines capable of operating in unpredictable environments. Consequently, these machines generally ended up being manually operated, serving to facilitate precision in the positioning of heavy building components. It is precisely at this point that the research explorations of in-situ fabrication come into play in the form of a generic robotic unit outfitted with scanning technology that can be employed in complex processes on a construction site.

Unlike mobile construction robots, smaller automated service robots (so-called AGVs – automated guided vehicles) have long ceased to be mere vision in the industry. In logistics they find application in warehouse automation, enabling the efficient transportation and arrangement of shelving systems according to an algorithmic logic.[5] High-end semi- and fully automated units are employed in the military and a current focus in robotic research is aimed at the development of humanoid service robots. In the private sector, inexpensive automatic robotic vacuum cleaners and lawn mowers equipped with basic sensor technology have managed to successfully penetrate the market. The most common application found in the public sector are the inspection and cleaning robots used for clean-up operations following environmental or natural disasters. And robotic couriers are presently being employed in over 200 hospitals worldwide.[6]

Automated robotics research is currently experiencing a quantum leap in development due to rapid advances in hardware technology and increasingly powerful processors. Nevertheless, the realisation of fully automated systems that are capable of handling every conceivable situation is still technically and conceptually extremely challenging and so far only possible to a limited extent. The inclusion of human interaction is therefore recommended for in-situ fabrication when it comes to the simplification of complex processes.

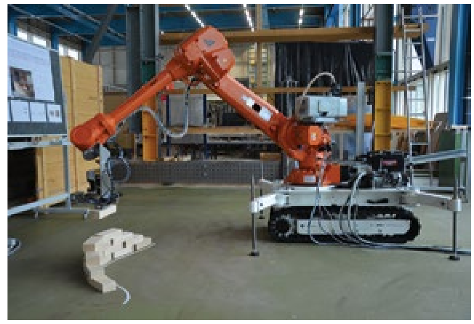
Fabio Gramazio and Matthias Kohler, Stratifications, Architecture and Digital Fabrication, ETH Zurich, 2011
below: The 1:1 Stratifications installation at the FABRICATE 2011 conference in London, performing an experimental demonstration of the handling of building tolerances.

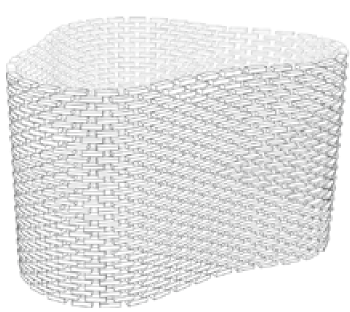
bottom left: The initial configuration of the installation's structure in which differently sized timber blocks are positioned according to a pixel image.

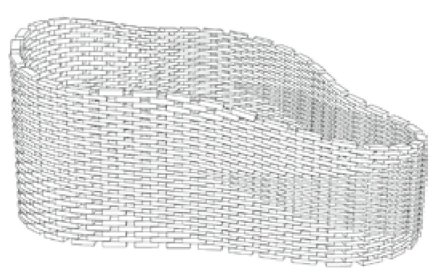
bottom right: The actual configuration after the blocks were robotically assembled, aggregated freely on top of each other.

Fabio Gramazio and Matthias Kohler, In-Situ Fabrication, Architecture and Digital Fabrication, ETH Zurich, 2012
top right: User interaction with the mobile robotic unit whereby the hand gesture is scanned and imported into the CAD software as a line segment.

centre right: The configuration of the wall structure is built accordingly.







BASIC RESEARCH

Basic research is needed to demonstrate the fundamental advantages of such novel approaches to mobile in-situ fabrication as the continuous digital fabrication of large-format structures. Initial steps have already been taken within the scope of the following research experiments at the ETH Zurich as well as a separate dissertation project.[7] Due to the complex requirements involved in direct fabrication on a construction site, the initial exploration was broken down into several areas of focus: assembling and outfitting a mobile robotic unit; handling building material tolerances; human–machine interaction; and positioning and localisation techniques.

Mobile Robotic Unit

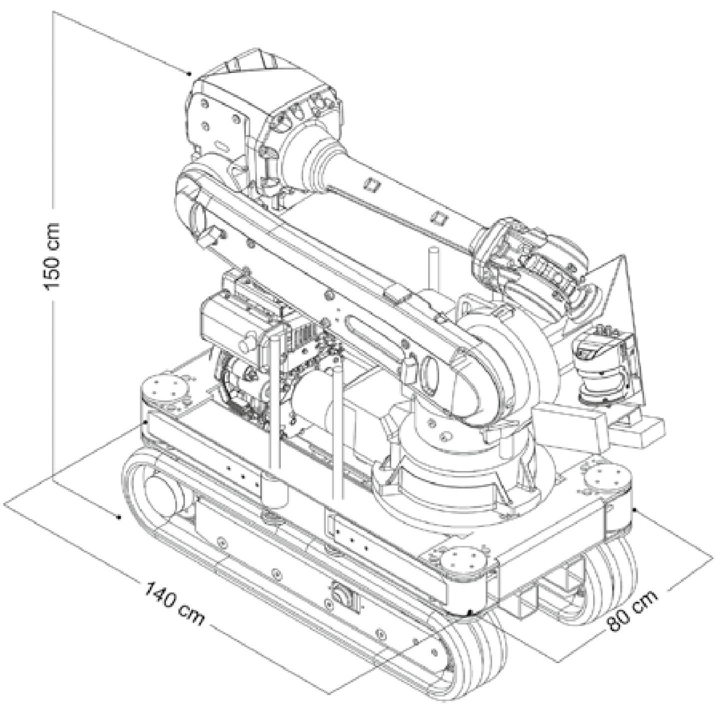
In order to investigate in-situ fabrication, it was first necessary to develop a compact, mobile robotic unit equipped for autonomously handling a variety of construction tasks. Within the scope of a research project funded by the European Union,[8] a mobile system was devised for the first time that could pass through any standard door opening when in a retracted position. Aside from mounting an industrial robot to a track vehicle, additional components such as sensor technology, universal grippers and a vacuum supply were integrated into the robotic system.

Handling Material Tolerances

One of the first robotic in-situ experiments focused on developing and testing a reliable robotic assembly technique for detecting and adapting to material and construction tolerances. Stratifications, a circular test structure, which was first publicly presented at the 2011 FABRICATE conference in London,[9] was assembled from 1,330 discrete wood elements at three varying heights. This experiment employed a robotic unit that could adapt to randomly arising deviations in tolerances. The combination of an integrated sensor (laser rangefinder) and algorithmic operational strategies enabled the robot to self-calibrate in response to any unforeseeable material changes or deviations that arose while stacking the wood elements, enabling it to successfully build a stable structure. In a broader sense, this experiment reveals that the architecture is no longer bound to a purely geometric (CAD) approach.

Human–Machine Interaction

Building on the experiments exploring handling with material tolerances and scanning technologies, a follow-up experiment turned the focus to 3D robotic environment recognition and interaction between the human operator and the robot. Interfaces were designed that would enable a robot to recognise and correctly interpret instructions given by a human operator. The central aim here was to figure out the most basic and intuitive courses of action that would also find application on construction sites. The mobile robotic fabrication unit was outfitted with a 3D scanning device for tracking and processing human hand movements. A 3D camera was then used to record the movement of a hand drawing a freehand line segment on the ground. Once the software had processed the corresponding data input, the robot was able to fabricate rows of masonry bricks along the delineated line. This experiment provided verification that the formation and assembly of building components fabricated by industrial robots can be influenced by human movement.



Fabio Gramazio and Matthias Kohler, In-Situ-Fabrication, Architecture and Digital Fabrication, ETH Zurich, 2009
The experimental setup: an industrial robot, ABB IRB 4600, mounted on a compact mobile track system that is sized to fit through a standard door frame on a construction site.

Positioning and Localisation Techniques

The Fragile Structure research experiment served to illustrate the advantage of employing the open-ended in-situ fabrication of a 'continuous building element'.[10] Here, certain operational strategies enabled the automated mobile robotic system to calibrate its own position relative to an existing structure. The experiment was conducted in an underground parking garage where the restricted ceiling height as well as the slanted and uneven ground provided conditions similar to those found on a construction site. The robotic assembly of discrete wooden elements into a complex, non-standardised 8-metre (26-foot) long structure served to further demonstrate the application of in-situ fabrication at an expanded, large-format scale of operation. Following repeated trials using a self-developed local referencing system based on markings and computer vision, it could be verified that after repositioning, the robotic unit is capable of automatically calibrating and building further on existing structures.

FIRST APPLICATION

The current ETH research project, Mesh-Mould,[11] builds on the realisation that although standard industrial robots may be capable of navigating a space with extreme precision, their payload capacity in comparison to objects that are typically conveyed on a construction site is still very limited. Here, the application of in-situ fabrication and its potential for the robotic fabrication of an innovative concrete formwork system is being explored for the first time. In-situ fabrication clearly provides distinct advantages over conventional manufacturing methods for producing complex concrete formwork, since these can only be carried out exclusively with robots. It interlinks the otherwise previously separated fabrication steps – such as the laborious construction of each individual formwork element, the bending and placement of reinforcement bars, and the pouring of concrete – into one continuous digital, spatial production process. This on-site approach to fabrication eliminates the issue of structural weakness in construction joints or size restrictions concerning the transportation of prefabricated components.

FINDINGS AND POSSIBILITIES

Initial key steps have been undertaken to utilise mobile production machines in the production of large-format construction systems in a continuous, open-ended process within unstructured and unpredictable environments. These studies have also provided fresh impetus for conducting further research on this topic in academic and industry settings, as well as finding applications in the construction industry.

Outfitting mobile robotic systems with scanning technology enables an ongoing exchange between the robot and its built environment. It provides robots with the ability to counter-steer and recalibrate in response to material tolerances or construction-site-induced obstacles with the aid of strategic programming. Sensors additionally facilitate interaction between the human and the robot, enabling the enhancement or simplification of otherwise complex operational and software processes.

Future in-situ fabrication requirements are expected to centre primarily on expanding the dynamic behaviour of the mobile robotic unit. Technical and conceptual modifications will enable increased automation and greater sensitivity in handling complex construction processes. The inclusion of multi-robotic cooperation will be crucial to this process, enabling greater dexterity through the application of multiple robotic arms, for example enabling the consolidation of several tasks into one single process. In addition to advancements in hardware and software technology, human–machine interaction and multi-robotic cooperation, future studies will need to focus foremost on scenarios for application in architecture – after all, mobile digital fabrication will not only transform the future building process, but will also have the capacity to significantly change the appearance of our built environment. AD

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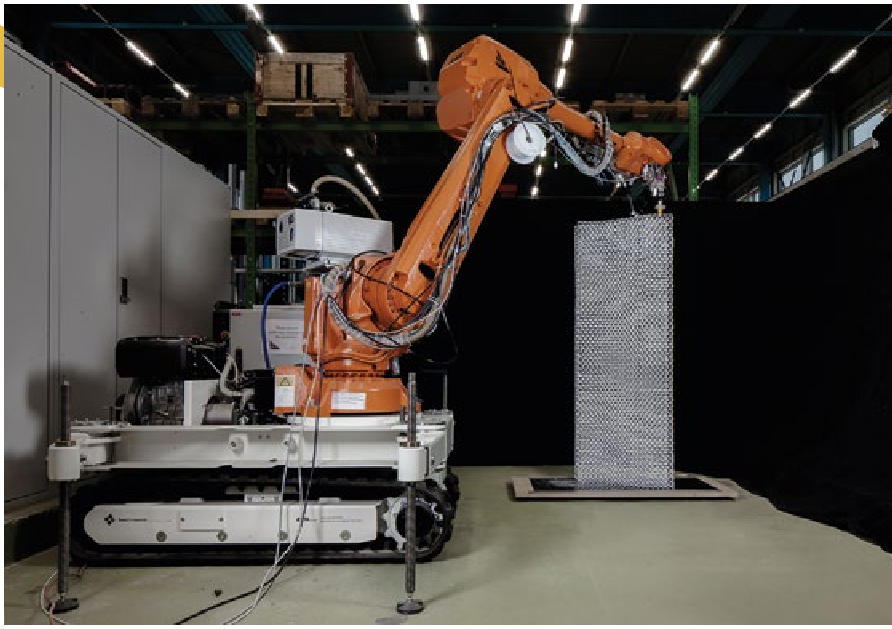
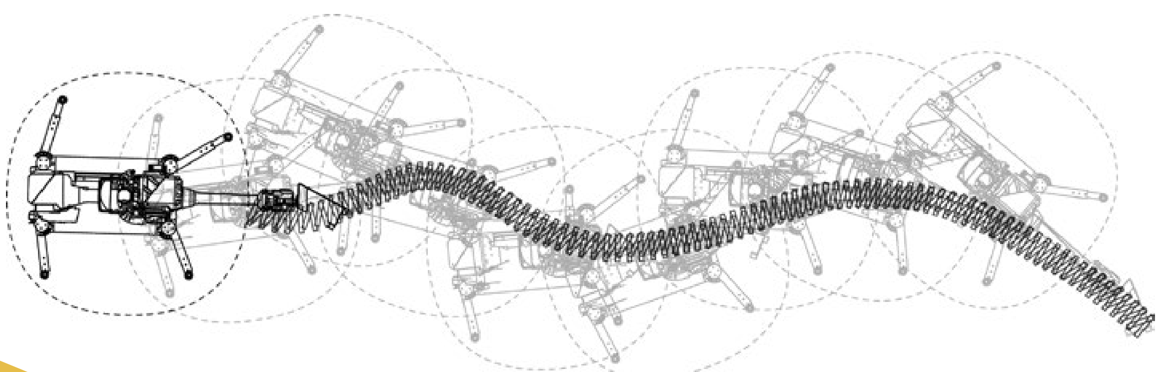
Fabio Gramazio and Matthias Kohler, In-Situ Fabrication, Architecture and Digital Fabrication, ETH Zurich, 2012
opposite bottom: The continuous production process of the mobile machinery. A scanning mechanism – developed for finding the centre point of a metal disc and setting it as the origin of the plane – is defined in the CAD model for each new position of the robot.

Fabio Gramazio and Matthias Kohler, Mesh-Mould, Architecture and Digital Fabrication, ETH Zurich, 2013
Large 1.8-metre (5-foot-11-inch) prototype extruded with the mobile fabrication unit. Simulation of a potential application on the building site.



Notes

1. Thomas Bock, 'Construction Robotics', *Autonomous Robots*, 22(3), 2007, pp 201–9.
2. Jürgen Andres, Thomas Bock, Friedrich Gebhart and Werner Steck, 'First Results of the Development of the Masonry Robot System ROCCO: a Fault Tolerant Assembly Tool', *Proceedings of the 11th International Symposium on Automation and Robotics in Construction (ISARC)*, Brighton, 1994, pp 87–93.
3. G Pritschow, J Kurz, Th Fessele and F Scheurer, 'Robotic On-Site Construction Of Masonry', *Proceedings of the 15th International Symposium on Automation and Robotics in Construction (ISARC)*, Munich, 1998, pp 55–64.
4. Tobias Bonwetsch, Fabio Gramazio and Matthias Kohler, 'Digitally Fabricating Non-Standardised Brick Walls', *Manubuild: Proceedings of the 1st International Conference*, Rotterdam, 2007, pp 191–6.
5. Erico Guizzo, 'Three Engineers, Hundreds of Robots, One Warehouse', *Spectrum*, 45(7), 2008, pp 26–34.
6. Richard Bloss, 'Mobile Hospital Robots Cure Numerous Logistic Needs', *Industrial Robot: An International Journal*, 38(6), 2011, pp 567–71.
7. The 'In Situ Robotic Fabrication: Robot-Based Construction Processes on Site' doctoral project is based on a collaboration between the research areas of experimental computer science and architectural digital fabrication. Doctoral candidate: Volker Helm. Supervision: Professor Dr Georg Trogemann, Laboratory for Experimental Computer Science, Academy of Media Arts Cologne, and Professor Matthias Kohler, Architecture and Digital Fabrication, ETH Zurich.
8. The In-Situ Fabrication research work was supported by the EU Project ECHORD. Team: Volker Helm, Dr Ralph Bärtschi, Tobias Bonwetsch, Selen Ercan, Ryan Luke Johns and Dominik Weber. Industrial partner: Bachmann Engineering AG (Zofingen, Switzerland).
9. The Stratifications project was developed in 2011 at the FABRICATE conference in London. Team: Andrea Kondziela, Volker Helm, Ralph Bärtschi and Dominik Weber with Bachmann Engineering AG (Zofingen, Switzerland.
10. The Fragile Structure project was developed in 2012 during an elective course at ETH Zurich. Team: Luka Piskorec, Volker Helm, Selen Ercan and Thomas Cadalbert. Students: Leyla Ilman, David Jenny, Michi Keller and Beat Lüdi. Sponsors: Schilliger Holz AG.
11. See Norman Hack and Willi Viktor Lauer's 'Mesh-Mould' article on pp 44–53 of this issue of AD.



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