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Author:	Dario Trabucco, CTBUH Research Manager, Council on Tall Buildings and Urban Habitat
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Robotics in Construction: The Next 50 Years

Dario Trabucco
CTBUH Research Manager

Council on Tall Buildings and Urban Habitat (CTBUH)
Venice, Italy

Dario Trabucco has been the CTBUH Research Manager since 2014 and is the Associate Professor in Building Technology at the IUAV University of Venice, Italy. Trabucco has been the Principal Investigator on many research projects exploring multiple aspects of tall building design and construction, ranging from new materials and components, to codes, standards and future trends. Trabucco has authored numerous publications resulting from research projects conducted in conjunction with industry leaders, architects and independent experts.

Abstract

Although As the construction industry responds to emerging technologies, the way buildings are designed, built, and managed will continue to shift. Parametric design, BIM, and virtual reality are just the beginning of evolutionary design procedures as building monitoring systems, smart technologies, and ICT are deployed to help buildings reach maximum energy-efficiency. The building construction site will also undergo massive change as advanced machines and robots take over operations currently carried out by human workers. This will benefit speed, quality and safety. Human workers will still be necessary but may become freed up from repetitive work to take on other roles, reducing fatigue on the body. In this developing paradigm shift, will emerging state-of-the-art technologies incorporate robotics on construction sites?

Keywords: Automation, Construction, Design Process, Robotics

CTBUH Research on Robotics in Tall Building Construction

CTBUH is conducting a two-year-long research, sponsored by Schindler, to understand the current state of robotics use in (tall) building construction, and its future evolution. The first stage of the project has been dedicated to identifying the needs of the construction industry that will generate the future robotization of building sites. What tasks will robots be called to complete? How does the construction sector differ from the other industrial sectors, and why are they responding so differently to the widespread use of robots? The first few months of the research have tried to respond to these questions, by consulting both robot companies and different players of the construction sector, to understand their needs, and the constrained environment in which they work.

Industry 4.0 vs. Construction Industry 1.0

The word "Robot," from the Czech word *robota* (forced labor), is used to describe an incredibly wide range of machines that can perform tasks automatically. According to this definition, both the vacuum cleaner that wanders around the living room floor by itself and the powerful arm that moves the chassis of hundreds of cars per day in a modern industrial plant can be called robots. A robot is, technically, a machine that can perform complex actions automatically. With this definition in mind, both machines described above can be seen as robots.

Thus, robots are required to have a certain degree of "intelligence" in order to be able to be defined as such, otherwise—for as complex as they can be—they are simple machines. Thus, the robotic arm that lifts the car chassis and moves it from one part of the production line to another, does have a limited amount of intelligence to perform this operation, and the same applies to the "robotic" vacuum cleaner.

It is thus important to define what "intelligence" means in this context. Artificial intelligence—an extremely complex capacity of some computers to learn from experience and make decisions autonomously—has yet to be applied extensively on robots (it is, indeed, applied to a limited portion of the most advanced ones). In this context, intelligence is mostly the capacity of a machine to put itself in the environment in which it is operating, and to interact with it. The vacuum cleaner can turn from an unexpected object without trapping itself, while the robotic arm can "feel" how much the weight of the car is bending its own mechanisms and parts, and adjust the movement it is doing so that the final position of the chassis is as accurate as planned.

By using the concepts above, the idea of robot has to be separated by the anthropomorphic and almost-intelligent devices seen in movies. They just don't exist (yet) and even the very few experimental prototypes that can run, do somersaults, or replicate many other human movements extremely well are far from becoming commonplace. Instead, hundreds of thousands of robotic arms, grapplers, pick and place machines, etc., are already revolutionizing many industry fields (see Figure 1).

Figure 1. The Ford model T assembly line is the prototype of industrial production. Hordes of workers do the same task all day long, while the car being assembled advances through the factory.

Figure 2. The Tesla model S assembly lines doesn't differ that much, in principle, from the Ford model T assembly line, one century before, except the workers have been substituted by robots. © Steve Jurvetson (cc by-sa)

Three main reasons are the drivers for the use of robots—instead of humans—to do "something": speed (thus resulting in cost), precision, and safety. Safety is relevant where the activity to be performed has an intrinsic danger for the life of the human being normally performing it. This includes for example de-mining a battle field or manipulating poisonous or dangerous goods. Precision is required in the pharmaceutic industry for extremely accurate measurements, or for the production of electronics, or to do surgery. But the one aspect that truly made a difference for the vast widespread use of robots is speed.

Automotive is probably the most striking example that can be given to visualize the revolution that happened in the past few decades. The assembly lines invented by Henry Ford over a century ago, where workers assembled the Model T piece by piece, each performing repeatedly one single operation (welding a piece, or screwing a piece in place) have not much evolved, but for the fact that robotic arms have now substituted the human worker in completing most of the assembly operations much more quickly, more precisely, and safely (see Figures 2 and 3). Food packaging, electronics, and several other manufacturing industries are relevant examples of this revolution.

In order to understand the reasons behind this massive widespread use of robots in such industries, it is important to recognize common traits and why they are the perfect environments for robots. The first aspect of such industries is the high number of products produced: millions of identical cars, dozens of millions of phones, computers, cameras, and hundreds of millions of cans of soda or cartons of milk. Performing such operations is a highly repetitive task. Once the factory is designed, the production line goes on for months or years producing identical items and robots, bolted on the factory floor, can thus repeat the same movement over and over. In this case, speed is a fundamental aspect of the equation, to reduce costs. Extreme precision is also of the utmost importance, and the smaller the end product (i.e., microchips), the more important the level of precision. Finally, hygiene and cleanliness are also mandatory, if not for the product (e.g., food), then for the quality of the production process (e.g., medical, electronic micro components).

The robotic industry we know today is the result of this: extremely precise and fast machines that repeat the same operation over and over.

There is a fundamental aspect that divides robotic arms in two broad families and that will be relevant to selecting robots suitable for the construction sector: caged robots and co-bots. Caged robots must, by law, operate in a human-free

Figure 3. A 3D Printing is seen as a "robotic" application to architecture, but a 3D printer is just a machine, as it has no "intelligence." Also, it is probably not promising as a technology: commercial buildings are more complex than a pour of concrete (the picture shows a military barrack).

environment. They operate inside protective cages that prevent any physical contact between the robot and humans and sensors immediately stop them if the cage is open. Co-bots (collaborative-robots) are instead designed to work in a non-exclusive environment (see Figure 4). Thanks to sophisticated accelerometers and breaking systems, co-bots instantly stop if they hit an obstacle (e.g., the body of a human worker). They are thus slower that automatic robots, in order to limit their kinetic energy (see Figure 5).

When applying the concept of robotics to the construction industry, one important caveat has to be made: the robotization of the industries that produce building materials or prefabricated parts of buildings (off-site) is very different from the robotization of the construction activities themselves (on-site). The first type is largely occurring already, as a natural combination of the three driving factors mentioned above. It is evident that most building material production industries can benefit from a combination of such three factors: more bricks being produced, safer sawing of timber elements, more accurate dimensions of glass or metal cuts.

On the contrary, on-site operations are much less prone to be changed for many reasons, but mostly because safety, speed and precision are not needed to the extent robots can guarantee. Indeed, building sites are dangerous workplaces, but there are not many on-site activities that have an intrinsic level of danger. Rather, incidents occur mostly as a consequence of worker misconduct, or accidental reasons that should be avoided as much as possible, but that can hardly be eliminated.

Precision is also a much-required element in the construction of buildings, but generally the tolerances of construction elements are in the range of millimeters or even centimeters, while in other industries the scale is that of nanometers.

As in most industries, higher speeds mean a faster return of the investment. Thus speed is also needed by the construction industry, but this clashes with the relatively limited number of identical operations that a building site usually requires. Even laying a couple thousand bricks to build a house has a different order of magnitude, in terms of number of repetitions, than industrial operations.

The existing commercial robots are thus over-specified (too fast, too precise) for application in a building construction site, and being over-specified are too much expensive for an extensive application. Also, the building site is an extremely rough environment: materials to be handled are heavy and dirty, two characteristics that make the production environment very much different from the suitable location for the delicate moving parts and sophisticated electronics of existing robots. But probably, the most important difference between an industrial plant and a building site is that, while in the production line the final product moves and the production machinery is bolted to the ground, in the building industry the final product is still, and the construction equipment moves ahead as the job progresses.

From the above observations, can be concluded that robotic arms, as they exist in other industry fields, are somehow unfit to be extensively applied on construction sites, for the excessive precision they have and for the small amount of identical operations to be repeated at one location. Such variability of operations requires the simultaneous presence of robots and humans, working side-by-side, thus requiring co-bots, with their constrained speed, rather than robots. A few exceptions exist, which will be mentioned later.

The Case for Robots in the Construction Industry

A survey conducted among professionals of various disciplines in the construction industry have identified various good reasons to push for the adoption of robots (actually co-bots) during on-site construction operations. Of course, speed, safety and quality are the most recurrent aspects in favor of widespread use of robots, but these—if seen as a general and unspecific request—will be of little use to identify which type of robots the (tall) building industry is looking for. Versatile robots that can perform all the infinitely variable tasks humans can do without their limitations (fatigue, shifts, in-precision, strikes, need for food, etc.,) are many decades away, and may never happen. As usual, a deeper dive into the specific aspects to be sought is necessary to identify the right solutions that machines are likely capable to perform in the near future,

Figure 4. Co-Bots (collaborative-robots) are robots that can work in a mixed environment with humans, thanks to their smaller size, slower speed, and special sensors to avoid injuries. © Daimler und benz Stiftung (cc by-sa)

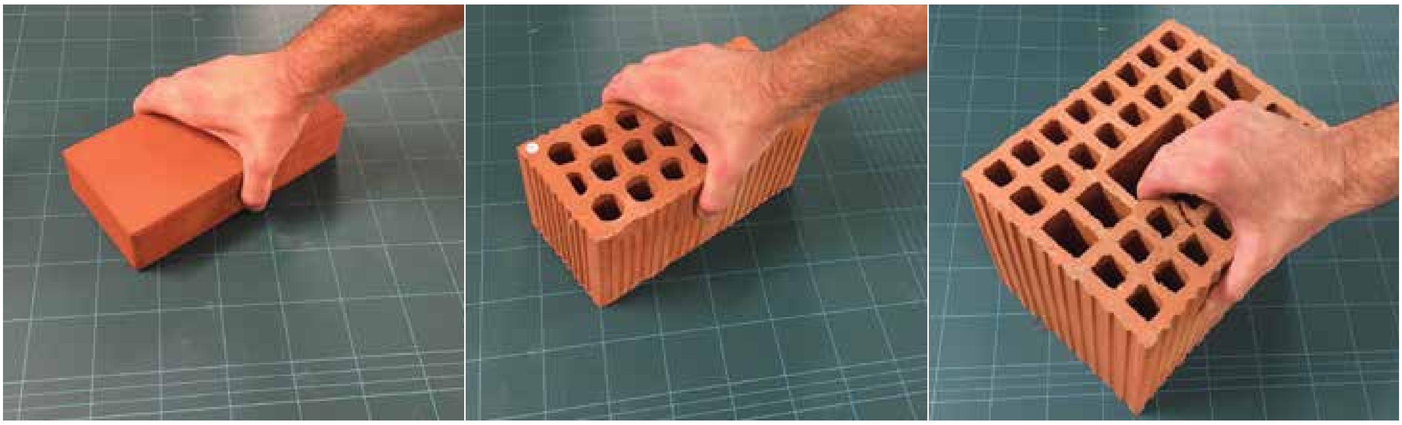

Figure 5. Bricks (like many building materials) have evolved adapting themselves to the human worker that assembles them. It is nonsense to build a robot to assemble brick walls: if they don't have to be assembled by humans, bricks can have other shapes, sizes, and weights.

if not already. In fact, where labor is not available for some specific task, or in some specific areas, there is the market opportunity—or even the need—to develop a robot to perform such activity.

In the construction process, several activities can be identified that don't require much "intelligence" to be performed, and are, at the same time, very demanding on the human body and to be avoided by workers especially in the developed markets. Schindler probably identified the "perfect" example of this that can serve as a reference for other potential applications, and developed a robot, called R.I.S.E.: This robotic arm is mounted on a movable platform that is lifted through an elevator shaft. While it is pulled up, the robot accurately measures the shaft and the concrete characteristics. It drills the holes and places the wall plugs on which the elevator guides will be mounted. It is almost the ideal application for a robot: the task is quite simple and highly repetitive, it requires good precision, it is in an isolated environment where no humans are present. But most importantly, because of the working conditions themselves—probably closer to a mine that to any other workplace (a confined and dark space with dust, noise and vibration caused by the drilling, and the risk of falling from the platform)—it is hard to find humans that want to perform this job, especially in developed countries where many other (less-demanding) jobs are available. Of course, in an open market, supply and demand always meet somewhere, but this meeting place may be costly enough (again, in developed countries) to create the business case for a robot.

If similar conditions happen in other segments of the building process, that is where robots will find their place.

A Rational Approach to Avoid Expensive Mistakes

One of the most relevant and likely unsurmountable limitations for the widespread use of robots in building construction is what can be seen as the quintessence of architecture: each building is virtually unique, for reasons that may be technical (i.e., two adjacent buildings may sit on slightly different ground conditions) or functional (i.e., two adjacent homes may have slightly different uses). Even when buildings are designed and built to be truly identical, the number of re-iterations is much more limited than the mass-produced products of industry.

Also, it is to be considered that architecture, and most architectural products (bricks, roof tiles, steel rebars, etc.) are the result of century-long or in some cases thousand-year-long evolutions. And the one factor that was common in all the different places and ages where such evolutions happened was the human body of the workers that had to use them. Bricks, for instance, have a particular size because they need to be comfortably handled by one person, who is holding a mortar trowel on the other hand. And the same a worker has to repeat this operation as many times as possible during the day. When the mass demand of buildings called for faster construction methods, bricks doubled in size, but holes were added to maintain pretty much their original weight and to reduce the impact of the increased size on the worker. When the size of bricks grew even further to speed up the construction, the brick became too big to be handled comfortably with the usual position of the hand, so two bigger holes were added to accommodate the worker hand, and more holes were dug to further lighten the brick. Similar "evolutions" can be described for many other building products, though bricks are probably the most relevant example of this. Acknowledging this, it becomes evident that the many robots that have recently been created and presented with great emphasis to construct brick walls are somehow "wrong." Not because they are ineffective—they seem to work well, though a good laborer is probably better, cheaper and faster—but because they are a nonsense: brick walls exists because of bricks, and bricks have certain sizes, shape and ultimate appearance because they need to be assembled by humans, using three-thousand-year-old techniques. If humans are not to be part of the equation anymore, then much more robot-efficient construction materials and products must be sought.

One last aspect needs to be considered, to remain human. Humans need to work, not just to have a salary to buy food, but because work gives dignity to humans. One major concern with the widespread use of robots, is that robots will replace workers. The most frequent counter-argument to this is that robots require engineers to be designed and skilled workers to be built. On the other hand, it must be acknowledged that not everyone has the capacity or the aspiration to become an engineer or an IT expert and some, maybe a significant share of the world population, are more suited to laying bricks, tying rebar or performing other similar tasks. If robots make workers obsolete, they will be unemployed. Several though leaders, including Microsoft Founder Bill Gates, propose to tax robots to create living subsidence for people whose job is now done by a robot, but though money is required for life, an occupation is required to live.

And in fact, the responders of the above-mentioned CTBUH survey cited the resistance of unions as the most frequent potential threats to the adoption of robots.

However, robots—or rather co-bots—will soon or later enter the construction site and in some cases as substitutes for human workers (the above-mentioned example of the elevator guide mounting is a "healthy" example of this) or, much more frequently, as "colleagues" of the worker. In every work relation, ease of dialogue and good communications are fundamental. The next generation of co-bots, faster and more precise as required on construction sites, gesture and natural language recognition are the fundamental development needed to facilitate the interaction of human workers (masons and iron workers, not computer engineers!), with their co-bot colleagues. The ideal goal will be to have co-bots performing dull-activities while their human colleagues are on lunch break, or sleeping at night. Such dull operations will need to be as

Figure 6. Images of human-shaped robots have existed for decades, but we are still far from seeing human-like machines. © Xavier Caré (cc by-sa)

variable as possible, and easily communicable from human workers through gestures and natural speech.

The ultimate goal both for the robot industry but also for the construction industry and their current workers, would be to have a co-bot understanding and responding to a command formulated in natural language and gestures, such as "while I'm taking lunch [indication of the time frame available], drill 5 holes of 10 millimeters [what to do] from here to here (pointing a finger on two points of a concrete wall) [where do to it] and insert some wall plugs like this (showing a wall plug of the required type)" likely, pronounced with a foreign pronunciation or with a strong local accent. Seeing a co-bot acting consequently is not so far in the future, since most of the technical elements needed are already there: the robotic arm exists already, its capacity to hold multiple actuators, and its capacity to perform the tasks required. The main aspect currently being developed is the language recognition capacity, but great advancements are still needed. The part of the equation that needs to be solved is the economic sustainability of the co-bot, which would likely cost several hundred thousand dollars (see Figure 6).

The Next Steps of CTBUH Research

Having identified the general frame of the problem, as described above, the CTBUH research will now look into several aspects, both related to the construction industry and to the robot industry. Regarding the construction industry, the research will try to select some opportunities for a "positive" integration of robots to perform a few selected tasks in the existing construction practice, taking Schindler's R.I.S.E. as a model. Also, CTBUH will develop new innovative ideas on how some construction procedures, materials and products currently used on (tall) buildings can be changed to be more easily performed by existing robots.

At the same time, the dialogue will continue with some of the largest robot companies and small startups, to identify how the robot industry can provide the right answers to the needs that the construction industry has.

References:

Bock, T. and Linner, T. 2015. **Robot-Oriented Design: Design and Management Tools for the Deployment of Automation and Robotics in Construction.** Cambridge: Cambridge University Press.

Bock, T. and Linner, T. 2016. **Construction Robots : Elementary Technologies and Single-Task Construction Robots.** Cambridge: Cambridge University Press..

Lee, K. 2018. **AI Super-Powers. China, Silicon Valley and the New World Order.** Boston: Houghton Mifflin Harcourt.

Waters, R. 2017. "Bill Gates Calls for Income Tax on Robots." **New York Financial Times.** 19 February 2017. https://www.ft.com/content/d04a89c2-f6c8-11e6-9516-2d969e0d3b65.