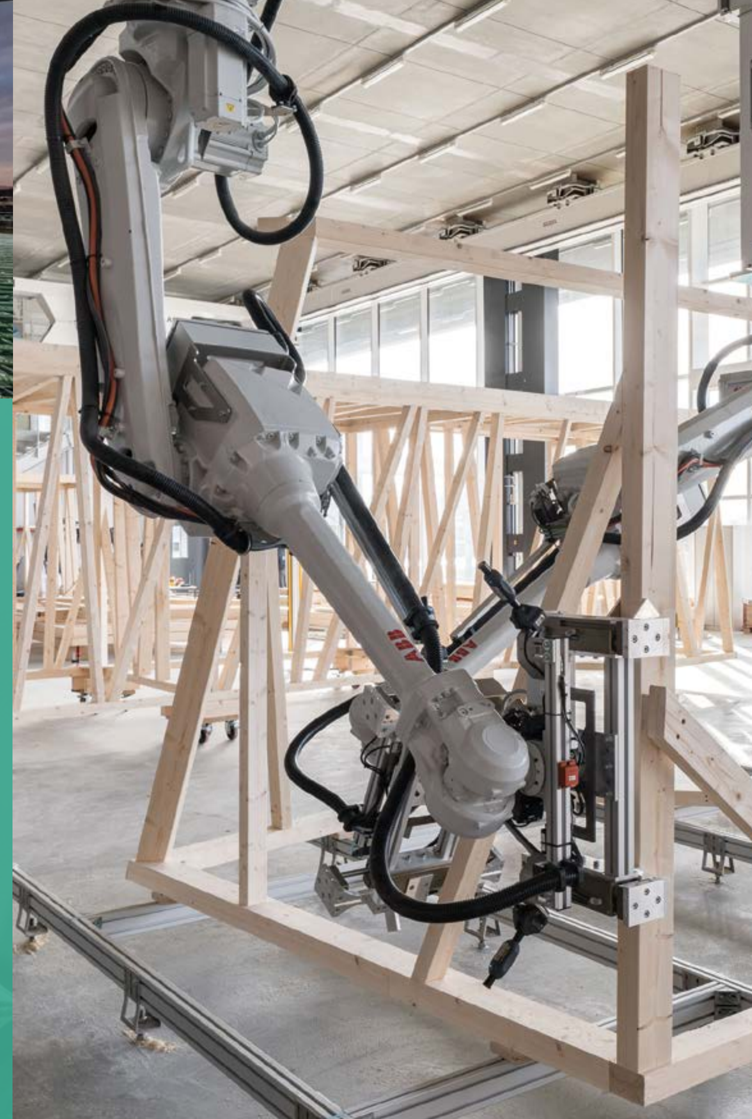

CTBUH Research Report

Robotics in Tall Building Construction

New Frontiers in Fabrication and Automation

Alberto Balzan, Claudia Cabrera Aparicio & Dario Trabucco

Council on Tall Buildings and Urban Habitat

Schindler

Contents

Introduction and History

Construction Robotics as Industrial Policy: Top Market Trends

Approaches to Robotics in Construction

Current and Future Applications

References

4.0 General Challenges and Drivers

4.1 Introduction

Researchers are increasingly intent on understanding and overcoming the obstacles to the adoption of robots in construction. A survey conducted by García de Soto (Chen, de Soto and Adey 2018) among sector professionals highlighted three key concerns in the construction automation field: efficiency, collaboration and capacity to increase market share, and enhancement of stakeholders' communication. Some of the mentioned factors hamstring innovation, while others drive further exploration of the potential of robotics in the construction industry.

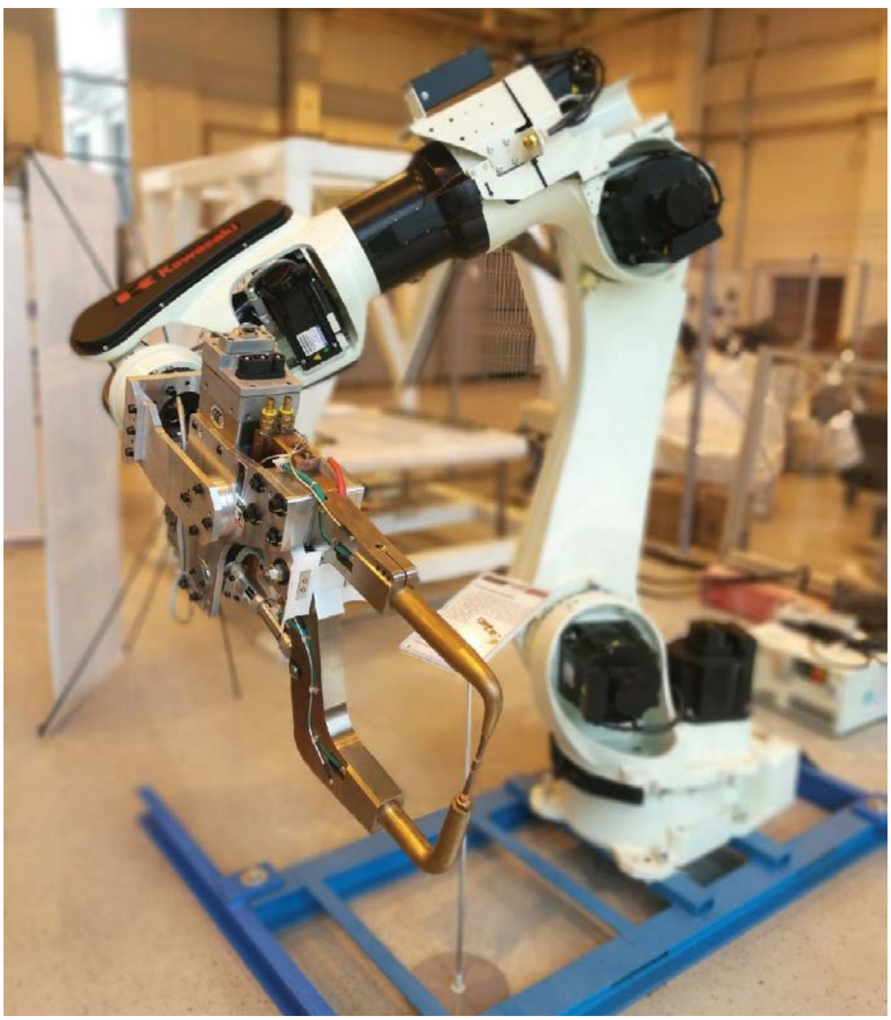

Figure 4.1.1. Industrial robots, like this Kawasaki Spot-Welding Robot, are sizable investments, presenting a potential barrier to widespread industrial robot use. © Mukszwei (cc by-sa)

Some of the main limitations to the widespread implementation of construction robotics include the large dimensions and heavy weight of the parts involved (and weight limits inside buildings), the lack of standardization in construction projects, inconsistent operating environments across projects, and the simultaneous need for on-site flexibility and adaptation to use robotic resources efficiently. There is also a need to produce a final highly-defined plan and design in order to robotize the construction work from the outset. Finally, the high cost of robotic devices, and the requisite expense of altering industrial robots to fit the aforementioned needs, are major hurdles to investment (see Figure 4.1.1).

4.2 The Uniqueness of Construction Projects

The uniqueness of each building project at all levels is translated to a greater difficulty to automate processes under changing requirements. Technical and functional heterogeneity (i.e., diverse ground conditions for contiguous buildings or slight differences in usage of two adjacent homes) make a higher degree of adaptation to the environment necessary. Even in those cases where two structures are identically designed, the number of operations that can be reiterated is lower than in automated production lines from other industries. While in production lines, robots and processes are fixed on the floor and the product moves, in construction processes the final product is stationary, and robots are required to move as erection progresses in unstructured environments.

Moreover, as Best and de Valence (2002) state, the "decision-making and situational analysis necessary for a robot to be self-directing as it goes about its assigned tasks demands very high levels of processing power contained in small, lightweight units," which on a construction site means a higher level of software complexity with smaller hardware for ease of movement. Construction projects are unique and have specific requirements, as assemblies are layered, and a high degree of human-robot interaction is required.

4.3 Safe Integration of Human and Robot Labor

A second limitation is related to the necessity to bring together robotic processes and the human workforce in a safe environment. It is important to differentiate between two types of robotic arms: caged robots and co-bots. The first class comprises robots that are only allowed to operate in a human-free environment, inside protective cages, using sensors that stop the devices in case the cage is opened during operation (see Figure 4.3.1). On the other hand, co-bots are designed to work in non-exclusive environments, and if they find an obstacle, they instantaneously stop moving. This drawback is due to the lower investment in co-bots instead of existing commercial robots (which are useful only for a limited target market) and the requirements that they must meet in order to guarantee safety in a human-robot collaboration context (see figures 4.3.2 and 4.3.3). It can also be concluded that existing commercial robots are

Figure 4.3.1. Some industrial robots, like these automotive assembly arms, are designed to work fully separated from human workers for safety reasons. © Norbert Kaiser (cc by-sa)

Figure 4.3.2. Co-bots, like this one developed by KUKA, work alongside and amongst human workers. © Daimler & Benz Stiftung (cc by-sa)

12.3 Case Study

DFAB House

Dübendorf, Switzerland, 2019

Figure 12.3.1. DFAB House is a 200-square-meter, three-story building in Zurich, placed atop a separate base structure (left), as part of a multidisciplinary experiment in robotic construction. A portion is constructed in timber (right). © Roman Keller

Project Overview

DFAB House can be considered the first case of a fully functional building that has been digitally designed, planned, and built. It is a house that has been constructed on top of the NEST (Next Evolution in Sustainable Building Technologies). A joint project of Empa (Swiss Federal Laboratories for Materials Science and Technology) and Eawag (Swiss Federal Institute of Aquatic Science and Technology), NEST is a research platform that acts as modular hub, to which new units are added and substituted, to test and share innovations and experiments related to the building field (see Figure 12.3.1).

Within this framework, DFAB House has been manufactured as a product of the Swiss NCCR, a multidisciplinary initiative that involves architecture, robotics, material and computer science, as well as civil and mechanical engineering. It has been designed by a group of researchers belonging to eight different ETH Zürich professorships, as a demonstrator of several digital fabrication technologies, conceived with the aim of exploring new ways of designing buildings, or parts of them. The house consists of 200 square meters, developed on three floors, and its realization has been made possible thanks to the collaboration of ETH Zürich with expert partners from more than 30 industrial enterprises, a context conducive to producing innovative and efficient solutions.

Robotic Applications and Innovations

As a demonstrator of digital fabrication technologies, there are at least six interesting processes, techniques and elements (called "Innovation Objects" by the developers) involved in this project (see Figure 12.3.2).

In-Situ Fabricator
This device is an advanced construction robot able to recognize its surroundings and therefore move and operate autonomously, by virtue of its integrated sensing and computation system. In contrast with other robots developed to accomplish traditional tasks, the "In-Situ Fabricator" is a versatile tracked platform, equipped with a six-axis robotic arm, that has been designed to fabricate innovative building elements on-site. The robot's level of sophistication is particularly elevated; indeed, it is able to autonomously operate and adapt itself based on unexpected material behavior, and without using external measurement tools.

Within this project, this device has been deployed to fabricate the "Mesh Mold", another "Innovation Object" (see Figure 12.3.3). Two vision-based sensing systems have been deployed, one for the robot's automated repositioning along the constructed element, consisting of a camera combined with markers located on the ground; and the other for process monitoring, consisting of two cameras that eventually enabled real-time adjustments of the end-effector.

Mesh Mold
This "Innovation Object" comes from the desire of designers not only to express the qualities of concrete through the possibilities opened up by the use of new digital tools, but also to optimize many aspects of the construction process related to the

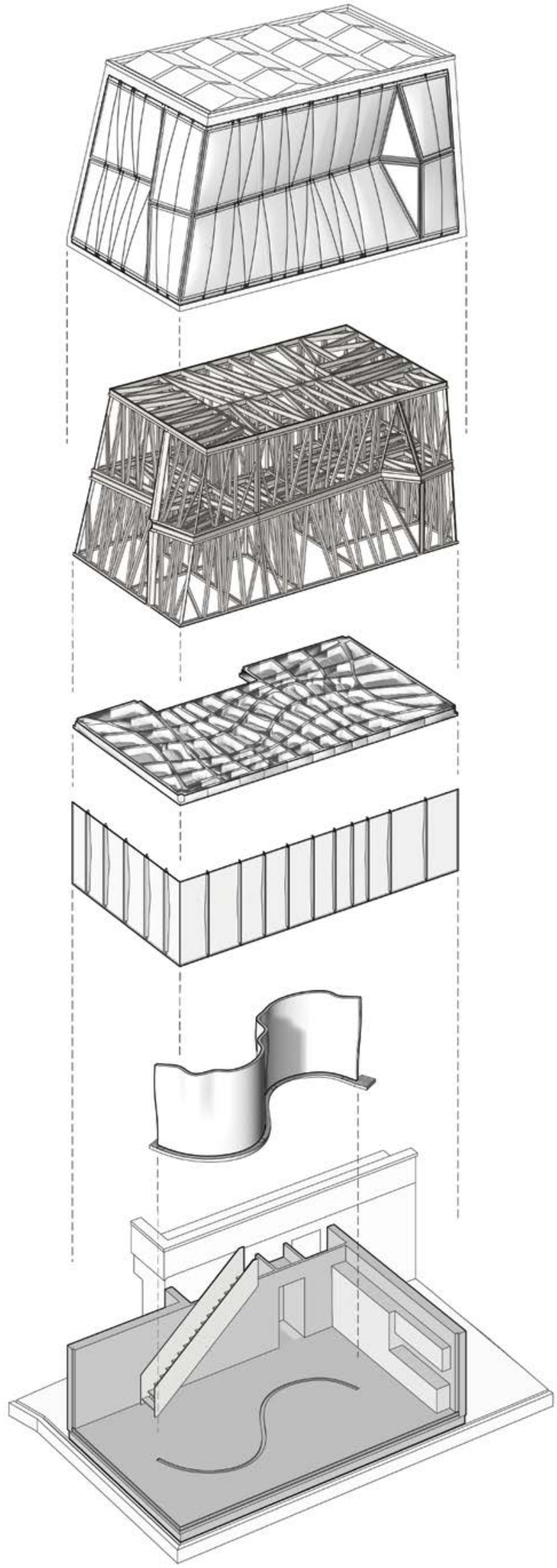

Figure 12.3.2. DFAB House was created using several digital fabrication methods, which were then fitted together into a final assembly. © Konrad Graser / NCCR Digital Fabrication

The construction industry is routinely identified as one of the slowest to adopt technological advances. And yet, the need to rapidly construct new buildings for a growing urban population, counteract the aging of the workforce and high labor costs, and reduce on-site waste, all point toward the advantages of automating construction. Through a historical review, comprehensive cataloging of both conceptual and existing industrial robotic concepts and techniques, and a series of robust case studies, this publication delves into the future of this promising field, identifying the incentives for, and obstacles to adoption by the construction industry.

Comparatively, the automotive industry has experienced the most significant changes in the transition from a human to a robotic workforce, and the lessons provided are numerous. Robots have been highly effective and advantageous at performing tasks that are repetitive, require high levels of precision, or are dangerous. While the size of the human workforce in the construction sector has declined, new jobs are being been created in the design, building and operation of such robots. Automation and robots have already been used in the construction of buildings across different heights, typologies, and complexities.

From simple automation to autonomous construction, from drone-based assembly to human-enhancing exoskeletons, the full range of possibilities—including government, private, and academic research, as well as real-world applications—is explored in detail in this comprehensive report.

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