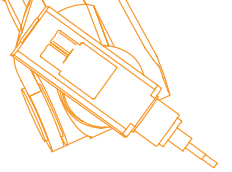

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Introduction

Rob|Arch: Robotic Fabrication in Architecture, Art, and Design

Towards Robots in Architecture

Architects have been fascinated by robots for many decades, from "Chantier de Construction Électrique", Villemard's utopian vision of an architect building a house with robotic labor in 1910, to the design of buildings that are robots themselves, such as Archigram's Walking City. In the 1980s and 1990s it briefly seemed as if robots had finally arrived in architecture, when the Japanese construction industry started using highly customized robots for high-rise construction. However, amid the turmoil of Japan's financial problems in the 1990s these experiments were discontinued. Many later robotic projects were performed in a purely virtual environment, as architects were unable to transform their theories into a physical output.

Today, architects, artists and designers are again approaching the topic of robotic fabrication but with a different strategy: Instead of utopian proposals like Archigram's or highly specialized robots like the ones that were used in Japan, the current focus of architectural robotics is industrial robots. These robotic arms have six degrees of freedom and are widely used in industry, especially for automotive production lines. What makes robotic arms so interesting for the creative industry is their multi-functionality and their low price: instead of having to develop specialized machines, a multifunctional robot arm can be equipped with a wide range of end-effectors, similar to a human hand using various tools. Furthermore, due to their prevalence in industry, these robots are not prototypical machines, but certified, reliable, and increasingly affordable, today costing 70% less than the average price in the 1990s.

General research into industrial robots has been going on since the 1950s as an interdisciplinary effort involving mostly mechanical and electrical engineers, as well as computer scientists and mathematicians to deal with various aspects, from kinematic calculations to the design of efficient motors. This has led to a wide range of industrial robots, from desktop-sized small robots with a carrying weight of a few kilograms to massive machines capable of lifting a car chassis.

Therefore, architectural research into robotics is not so much directed at reinventing machines for architectural fabrication, but rather at re-using industrial robots as a well-established basis and adapting them for architectural purposes by developing custom software interfaces and end-effectors.

Pioneering Work

While the use of industrial robots in the construction industry was explored by researchers as early as the 1980s, pioneering work was done at ETH Zurich by Fabio Gramazio and Matthias Kohler, whose projects such as the Gantenbein Vineyard Façade showed that robotic arms are not only capable of replicating human labor, but can perform fabrication strategies that are outside the scope of human labor.

That was in 2006. In the past six years, more than 20 architecture faculties around the globe have acquired industrial robots and are actively researching new and innovative uses for these multifunctional machines, among them the University of Stuttgart, whose research pavilions have been published worldwide by architectural and mainstream media.

At the end of 2010, the Association for Robots in Architecture was founded, with the goal of making industrial robots accessible to the creative industry. We pursue that goal with a dual strategy, on the one hand by developing custom tools for accessible robot control, which later resulted in e.g. KUKA|prc, and on the other hand by acting as an open platform for artists, designers, researchers, technicians, and corporations involved in creative robotic fabrication.

The idea of organizing the first international conference dedicated to robots in architecture, art, and design emerged in mid-2011 and has since then met with an extremely positive feedback from both universities and industry partners.

Rob|Arch

Robotic fabrication in architecture, art, and design is a relatively young discipline, whose focus is on applied research, performed on the one hand by young designers, artists and researchers from the "digital generation" and on the other by innovative firms and startups, researching applications that go beyond typical industry solutions. This is reflected in the structure of this book, which does not consist solely of full-length scientific papers but has four distinct sections: workshop papers, research papers, project papers, and industry papers.

Workshop Papers

One of the centerpieces of the Rob|Arch conference is the robot workshops, organized by ETH Zurich, University of Stuttgart, TU Delft, TU Vienna, TU Graz, Harvard GSD, SciArc, and HAL/Robots in Architecture. For the first time, these internationally recognized institutions are opening their robotic labs and allowing participants to take part in their exciting research.

These workshops are not recapitulations of existing work, but contain new ideas that were developed for this conference and are published in this book. Stuttgart's workshop contribution builds upon the joining technology that was initially developed for the research pavilion, and the influence of biomimetic design strategies, while the ETH's workshop paper shows how their robotic bricklaying algorithm has evolved into an accessible design tool. New interfaces are also a significant topic for most of the other workshop paper: Thibault Schwartz presents a versatile tool

for the visual programming of ABB robots, while TU Vienna links the fabrication process with real-time data captured from a camera and SciArc explores cooperating robotic arms. Harvard GSD's workshop focuses on ceramics as a material, while the remaining two workshops deal with subtractive fabrication methods: TU Graz explores robotic milling of foam glass, while TU Delft uses wire cutting for the rapid generation of three-dimensional free-forms.

Research Papers

Research papers are full scientific papers that were reviewed by the scientific committee and show a wide range of robotic applications that go far beyond today's industrial applications.

Despite the large spectrum of applications, we can still identify a common ground linking these research projects. Aggregations can be observed in multiple contributions, from uniform black balls that are robotically glued together to form organic structures, via macro-scale granulates, to metallic molecules that are shaped by robot-mounted electromagnets. New robotic end-effectors are also explored in various papers, such as for the robotic bending of metal facades, the shaping of clay, or simply for holding a tile long enough at an arbitrary position in three-dimensional space until the bonding material sets.

The third common topic is augmented reality and non-physical fabrication, where on the one hand gestural interfaces and head-mounted displays assist in the design and fabrication of physical objects, while on the other hand robots are programmed to paint with light or even to use light for the visualization of non-visible radiation - controlled by a robotic arm.

Project Papers

The project paper section contains innovative robotic projects from a wide range of robot users, from mechanical engineers to artists. The deformation of metal is explored in very different ways, from the bending of metal rods - either for creating three-dimensional objects for the Venice Biennale, or as reinforcement for non-standard concrete structures - to the three-dimensional deforming of sheet metal with a spherical tool.

Another area is the robotic application of materials, such as the weaving of spider-silk-like nylon strands, the shaping of plaster, and the extrusion of recycled plastic for furniture design. Furthermore, custom end-effectors, e.g. chainsaws and jigsaws, are explored, along with potential uses of industrial robots for large-scale architectural projects.

Industry Papers

In addition to the workshop, research, and project papers, Rob|Arch's innovative industry partners were invited to submit papers that showcase their most recent developments in the context of robotic fabrication in architecture, art, and design. Robot manufacturers present their newest series of industrial robots, alongside software systems that allow the direct loading of CNC code or the simultaneous control of multiple robots. Various interesting and innovative robotic fabrication methods are discussed, from the robotic winding of com-

posite materials, to automated steel beam construction, high-end subtractive fabrication, and new programming strategies. The industry papers in particular show that robots are already being used for various tasks in the building industry and will soon become valuable state-of-the-art tools for the creative industry.

Outlook

The contributions presented in this book show that robotic fabrication in architecture, art, and design has evolved from being a small, specialized, and exclusive field of research, to a large community where robots are no longer used simply for milling or welding – as they were in the past decades – but as multifunctional machines that can perform an extremely wide range of tasks, from replacing human labor to performing tasks that would be impossible for the human hand.

New interfaces, developed by architects and designers themselves, enable the creative industry to control robots out of common Computer Aided Design (CAD) software, instead of having to rely on engineering-focused, specialized robotic software. This customization, not only of the end-effectors, but also of the software interfaces, allows architects and designers to move beyond industry-standard robotic applications towards highly optimized and customized machines. Architects, artists and designers have advanced from being mere "users" of robots, and have successfully emerged as recognized developers and trendsetters in robotic fabrication.

We are extremely grateful to our supporters, conference partners, and workshop hosts, as well as all the authors, for making this significant event happen. Special thanks go to Rob|Arch's main sponsor KUKA, represented by Alois Buchstab, for their steady support, not only of this conference, but of innovative and creative robotic projects in general. We would also like to acknowledge the fast growing community of "Robots in Architecture" who share their expertise, knowledge and passion of robots to meet the Association´s goal of making robots accessible to a wide range of new users.

Robotic fabrication in architecture, art, and design has gained great significance within the space of just a few years. As a central node of the creative robotic community, Rob|Arch will continue to carry this momentum. We strongly believe that, this time, robots are here to stay.

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