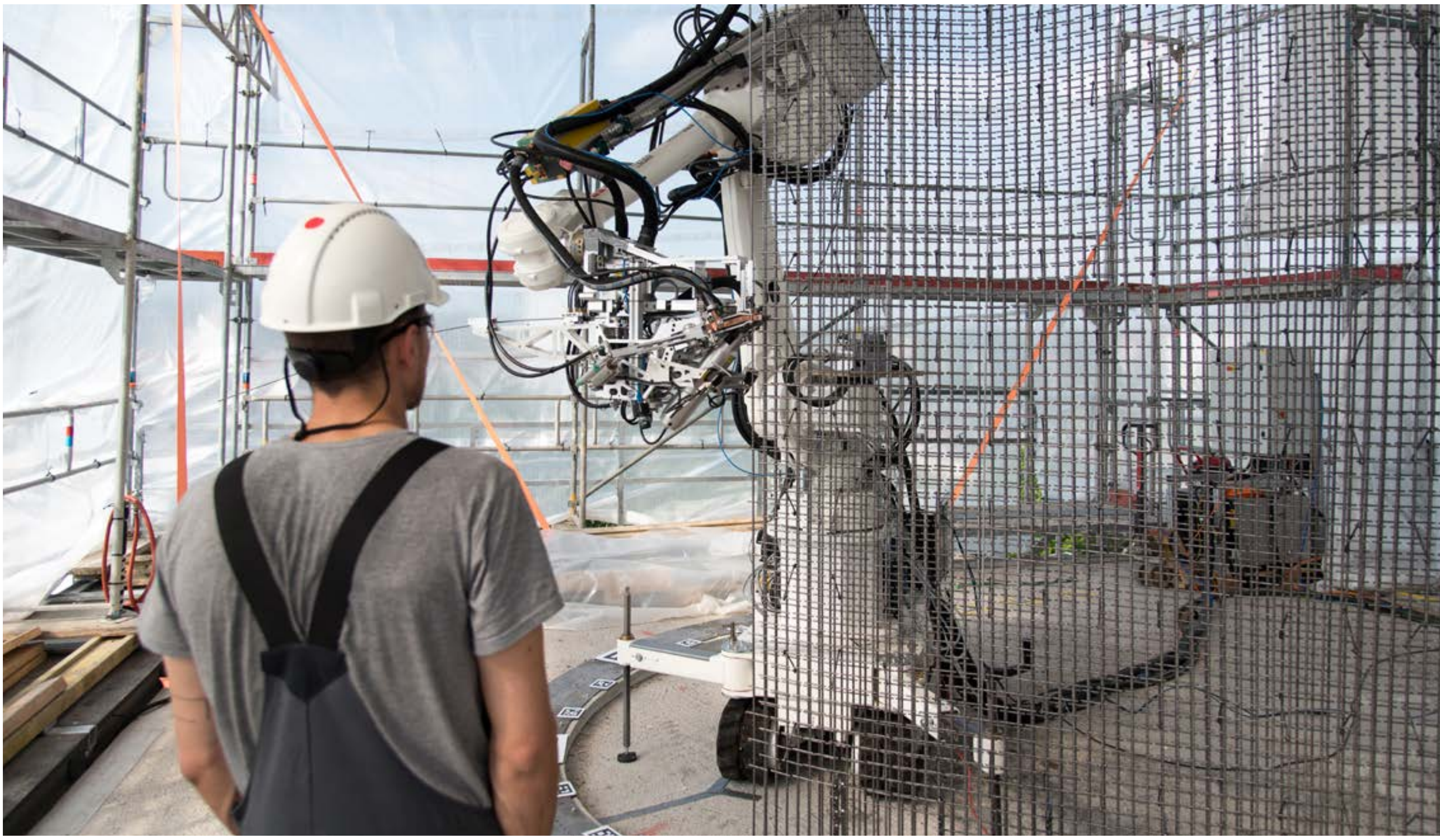
WHITE PAPER

Building the future – how robotic automation can transform the construction industry



Contents

Introduction – a revolution waiting to happen

Building is one of the oldest human activities, with structures still standing that were originally built thousands of years ago. Throughout the course of history, structures have been built that have tested and expanded the limits of human ingenuity, from the pyramids of Ancient Egypt to modern-day projects like the Shard in London or the Burj Khalifa in Dubai.

Today's challenges facing the construction industry go beyond just engineering. The industry faces several mega-trends that, taken together, demand the industry finds ways to change not only how it works, but also what and how it builds. Encompassing urbanization, skills shortages and worker safety and the need to massively improve environmental performance, these megatrends will demand innovative approaches to help ensure that more homes can be built to consistent levels of quality, more quickly and with a reduced environmental impact.

Achieving this will require a new kind of ingenuity, where human imagination and expertise are combined with technology to produce a new breed of buildings utilizing new techniques. It will also require a new way of working, with the prospect that many parts of the construction value chain will redefine their roles and grasp new opportunities to grow as the industry reshapes itself.

Core to the future of construction will be the uptake of new technologies, with software, automation and robots playing a key role in helping to create, manufacture and assemble both components and even entire structures.

"We need to redefine what construction is. In the future, construction will be as much about factory manufacturing as it is about building sites."

Brent McPhail, Founder & CEO, Brave Controls

For the construction industry, there are encouraging signs of new approaches developing after the pandemic, together with some underlying trends acting in its favor. The continued trend of globalization has enabled western companies to invest in bricks and mortar facilities beyond their own shores, while entrepreneurs in developing markets are also leading to continued construction demand.

Trends such as e-commerce and the proliferation of distribution facilities, online activity and the subsequent growth in demand for data centers and the emphasis on new renewable energy technologies are all having an effect on construction activity. There is also the increasing urbanization of society and the consequent demand for affordable housing that does not take vast amounts of time and resources to construct and which contributes to protecting the environment both during construction and over its lifetime.

The report Global Construction 2030 by Global Construction Perspectives and Oxford Economics[1] forecasts that that the volume of global construction will rise by 85 percent to $15.5 trillion worldwide by 2030. It predicts that three markets, China, India and the US will dominate, accounting for some 57 percent of global growth. The same report predicts that India will become the new powerhouse of growth in construction, with both the US and India beating China, while the UK is set to overtake Germany as the world's sixth largest construction market by 2030.

What needs to change?
In many ways, construction is least affected by the technological advances that have taken place in other industries over the years. Compared to the massive advances in the automotive manufacturing sector over the past 50 years for example, where companies utilize the latest technologies to produce a wide variety of options for customers, the construction industry has remained relatively unchanged, with many practices largely untouched by innovation.

One key reason for this lack of innovation has been the inherently outdoors-focused nature of the work carried out. The fact that most actual construction takes place on the site that the building will occupy, with much fabrication of structures from an assembly of parts and materials on site, constrains the use of production methods and the economies of scale that have long been the norm in other sectors.

Consequently, while productivity and efficiency have advanced significantly in other sectors, levels have remained largely static in the construction industry, with the industry struggling to keep up with demand.

Nevertheless, things are starting to change. The need to improve productivity and efficiency, combined with the pressures placed on the industry by megatrends such as urbanization, labor shortages, changing consumer demands and the drive for decarbonization, are creating a 'perfect storm' of conditions that are leading a growing number of companies to look for new alternatives to established practices.

It is for this reason that a growing number of companies are looking to alternative methods of construction and to adopt practices and technologies that have enabled other sectors to transform their productivity, efficiency and responsiveness to changing market conditions.

—
The global construction industry is faced with a perfect storm of challenges that will affect its ability to meet growing demand in the future.

Challenges facing the construction industry

Although the construction industry has experienced peaks and troughs many times throughout history and has learned to weather them, current trends are affecting the industry on many fronts and amount to an unprecedented combination of challenges.

These trends can be divided into four main megatrends: urbanization, mass customization, labor shortages and decarbonization.

1. Urbanization

The ongoing growth in the global population is seeing a rise in the number of people moving to cities, a trend that is projected to continue at a steady rate over the coming decades as people are attracted by the promises of better services, accommodation and employment opportunities compared to rural areas.

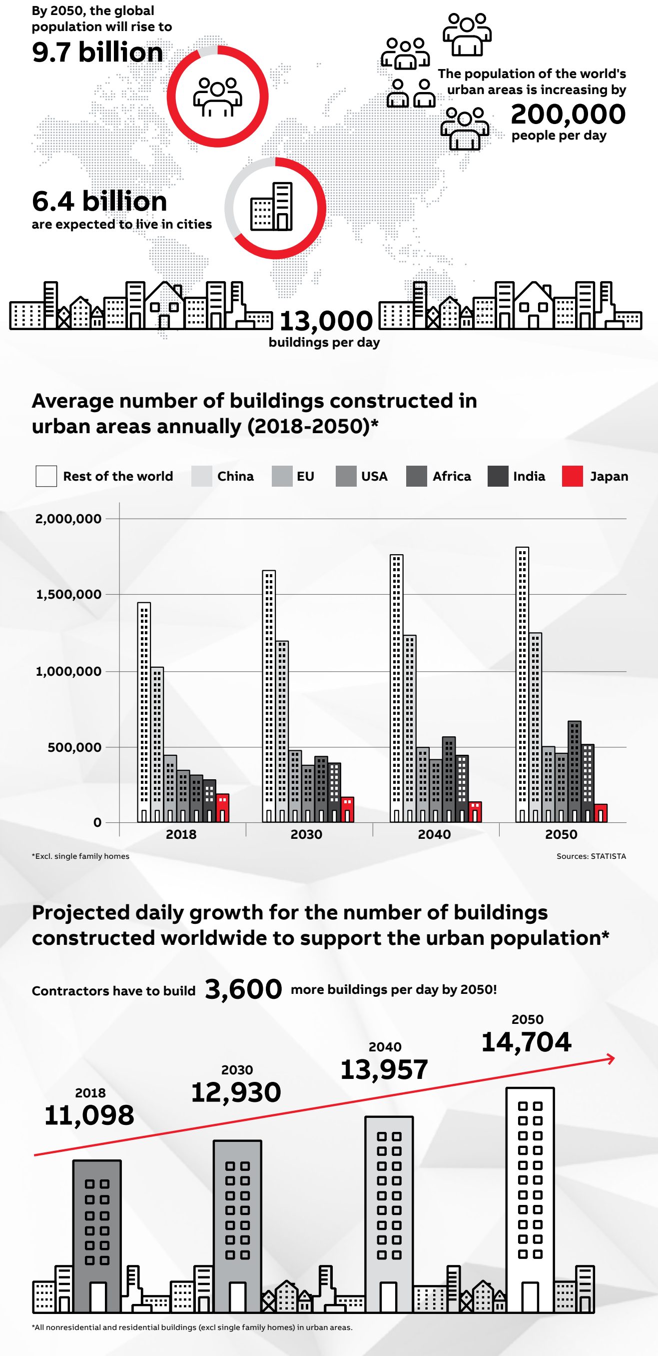
The extent of the rise is highlighted by estimates from the United Nations, which predicts that 68 percent of the world's population will be living in cities by 2050, compared to 55 percent today. Such a rise would add 2.5 billion people to urban areas, 90 percent of which will be concentrated in Asia and Africa[2].

With the pressure that such growth will place on already stretched resources, providing the housing and infrastructure will require substantial programs of sustainable development, including the provision of quality housing and communities for people across a broad spectrum of incomes and social needs. Estimates by German research company Statista, compiled in 2018, point to a need for 13,000 new buildings to be constructed every day between now and 2050 to keep pace with this demand. With companies already struggling to find the skilled workers they need to complete existing projects, such a sustained rate of development is likely to put an increasing strain on the available global supply of resources.

Demographics – meeting the changing needs of an ageing population

An acceleration in an older population will also change the makeup of the building environment. Projections suggest that in the UK within the next 20 years, the proportion of people of pensionable age for every 1,000 people of working age will rise by about 20 percent, from the current figure of around 300 to 360. By 2060, this number will approach 400[3].

DID YOU KNOW? To meet the challenges of urbanization, the global construction industry will have to build 13,000 buildings every day until 2050.



Rising urbanization coupled with a growing shortage of skilled labor is already putting constructors under pressure to keep pace with demand.

This trend is also reflected globally. In its report World Population Prospects 2019[4], the United Nations estimates that by 2050, 1 in 6 people in the world will be aged 65 or over, compared to 1 in 11 in 2019.

This development will have a profound effect on the type of housing stock demanded, the provision of healthcare facilities such as local clinics and doctors' surgeries, as well as possible changes in the requirement for public transport and its supporting infrastructure.

2. Mass customization

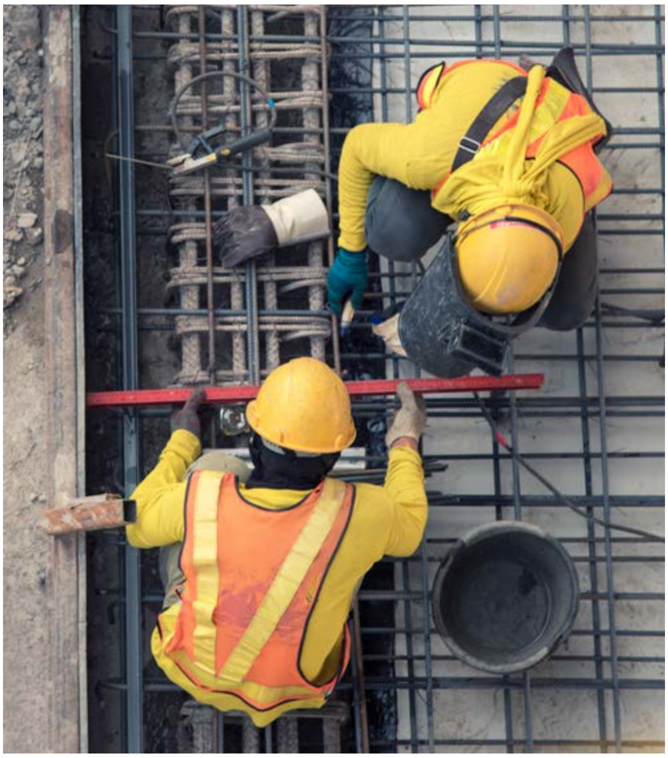
Today's consumers increasingly expect personalized goods. In the automotive industry, for example, manufacturers are building cars to specific customer orders, which may include requirements such as engine type, wheel trim, interior fabrics and colors as well as requests for custom-designed paint schemes. Likewise, companies in other sectors such as furniture and those specializing in the production of building components such as windows and doors need to be able to offer their products in a wide variety of styles, colors and fittings to meet different customer needs.

To date, customization of buildings has tended to be limited to either specific projects and/or the higher end of the market, where customers with higher disposable incomes are better placed to invest in non-standard structures built to their specific requirements. With the need to build quality structures more quickly and across a wider range of incomes to address the megatrend of urbanization, the option of customization needs to be democratized to broaden its reach across all sections of society. This will enable mass production of customized structures at prices that are profitable for construction companies, driven by reduced waste and reduced costs of rework, while also being affordable for buyers.

The ability to economically customize building design is also of value when it comes to creating structures that can make best use of the inherent characteristics of site locations. A building located in a shaded area, for example, may require different features, both internally and externally, to make best available use of available natural sources of light and heat compared to one situated in a position that receives plenty of sunlight. Equally, a structure built for a European country is likely to require different design features and construction materials than one located in regions such as Africa or Asia, with their different climate profiles.

3. Labor and skills shortages

The issue of labor and skills shortages is one that is growing in both importance and urgency, with companies across the construction industry experiencing difficulties in finding and retaining both skilled and un-skilled workers. A survey conducted by McKinsey and Company, 'The next normal in construction'[5], (June 2020), revealed that 87 percent of respondents believe that skilled-labor scarcity will be



—
Many companies are struggling to recruit new workers to work on building sites.

significant for the industry, and almost 50 percent of respondents expect that it will become even more of an issue the next two decades.

According to the Turner and Townsend International Construction Market Survey 2019[6], some 65 percent of global markets surveyed reported a skills shortage, up from 58.7 percent in 2018. In the EU, for example, vacancies in the industry as at Q2 2020 stood at 217,253, including both low and high-skilled positions[7].

There are varying reasons for this. Compared to other industries, the construction industry has a poor track record in health and safety, with higher-than-average levels of injuries and fatalities. Construction workers are three-to-four times more likely to be killed in the course of their employment than workers in other industries, with a 2015 report by the International Labor Organization (ILO) estimating an average 108,000 fatalities per year in the industry[8], either directly from risks such as falling objects or being crushed by heavy objects, or indirectly from exposure to risks such as asbestos or other hazardous substances.

Another factor is the growing gap between the number of workers leaving the industry – either through injury or retirement, and those entering it. In the US, the National Center for Construction Education & Research estimates that around 41 percent of the current construction workforce will retire in 2031[9]. Similarly, in the UK, around one fifth of the nation's construction workers are now due for retirement, leaving a potential shortfall – further compounded by Brexit – of around 200,000 workers[10].).

At the same time, younger workers are not entering the sector to replace them. Figures from the UK's Department for Education, for example, show that the number of new construction apprenticeships for January 2019 fell to 950, down from 1,216 the previous year.

A core reason for this is the industry's poor image problem. Many younger people especially are reluctant to consider the industry as a career, perceiving it as a dirty, low paid and dangerous occupation with low prospects for advancement. Construction companies are competing with the more technology-based industries such as automotive and aerospace, which offer better prospects that make better use of the inherent skills of the so-called 'Xbox generation' who have grown up with technology and expect to use it in their careers.

The conventional solution – importing immigrant workers from other countries – is also becoming less straightforward, as movement of workers becomes restricted by a combination of tightening immigration controls, availability of better, more attractive jobs in their home markets and moves by governments to hold on to their domestic supply of skilled workers.

"Finding highly skilled labor to do complex construction work will be increasingly difficult in the future. Robotic automation is therefore very much on the radar for many construction companies."

Ammar Mirjan, Chair of Architecture and Digital Fabrication (Gramazio Kohler Research), ETH Zurich

Solving the skills shortage requires a different approach to the way construction currently operates, with digital technologies and offsite construction viewed by industry observers as the way forward. Transforming the construction industry into a more technical, high skills-based operation using indoor construction of precast components can make it more attractive to young people accustomed to the digital world and who want to 'work smarter, not harder.'

4. Decarbonization and sustainability

With cities already consuming 75 percent of the Earth's natural resources and generating 80 percent of global greenhouse gas emissions[11], any future development must also focus on reducing environmental impact, employing strategies aimed at achieving improvements in areas including energy efficiency, encouraging the use of environmentally friendly building materials and optimizing building design to achieve improved lifetime performance.

In the future, homes and other structures will almost certainly be built to be more energy efficient, potentially using new materials and even structural shapes as a way of minimizing energy consumption through the better use of heat and light. The pace and scale of this change will likely depend on whether it is led by regulation, customer demand or a combination of the two.

The construction industry itself will also need to radically improve its environmental footprint. The industry accounts for 36% of global energy use and 39% of CO_2 emissions[12], while buildings account for 40% of global energy use[13]. Together, this puts a real onus on the industry to find ways to optimize the way that it designs, constructs, and manages buildings, including demolition, to reduce energy use. The industry is one of the prime producers of waste – in the UK every year, around 400 million tons of material is used in construction, with around 120 million tons going to waste[14], while in Europe, the industry is responsible for 34.7 percent of the continent's waste[15].

Waste reduction and sustainability are two key drivers in the growth of offsite fabrication. Offsite production allows construction waste and emissions to be halved through production efficiencies and the increased scope for recycling. There is also scope for reducing wastage of materials on site, cutting the energy used in their extraction production and transport, while cutting the number of lorry loads needed to the site.

Building off site allows major building components such as floors, walls and roofs to be fabricated using panels made of heat insulating materials, or to incorporate under floor heating, electric wiring looms to avoid wasted cabling, broadband networks to make it easier for occupants to work at home and pre-installed solar panels to cut reliance on the grid.

For example, WeberHaus of Germany, a leading manufacturer of pre-fabricated homes, has a wall system that uses ecologically sound materials that provide high thermal insulation while offering breathability, achieving very low U values and providing comfortable temperatures year round.

Drivers for change

In addition to the megatrends identified previously, the construction industry is also facing numerous challenges that provide further added incentives for improvement and a shift to new technologies and techniques. In its 2017 report Reinventing construction: a route to higher productivity, global management consultant McKinsey and Company estimates that productivity growth in the construction industry averaged just one percent per year over 20 years, compared with 2.8 percent for the total world economy and 3.6 percent for manufacturing[16].

Improving productivity

While construction is one of the world's largest industrial sectors, its productivity has remained virtually stagnant for several decades. As a result, cost and time over-runs are commonplace, limiting the number of projects that can be worked on and hampering the efficient deployment of workers.

One of the key reasons for the sector's low productivity is its low appetite for innovation, with many building processes still largely the same as they were 100 years ago. Compared to the automotive and manufacturing industries, which have embraced the opportunities of new production technologies including robots and, more recently, digitalized manufacturing platforms, the construction industry continues to techniques which are increasingly unsuited to the rising challenges it is now facing.

"The construction industry is a testbed of what can happen if you don't embrace innovation."

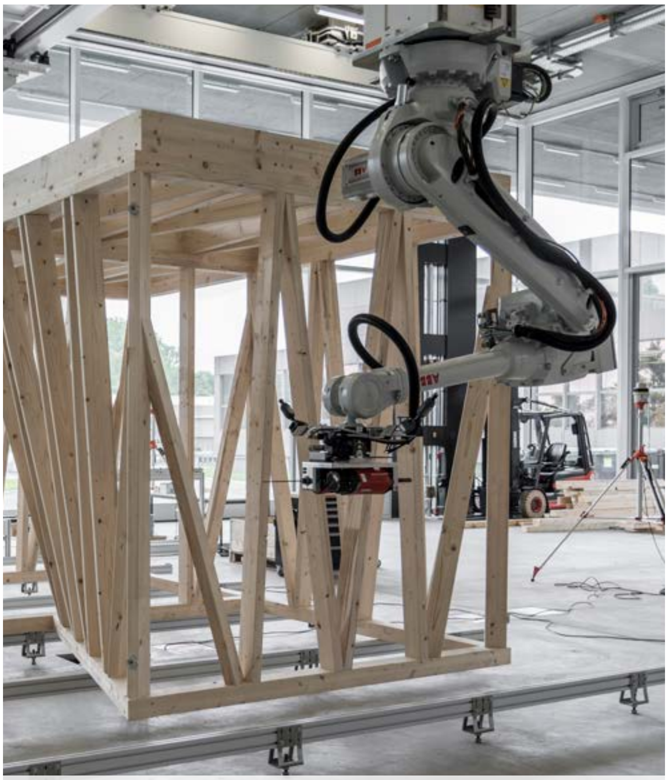
Oliver Lang, Intelligent City

Where new technologies have been introduced, they have tended to focus mainly on the use of on-site equipment such as earth moving, cement mixing equipment and power tools. While there are signs of an emergence of projects that are starting to use automation – our recent survey of 1,900 construction industry companies reveals that 55 percent of respondents are using some form of automation – many are still at the experimental stage, with robots being trialed in specific projects.

Another factor has been the traditionally ready supply of labor. While productivity has been a recognized problem for the construction industry over many years, there has not been a strong motivation for contractors to improve this because of the historically high availability of workers. With little need or desire to improve, there has been a reluctance to adopt new techniques that could help boost performance – this will almost certainly change as the 'skills timebomb' makes itself increasingly felt.

Productivity is a major driver for adopting automation in the construction industry. Whereas productivity in the automotive sector, which has fully embraced modern production technologies has improved by 30 percent over the last few decades, this has not been the case for construction. To improve this, companies particularly need to reduce time on site, because if they can construct the building faster, they get paid faster, with lower overall costs. Faster completion of projects also opens the way to handle more projects, with workforces able to be utilized more effectively.

Capable of handling processes faster, more efficiently and to higher levels of quality, and with the ability to augment the performance of human workers, robots could almost certainly deliver improvements that could help the construction sector to radically improve its productivity. The prize for achieving this is considerable - according to the McKinsey report, matching the construction sector's productivity to that of the total global economy could add around $1.6 trillion to the sector's value, paving the way for improved profitability[16].



Credit: Gramazio Kohler Research, ETH Zurich

—

Benefits of using robots for building tasks include their ability to do things faster, more efficiently and to a higher level of quality.

Meeting targets
Construction companies are chiefly constrained by the schedule and budget of their clients and must manage the flow of materials and equipment to the site to achieve these targets, while seeking to reduce delays and waste. It has been estimated that between 10-to-30 percent of all material delivered to a building site is wasted[17].

The traditional approach to construction, with its focus on on-site fabrication and erection of component parts, means that weather can play a major role in dictating project timeframes. Periods of wet, cold or particularly hot weather conditions, for example, can delay work as tasks become either difficult or impossible for workers to perform. The sequential nature of many building operations can also mean that a delay in one part of the project can have a direct impact on one or more associated stages, potentially stretching timescales further.

Offsite construction is also immune to weather that can cause delays, while also being less susceptible to the costs and risk of employing subcontractors. Typically, offsite building can reduce building completion times by around one third[18].

Quality
In its report 'Improving Quality in the Built Environment' the UK's Chartered Institute of Building (CIOB) regards building quality as the most important issue facing the industry. The report quotes figures from the house building industry's Customer Satisfaction Survey for 2016/17 that recorded 99 percent of house owners who responded had reported faults with their builders[19].

The CIOB report also cites that the measured direct costs of avoidable errors are in the order of five percent of project value, equating to approximately £5bn per annum across the sector in the UK. The report recognizes that the industry should learn from other industries and adopt international best practices and innovations.

With its controlled environment, offsite production has a role to play in quality management. With standardized practices and tools and in-factory quality checks, defects can be halved, with the best producers achieving defect free rates above 95 percent.

Cost control
As with most sectors, controlling costs and maximizing profit remains a major challenge for the industry. Construction cost inflation is based on various factors, including local labor costs driven by skill scarcity. This can lead wide discrepancies, such as the recent 43.5 percent increase in construction labor costs in Buenos Aries in 2019 and a 15 percent increase in Istanbul[20].

Many markets have low margins, which, when combined with growing project complexity, increasing competition from Asian companies and supply chain constraints such as the USA's 25 percent tariff on foreign steel and 10 percent tariff on foreign aluminum, will likely continue to squeeze the profitability of construction companies.

Using centralized, offsite production can help keep costs in check by improving the productivity of individual employees while allowing the adoption of lean production techniques, the removal of waste from the process and the optimization of supply chains. It also cuts labor costs by allowing highly skilled staff to supervise largely automated machines, rather than the labor-intensive on-site methods of each person carrying out physical tasks.

—
The success of building projects is often dependent on the weather, with periods of wet, cold or particularly hot weather often to blame for delays as tasks become difficult or impossible for workers to carry out.

Answering the challenges – the rise of alternative building techniques

The pressures of addressing the challenges detailed in the previous section are leading to a growth in the adoption of alternative building techniques utilizing a wide range of both traditional and new approaches and materials. These techniques offer a range of benefits, including much faster construction times, the use of building materials with a reduced energy footprint and improved lifetime performance in terms of reduced energy consumption and CO_2 emissions.

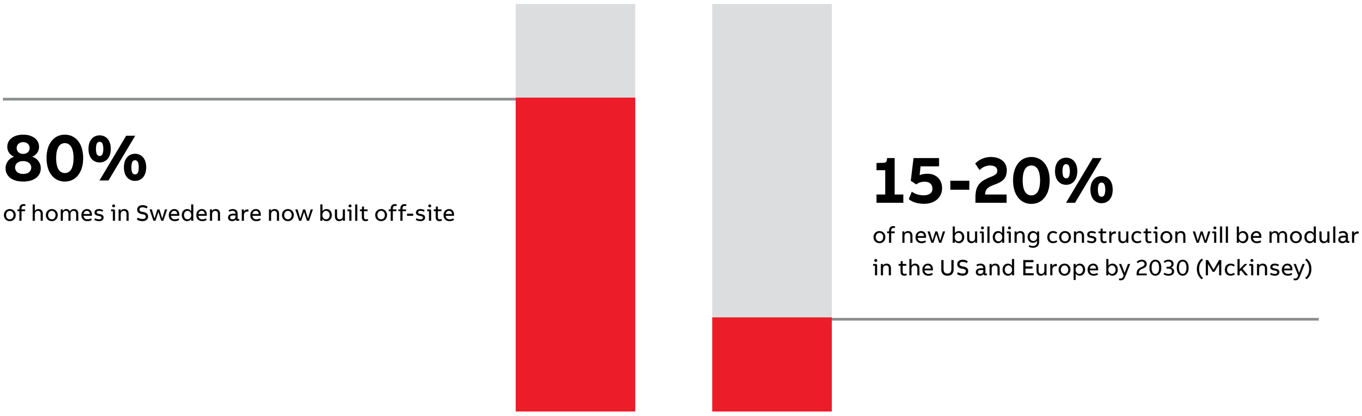
These techniques can be classified into two main categories:

1. Modular fabrication

While the history of modular fabrication of housing dates to the early 1900s, its emergence as a viable construction technique has happened only relatively recently as new forms of technology, including both robotic automation and building design software, have helped speed its adaption.

Today, off-site modular construction is being used to build an expanding array of structures over and above residential housing, including hotels and offices, with the world's tallest modular tower recently completed in Croydon in the UK[21].

While still not yet at the stage of mass market adoption, modular pre-fabrication has been growing. A report by Mckinsey also estimates that about 15 to 20 percent of new building construction will be modular in the United States and Europe by 2030[22]. Countries including the UK, Germany and Japan, are all projected to see a rise in the number of off-site pre-fabricated single family homes produced between 2013 and 2018[23]. In Sweden, some 80 percent of homes are now built offsite[24].



Benefits of modular construction

Modular pre-fabrication offers the ideal marriage of standardization and mass customization, with prefabricated elements able to be combined in a variety of configurations to produce differently shaped buildings and structures.

Components can be manufactured in a variety of materials, using concrete, glass, steel frames or wooden panels, which can be used alone or combined to form entire sections before being shipped to site for final assembly. In some instances the factory stage will also include fitting out the manufactured sections, with additional elements such as heating and lighting built in. The growing capability of robotic automation means that robots can be used throughout this process, handling key tasks including lifting and assembly of heavy components, joining, gluing, and screwing components together, sanding and finishing surfaces and fitting doors and windows.

With the work done in factories instead of on-site helping to remove many of the variables associated with onsite construction, modular fabrication provides several advantages compared with on-site construction including:

1. Reduced project times
With the complete production operation carried out in factory, off-site modular fabrication helps to provide much greater predictability, with no disruptions caused by weather or delays arising from tasks that need to be completed sequentially. With production plants able to operate around the clock, restrictions imposed by conventional building site working hours are also removed.

This can help to substantially reduce project times, enabling projects to be completed on time.

2. Improved quality and consistency
The inherent benefits of a factory-based approach, with staged inspection checks and a consistent and organized production environment, make it easier to ensure consistent quality of finished work, with any defects able to be spotted and addressed in advance. Where structures need to be fitted together onsite, this can help to ensure that any issues are resolved before they can cause potential delays. It can also help to eliminate the time and cost of rectifying faults once a structure is completed.

3. Reduced costs
The application of lean manufacturing principles in a factory environment can help eliminate many of the costs arising from the complications, delays and excessive effort that can occur onsite, allowing better utilization of both workers and manufacturing equipment such as robots and other machines. The improved management of cost per unit also means that economies of scale can be achieved, with more units able to be produced at a lower cost, with consequent savings able to be passed on to customers in the form of lower prices.

4. Enhanced working environment
Compared to a building site, a controlled factory environment presents a significantly reduced scope for accidents, with greater levels of protection against potentially hazardous situations that help to reduce some of the most common sources of injuries in the construction sector such as falling from height, slips, trips and falls and caught in, beneath or between situations. As well as improving health and safety, a less risky working environment can also be beneficial in helping to attract and recruit workers.

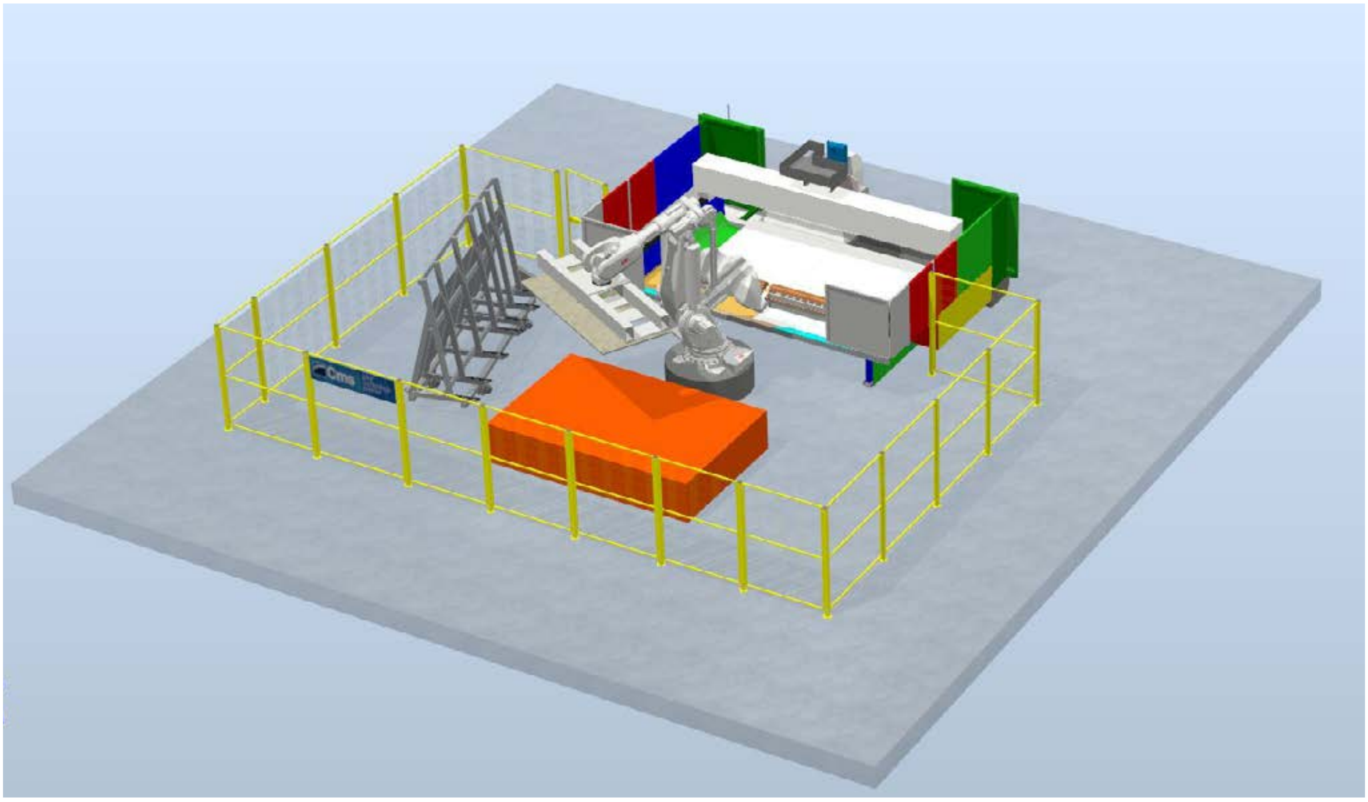
5. Improved environmental performance
A particular benefit of modular fabrication is the scope for reduction of waste. Vancouver-based Intelligent City specializes in off-site construction of mass-timber-built modules that can be connected to produce buildings up to 18 stories high. The company uses ABB robots to process, handle and assemble large sections of timber, using designs generated by its Platforms for Life (P4L) design software, with ABB's RobotStudio® offline programming software being used to plan tasks and movements for the robots. The improved precision this delivers during production has meant that the company has been able to significantly reduce waste by effectively designing it out, ensuring that structures are cut or joined at optimum points. The use of mass timber for main structure and envelope further reduces the carbon footprint of buildings.

6. Reduced risk

Another key benefit of modular construction is its potential to reduce the risks associated with building and handover to the customer. Key to reducing risk is the reduced project timeframes referred to earlier. In addition to eliminating factors such as delays caused by weather, producing in a factory environment also helps to address other issues such as component availability and incorrect parts being sent to site.

Where automation is used as part of the offsite construction mix, risks can also be minimized in other ways. Firstly, automating key tasks means there is less impact on production that could be caused by the absence of a worker from sickness or other reasons, eliminating disruption both to the workflow and any ramifications that could affect consistency.

Secondly, the increasing use of building design software to guide automated offsite production processes makes it possible to show a customer what their structure will look like before it is built. By enabling specific requests for things such as added features or design changes to be accommodated in the model before production starts, the risks of any unexpected deviations in the final product that may result in either additional changes or rejection by the customer are greatly reduced.



—
ABB's RobotStudio software relays instructions from building design software packages into commands for the robot to follow. This means that production of the manufactured part will be an exact interpretation of the design, with no variations that could affect quality or fit.

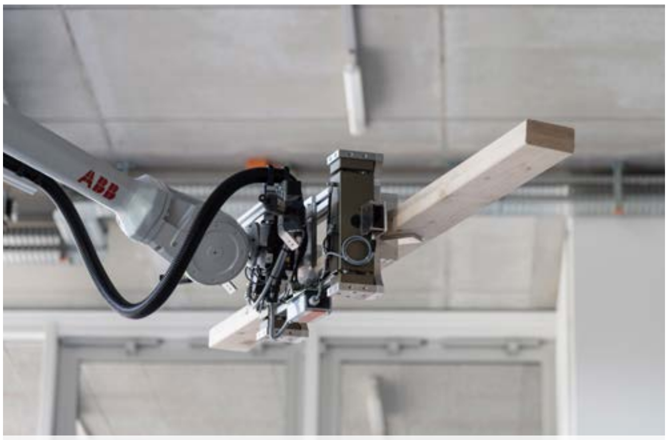
How can robots help with offsite modular construction?

The expanding capabilities of robotic automation make it ideal for handling the many varied tasks involved in modular construction processes.

Examples of possible applications include:

Lifting and handling
With the ability to handle materials ranging from wooden panels to steel beams, robots are well-suited to the requirements of modular construction. Working as standalone units or as part of production cells, they can be used to transfer processed component parts between stages, eliminating the risk of injuries to human workers caused by lifting and carrying heavy loads.

Assembly
The ability of robots to handle heavy loads is also beneficial when it comes to the assembly of component parts into complete structures. An example is the placement of horizontal and vertical wooden or steel beams. At Z Modular in Canada, for example, robots are used to lay steel beams that form the framework of prefabricated units for structures ranging from single story homes to multi-story hotels. Weighing several tons, these beams are precisely placed by the robots to allow them to be joined together utilizing a mixture of robotic automation and human labor.



Credit: Gramazio Kohler Research, ETH Zurich

—
Capable of handling a range of loads with high precision, robots are well-suited to the demands of off-site modular fabrication.

Joining of components
Robotic automation can be used to handle a variety of tasks involved in joining components. Robots can be used to perform a range of functions, including drilling holes for bolts or screws and placing and fastening them into place, saving time and reducing the risk of stress-related injuries caused by performing repetitive actions. For structures featuring metal elements, robots can also be used for riveting components together, utilizing approaches originally developed for automotive manufacturing applications.

CASE STUDY - Z MODULAR

The A- Z of modular construction

When you are an expert in the manufacture of structural steel, it's only natural to seek to add further value to that product. What could be more natural than to use that steel expertise to move into modular construction?

This is the origin of Z Modular, which describes itself as a one stop shop for modular buildings and services. The company sees the time as ripe for its particular skill set - with growing populations putting pressure on housing, the need for rapid construction of homes has never been more acute.

The company is building up extensive experience with projects ranging from work force housing in Ohio, residential flats in Texas and a Holiday Inn in Florida, as well as office developments in California and Texas.

David Warne, VP Architecture and Design, Z Modular and Principal, Skyhook (a sister company Architecture firm) says: "We need a system to build housing rapidly to meet the crisis, but the construction industry currently has a very low level of automation use. To help this situation, we have set up as a developer that takes projects through the complete process of developing, designing, fabricating and automating all processes and designing the project to maximize the use of robots."

Z Modular offers a complete project management process from concept to occupying the building, with clients able to optimize the size and shape of the project plan to fit with local zoning laws. This produces several pre-built, customized modules that are bought as products to stack in different shapes, with the customer ordering modules online.

Based on a steel frame, its construction method employs self-bracing structures – using its steel fabrication experience, Z Modular has designed a connecting unit called VectorBloc that connects and anchors the corners of every unit, allowing for more factory completion than other modular construction systems. Giving scalability of designs, it ensures building sizes and configurations can be almost limitless. Ceiling frames are built up to become 3D frames and a scanner is used to detect any changes or distortion.

Robots from ABB are employed in the construction of the steel frames, being used for welding and handling of the beams. The robots help to substantially reduce the time required to build a steel-framed building. Designs from the 3D CAD software are relayed to ABB's RobotStudio® which turns them into instructions for the robots to enable the structures to be built to the customer's requirements.

The efficiency and handling capabilities of the robots has helped to improve labor utilization and improved health and safety, removing the need for people to handle the steel beams. Risks to Z-Modular's customers are also virtually eliminated as the modular homes are built exactly according to their requirements through using the robots to accurately turn 3D CAD designs into the finished product. Z Modular estimates it can save six months of construction time on a typical project through automation, with the company able to produce up to 30 modules a day, equivalent to around 10,000 square feet per day.

Each module is produced on a production line, taken forward to the next stage using a crane or tug.

After the robotic fabrication stage, a CNC machine cuts the structural deck while studs are machine manufactured off-line into panels and secured to chassis frames in the line by people and modules are completely outfitted with all electrical and plumbing services installed.

To maximize its production efficiency, the company has adopted a process of continuous improvement. "An assembly line engineer will look at all the end points of the production line," says Warne, "both in and out, to constantly refine processes and see how new equipment will change the line. For example, we have looked at drywall robots but do not believe they are efficient enough yet. We also use a laser ferrometer for checking alignment – this is not fully automated yet but could be in the future."

The scanning of modules was a major step towards higher quality. "The first modules were hand built – we were not sure of the heat stress from welding, which was distorting the frames as the manual jig could not hold tolerance," says Warne.

"Using the scanner, we could vary the weld process to adjust stresses – the robot is used to tidy up tolerances, as the rest of the assembly process depends on the critical frame accuracy."

"We leverage all the possible efficiencies of factory production," adds Warne. "A study by MK looked at the difference between onsite and factory construction and concluded that robots make true modular possible. But it also needs a complete supporting system – BIM, PRP, scheduling, purchasing, a way to plan and direct robot movements. It all needs to come together.

"By contrast, some companies make modular buildings just as they are built on site but in a giant warehouse. This is not efficient, and the only advantages are getting workers inside out of the cold."

Currently Z Modular can build projects up to 20 storeys self-supporting, and over 40 storeys using lateral concrete cores. Sizes can vary according to different regulations. The modular approach to projects means that the company is not restricted by distance from the build site. "We serve a 500-mile radius," says Warne. "We can ship to the other side of country, which means that the only restraining factor is the gas cost – but effectively we can ship across the world.

"For example, we had a project in Washington, where LEED (Leadership in Energy and Environmental Design) legislation meant that we needed to order materials from within 500 miles of the site. To us, this shows the gaps in the industry, in that it is not yet big enough to take on smaller projects everywhere.

"Other examples of local conditions affecting us include legislation in Ontario, where we cannot build more than three stories – we need to explain why a building is safe above this level for each project."

When it comes to the direction and future of the industry, Warne is clear on the need for big investors to start modular factories, which require enough start-up capital to launch a new plant and hire staff to meet the company's target market.

Warne admits modular is not the way to meet all challenges in construction but says it does go a long way to answering some of the most pressing questions facing the industry. "It is a good answer to the housing crisis," he says. "It is faster, smarter and produces less noise with far less time on site.

"Modular is also easier to regulate due to its high accuracy and produces fewer toxins from unregulated chemicals and processes on site. Overall, we need to think about housing in a more sustainable way and modular is really all about sustainability."

Welding
A well-known application for robots, particularly in the automotive and metals manufacturing industries, welding is necessary in modular construction processes for tasks such as joining steel beams to form the frames for floors, walls and roof supports. With their inherent precision and repeatability, robots can be used to deliver a consistent high-quality weld, speeding up production and enabling more units to be produced per shift.

Finishing
Finishing operations such as grinding, sanding or polishing can also be performed using robots. Effectively providing a robot with a sense of touch, the use of force control technology provides accurate feedback on the relative position of the robot arm to the part or parts being processed. This enables a high-quality finish to be achieved, with any surface defects or irregularities being sensed by the robot which can then apply the necessary force needed to rectify them.

Fitting of windows, doors and facades
Robots can be used to assist human workers with lifting and positioning potentially heavy and cumbersome doors, windows and facades into place, speeding up the fitting process. By reducing the amount of labor involved in handling this task, robots can also help to enable people to be deployed to other tasks, making best use of available resources.

Quality inspection
Combining BIM with laser-scanning techniques, both the quality and quantity of prefabricated components can be checked to ensure that construction line is not delayed due to a lack of components or component defects.

Painting and spraying
Painting walls is ideal for automation as the toxic chemicals involved and the repetitive movements needed can be harmful to human workers.

2. 3D printing

Interest in using 3D printing for construction is increasing as its various benefits are realized by construction companies around the world.

3D concrete printing can be a sustainable solution as it enables complex shapes to be produced in-situ, reducing energy consumption compared to conventional manufacturing processes where materials and /or structures have to be pre-fabricated.

The main advantages of 3D printing include:
- Reduced building time
- Cheaper construction
- Freedom of shape and form
- Integration of functionality

Credit: BAM Weber Saint-Gobain

—
Robotic 3D printing is opening exciting new possibilities for the design and manufacture of structures and structural components.

- Reduced material consumption, which means less cement and less CO_2
- Ability to utilize range of alternative materials including industrial waste by-products, plastics and glass
- Structures can be made to be stronger without the need to increase structural density, reducing the total amount of materials needed and the overall weight of the structure itself
- Reduced generation of waste
- Improved brand image for construction companies through improved sustainability

A major benefit of 3D printing is the ability to recover and reuse potentially harmful or environmentally unfriendly by-products from other industries, as building materials. Fly ash and slag from the coal industry and steel industries, glass and plastic are examples of materials that can be used for 3D printing. Where recycled glass is used, it can be used as part of cement mixes as a substitute for construction sand, which is facing a growing shortage.

How can 3D printing help the construction industry?
The increasing freedom and range of expanded possibilities offered by 3D printing, coupled with its ability to utilize a wide range of building materials providing a more environmentally-friendly alternative to conventional cement mixes, means it is becoming especially valued for its ability to help create new features that can help to boost the sustainability of buildings.

For a building to be considered sustainable, it should ideally be able to provide an environment where people can live and / or work comfortably whilst minimizing its impact on human health and the environment through efficient use of resources such as water and energy. The structure itself should also make a minimal impact throughout its lifetime, from construction to eventual demolition and disposal. How this can be achieved has been subject to extensive research, with institutions such as ETH Zurich University and IndexLab in Italy looking for ways to create structures – including 3D printing using robotic automation – that offer a minimal environmental footprint by using different materials and approaches.

Key elements of a sustainable building project include:

- Smart design. The building should feature a smart design that maximizes the opportunities to offer maximum usability whilst minimizing both short- and long-term environmental impact. This requires architects and designers to know what is possible, what can be achieved, and how.
- Efficient technology. The building should use the appropriate level and mix of technologies needed to maximize sustainability. As sustainability covers the complete building life cycle, this can include the technologies used to construct the building, including techniques such as modular fabrication and 3D printing.
- Designing buildings with sustainability in mind from the outset. The building should be able to make maximum use of available resources whilst minimizing the need to draw on additional supplies of energy, water or other resources. To achieve this, a passive design approach can be taken where various methods can be built in to enable maximum use of natural heat, light and ventilation.

CASE STUDY - INDEXLAB

Demonstrating the possibilities of 3D printing

Examples of the use of 3D printing in construction are well-illustrated by research carried out by IndexLab. A research laboratory based in Italy at the Politecnico di Milano, IndexLab is using art to push the boundaries of construction techniques, producing free-form sculptures, complex structures, façades and art installations using new tools and processes.

This focus on art underpins IndexLab's entire philosophy of design for construction. Founder of IndexLab, Pierpaolo Ruttico, says “Construction and art will increasingly become knitted together and aesthetics will bring link them. A building must be beautiful first and then a sustainable way of building it has to be found. It is always a matter of finding the balance between top-down and bottom-up design approaches.”

Such an attitude demands a willingness to go beyond conventional construction techniques – the methods IndexLab is investigating include rapid creation of polystyrene molds for producing mass customized elements.

ABB robots play a big role here, being used for shaping the molds. An algorithmic design approach generates complex geometries and translates them into instructions for the robot.

The resulting products are used to demonstrate automated construction techniques to constructors and to help train the next generation of architects, engineers and builders about what can be achieved by combining robots and software to enable design for manufacture.

Ruttico adds “We went from polystyrene, to pairing hot-wire cutting of foam with thermoforming, which allows complex shapes to be cut and then put together quickly with no waste. Robotic hot-wire-cutting and thermoforming is a process that is much quicker than milling, spray-coating and polishing. It is also much more sustainable, as we are basically dealing with polystyrene both for the mold and the plastic you are putting in, allowing complete recycling. Thanks to this method and the robot, it is possible to manage the continuous and systematic variation of the elements and achieve mass-customization in a cost-effective way.”

—
Italian research laboratory IndexLab is helping to explore new applications for robotic 3D printing.

IndexLab makes widescale use of the flexibility of robots, using their pick and place abilities to prove concepts and then using them on building sites to construct facades.

The wide range of techniques employed by IndexLab include metal 3D printing, which it has found very useful in mass customized nodes. The method can be used to weld and manipulate beams – to which 3D printed parts can be added.

Printing on curved surfaces, working on structures that mix 3D printing with flat panels to allow complex geometries, robotic wood cutting and the use of advanced composites allowing the creation of customized structures are all in IndexLab's skill set.

Using 3D printing as proof of concept
For architects, 3D printing also makes it possible to produce small-scale proof of concept models that can be used to demonstrate the viability and effectiveness of different shapes, surfaces and facades before moving to full construction. This ability to demonstrate alternative methods of design and construction is proving to be a major asset for architectural practices when advocating new approaches to building companies.

CASE STUDY - ZAHA HADID ARCHITECTS

A helping hand to build unique visions

Renowned for its radical and transformative designs, Zaha Hadid Architects (ZHA) is embracing the possibilities of robotic construction to advance its passion for creating buildings that excite and stimulate.

Shajay Bhooshan, senior associate for ZHA, emphasized how technology is fundamental to the architectural vision. “Design is very much connected to the way things are built, so understanding the means of construction is relevant to the design. The success of the practice is partly due to our ability to embrace and adapt technology to use in the architecture industry.”

One of the drivers for the adoption of new construction techniques is the growing emphasis on sustainability, not only in the construction stage but also over the lifetime of the building.

Says Bhooshan: “We are increasingly looking at research related to sustainable development through creating appropriate shapes – building complex geometries that are both spatially engaging and environmentally adaptive.

The company is seeing a growing number of client briefs with sustainability as one of the key design criteria, particularly for buildings in the public domain. “It’s now vital to address these issues to compete and win work in the public sector.”

As a consultancy that has pushed the envelope of architectural design over the years, ZHA sees landmark developments as paving the way for technological upgrades, setting new paradigms for design.

Says Bhooshan: “Robotics helps to provide examples of what can be achieved. Architects must be able to tell a story to convince others to invest in the project, so they need to present an image of what it is going to look like. Clients will want to know how the project is going to be built, so having smaller proof of concept examples helps to foster and develop the project.”

As with others in the industry, Bhooshan emphasizes the importance of bringing together computational design and robotics: “Digital design and robotic fabrication are compatible and augment and enhance each other. This combination makes non-standard elements affordable if you can manage the complexity and then disassemble into parts that can be made and transported to site. In this way, we can move away from repeat elements and feasibly get to a unique kit of parts.”

The form that buildings can take using robotic techniques is also changing. Curved surfaces are desirable as they use less materials, but until now, designers have been largely restricted to prismatic elements – robotic fabrication makes forming curvatures more possible.

“Robots don’t care whether what they’re making is curved or straight,” says Bhooshan. “In fact, with 3D printing, it’s much harder to produce a straight wall than a curved one, and curved and non-prismatic structures are much more common. 3D printed geometry is also cheaper and has an aspirational aesthetic that is different from the mass produced.”

The major difference between construction and other industries is scale. “Architects always strive to design unique projects that suit the requirements of the location,” says Bhooshan. “This hasn’t been the case in manufacturing, but robots are an enabler for making customization more affordable and feasible in an industrial context. These changes are also possibilities for architecture - mastering robotics promises to bring efficiency when you want to produce a single instance.”

How can robots help with 3D printing?
Robots are well-matched to the demands of 3D printing. With the ability for 3D plans from building design software to be converted into commands via ABB's RobotStudio offline programming software, our robots can be used to precisely perform the various movements needed to create a range of structures, from individual curved surfaces for walls and facades through to complete structures such as bridges or even houses.

CASE STUDY - MAGIC QUEEN

Magic Queen exhibition, La Biennale Architecttura, Venice, 2021

ABB provided a 3D printing robot for a dynamic exhibit called 'Magic Queen' at the 2021 La Biennale Architecttura event in Venice. Created by Austrian architectural firm MAEID, the exhibit will develop over a series of months, with the robot being used to create the largest 3D printed biodegradable structure ever made, featuring a landscape made from natural materials planted with mushrooms and tended by the robot. The robot is AI-enabled, enabling it to build the landscape, water the seeds and monitor the surrounding environment via feedback from temperature and other sensors incorporated into the exhibit.

Designed to run for several months, the exhibit demonstrates what can be achieved by combining robotic automation and software technology with human imagination and collaboration to produce the new types of structures that can be deployed in the future to enable more sustainable construction.

—
An ABB robot forms the centerpiece of a sustainable architecture exhibit at the 2021 La Biennale Architecttura event in Venice. Called the 'Magic Queen', the exhibit aims to show how technology and human imagination can be combined to produce sustainable structures that can form part of the future of construction.

CASE STUDY - MX3D

MX3D printed bridge, Amsterdam

The innovative 3D printed bridge, built by ABB robots, will span a canal in historic Amsterdam. When installed, the fully-functioning stainless steel pedestrian bridge crosses the Oudezijds Achterburgwal, one of the city's oldest canals.

Dutch 3D printing startup, MX3D, invented a 3D printing technique whereby ABB industrial robots supported a 3D printer which printed multiple lines of steel at once, similar to weaving a basket. As six-axis robots, the ABB IRB 2600 and IRB 6700 robots enabled MX3D's printing head to be precisely controlled across a wide range of positions, so the bridge design was not constrained by limits on the printing capabilities.

Built in an offsite facility, the bridge spans the six meter canal nearby some of the city's most iconic sights including the home of the Dutch East India Company and the New Market, setting for Rembrandt van Rijn's masterpiece "The Anatomy Lesson of Dr Nicolaes Tulp".

MX3D's software translated a design to a laser pattern, which is translated to ABB's RAPID software which instructed the robots' movements. ABB worked closely with MX3D to train their employees on how to use the robots.

The production process is simple: A welding head is attached to the end of the ABB robotic arm and small amounts of welding material are added in the production process, resulting in self-supporting metal rods and structures that are essentially made of a multitude of welded points. The robots are printing large parts of roughly one meter steel plates at a separate location. The parts will be assembled after printing.

This bridge demonstrates how 3D printing is a practical tool to create large-scale, functional objects with unique forms and materials. The use of additive 3D printing can also reduce waste by using the exact amount of materials needed – traditional bridges are typically made of carbon-intensive concrete which is poured into molds, often with great waste.

"The MX3D project is a great illustration of how industrial robots are coming out of the factories and playing a major role in public spaces, from material fabrication and construction to public works and lighting. It's a very exciting and innovative time," said Martin van der Have, Sales and Marketing Manager for ABB Robotics BeNeLux. "Applying robotic welding technology on this scale and realizing the 3D construction of large objects without any support structure is an important step in the development of new manufacturing technologies. The MX3D project is a unique and ambitious initiative, as well as a good platform to showcase the outstanding motion control and programming capabilities of ABB robots."

Applying robots to on-site construction
While off-site fabrication offers significant advantages over traditional building sites, including protecting workers and the overall construction process against the vagaries of the weather, on-site construction is nevertheless another area where the benefits of robotic automation are being evaluated.

Compared to the consistent and controllable environments that can be achieved in offsite manufacturing facilities, building sites present a number of challenges for the design and application of robots, including rough, uneven surfaces, obstacles and moving hazards in the form of people and other machinery. To counter this, robot manufacturers, including ABB, as well as other parties including research institutions and specialist systems integrators are looking for ways to develop solutions utilizing features such as all-terrain caterpillar tracks, collaborative laser scanners and other technologies that will help broaden the application of robots on building sites.

Although site conditions are a challenge, robots have been developed that work on mobile, elevated work platforms that can drill holes in ceilings, while automated systems for tunnels have also been used. Robots have been used to 3D print buildings in concrete on site, including a two story 640 square meter administrative building in Dubai. There are also robots that have been developed to build brick walls, perform painting applications and lay paving slabs.

With some companies concerned about the time, cost and practicalities of delivering complete structures and large component parts from offsite construction facilities that may potentially be many miles from the actual building site where they will be assembled, another alternative that is being looked at is the concept of ‘factories on the fly’. Effectively enabling the advantages of offsite construction to be realized closer to site, these temporary factories can involve options including converting nearby disused structures into a factory, building a dedicated manufacturing facility or other measures such as a containerized solution, with the resulting production facility being geared up with the necessary automated production equipment that can be used to build the components required for the project.

Some examples of on-site construction applications utilizing ABB robotic solutions

Installation of Elevators
Schindler Elevators

Walk paths and sidewalks
ODICO

Masonry walls
NCCR Digital Fabrication

Drilling
ULC Technologies

Why is now a good time for automation?

The mounting challenges facing the construction industry provide fertile territory for robotic automation. With the growing shortage of labor and skilled workers, it is increasingly difficult to meet the need to produce more buildings more sustainably to a greater range of designs.

While robotic automation almost certainly holds the key to solving the challenges this presents, market penetration is very low. Figures published by Statista show that in Europe, Belgium and the Netherlands are the largest construction market for robots, with 1.5 per 10,000 workers in the construction industry[25]. This is very small compared to the overall Western European average of 225 robots per 10,000 workers deployed in manufacturing applications, with Germany leading the way with a density figure of 346 robots per 10,000 workers[26].

In comparison, Singapore, Japan and China have all been increasing their deployment of robots in construction projects, with Singapore in particular declaring its intention to use robots in increasing numbers both to reduce its reliance on overseas labor and meet the demands of housing an ageing population[27].

Factors leading to a changing attitude towards robotic automation include changing market expectations and developing regulatory environments. These pressures include public budgets being squeezed and many people having concerns about the affordability of homes. Owners and customers are increasingly demanding buildings that are adaptable and have a low cost of ownership, while both owners and governments are keen to have buildings that are more energy efficient and make better use of resources in their construction and operation.

The issues around rising urban populations and the growing proportion of single person households increases the pressure to find building land. This in turn could encourage companies to find construction methods that can make better use of land, allow more efficient and much faster construction of buildings to meet rising demand and use techniques that allow more customization to meet individual needs.

Automation has already gone a long way to solving many of the issues faced by other industry sectors and can also do the same for the construction industry. Trends including the merging of automation and digital software technologies that are opening new possibilities for mass customized building design and construction, combined with the development of lightweight, more environmentally friendly materials, could allow the industry to attain a new level of efficiency, productivity and performance in their built products.

—
Singapore is one of a number of countries that are increasingly looking for ways to answer their domestic construction labor shortages with robotic automation.

Uptake of robots in construction – a global picture

To help ascertain the take up general level of understanding of robotic automation in the construction market and identify potential pain points that are hindering the wider uptake of robots, ABB surveyed 1,900 representatives from a range of companies in the construction value chain, including residential and commercial developers, component suppliers, contractors and subcontractors, architects and designers and consultants. To provide a global picture, the survey covered a range of countries, including Austria, Canada, China, France, Germany, Italy, Sweden, Switzerland, UK and the USA.

Number of businesses surveyed in each country:

Country	Count
USA	200
China	200
UK	200
Canada	200
Germany	200
France	200
Italy	200
Sweden	200
Switzerland	200
Austria	100
Total	**1900**

Breakdown of respondent base by occupation:

Sector	Count
Residential construction	779
Commercial construction	512
Component supplies	72
Contractor / Subcontractor	300
Architect / Designer	171
Consultant	35
Other – please specify	31
Total	**1900**

The survey revealed a number of key findings, which are covered below:

1. Nearly all construction companies anticipate a skills crisis by 2030

Of the 1,900 people surveyed, 1,734 responded yes to the question "Do you think the construction industry faces a skills crisis over the next 5-10 years?", amounting to 91 percent of respondents. This sentiment was reflected strongly across all countries surveyed:

Do you think the construction industry faces a "skills crisis" over the next 5-10 years?

	Yes, definitely	Yes, maybe	No	NET Yes
UK	47%	43%	11%	89%
USA	49%	36%	16%	85%
Canada	46%	42%	13%	88%
Italy	52%	41%	8%	92%
Switzerland	58%	38%	5%	95%
China	41%	51%	9%	92%
France	47%	43%	11%	89%
Germany	82%	14%	5%	96%
Sweden	47%	48%	6%	95%
Austria	62%	35%	3%	97%
Top line average (all results)	**52%**	**39%**	**9%**	**91%**

Evidently, the issue of skills shortages is a major concern for the construction industry. Supporting this finding, 41 percent of respondents across all countries said that they were currently worried about the lack of people joining the industry, although this was less a concern in China, where only 16 percent of respondents identified it as a concern. A further 36 percent said that their business struggled to recruit and retain staff for roles that are either perceived as repetitive and dull tasks, or which include dirty or potentially dangerous tasks.

It should be noted that while the problem of future worker shortages is a concern, only 10 percent said that they currently struggle with labor shortages on their projects. This could suggest that a lack of labor and skills is not of great concern today but is a problem that is widely perceived across the construction industry to be inevitable in the future.

Many in the industry see robots and robotics as a way of addressing the skills shortage, chiefly by making construction a more attractive and safe industry in which to work.

- 32 percent say that robots and automation could make their workplace potentially safer for employees
- 34 percent say that robotics and automation could either reduce the potential for injuries
- 31 percent say that robots undertake or could undertake some of the dirty, dangerous and repetitive tasks that many employees do not enjoy doing

How can robots help tackle the skills crisis?
Robots can make construction safer by handling large and heavy loads, accessing dangerous spaces and enabling new, safer methods of construction. Using robots for the repetitive and dangerous tasks that people increasingly do not want to do means automation can help support the industry's labor and skills crisis and make construction careers more appealing to young people.

Highlighting the importance of the human factor, these results demonstrate that robots are seen as a key tool that can help to improve working conditions and job satisfaction and enhance workplace safety. By providing an alternative means of handling repetitive, dangerous and difficult jobs, robots can help to greatly enhance worker performance and minimize issues arising from boredom, injury or error.

Increased adoption of robotic technologies, and improved accessibility to them along with better training, will be important in the coming years in reducing the severity of an anticipated skills shortage.

"The crisis with resources is enormous – we have found that robots are the key to solving the problem of a shortage of skilled labor. Another factor is that young people are not interested in doing heavy tasks manually."

Ulf Hakansson, Skanska

CASE STUDY - SKANSKA

Skanska rewrites the rules of rebar fixing

As a major player in the construction industry, Sweden's Skanska has immense experience in the building of major facilities such as bridges, tunnels, motorways, and airports. With the world looking to improve the sustainability of cities and transportation, building them quickly and efficiently, with fewer resources and less pollution, has become a priority.

With much of its focus being on-site tasks for discrete projects, Skanska has been looking at ways to automate aspects of the build process to make them safer, faster, and more adaptable.

One area the company has been investigating is using robots to produce cages of steel bars (rebars) that help to reinforce concrete structures. As a time-critical operation, the time required for this operation can have a significant impact on the duration of a project, with all work needing to be done before the main construction stage can get underway.

Trials using ABB robots and ABB's RobotStudio offline programming and simulation software, have met the goals of improving the speed and efficiency of the rebar cage manufacturing process. Overall, Skanska has reduced the time needed from 16 hours per tonne to just 1 hour per tonne.

A major benefit has been the ability to reduce the number of people involved in the rebar process, allowing workers to be used for other tasks and projects – this factor is particularly important as it is growing increasingly difficult to find workers that want to do these sorts of tedious and demanding tasks.

Ulf Håkansson, Skanska's design manager for large projects group and former director of Research and Innovation at corporate HQ, says: "When it comes to safety and automation, it is crucial to automate certain tasks that result in a lot of injuries and where people are doing tasks they shouldn't be doing. Building rebar cages is one of these - it is perfect for robots and automation and when performed in this way, it can improve health and safety significantly."

After efficiency and reducing the time needed for constructing rebar cages, Skanska sees skills shortages and the lack of resources as the second most important factor driving automated construction. Says Håkansson: "The crisis with resources is enormous – we have found that robots are the key solution to solving the problem of a shortage of skilled labor. Another factor is that young people are not interested in doing tasks manually."

Repetitive and time consuming, rebar manufacture is an ideal task to allocate to robotic automation.

2. Sustainability and the environment are expected to be major catalysts for accelerating investment in robotics

	Driver	Ranking
Which issues do you consider are the future drivers for change within the construction industry over the next 10 years?	Environment/sustainability	#1
	Lack of skills	#2
	Health and safety	#3=
	Premium homes	#3=
	Lack of labour	#4=
	Low-cost homes	#4=
	Government targets (e.g. home building)	#5=
	Quality	#5=
	Reducing waste	#6

The growing need for sustainable development was highlighted as the major driver for change within the construction industry in the next 10 years, with the need to reduce waste also identified as a key concern. This finding reflects a clear understanding that things need to change if the industry is to be able both to minimize its environmental footprint and deliver homes of the future offering improved levels of lifelong energy efficiency and reduced carbon emissions. One potential driver for this is the growing introduction of regulations from governments worldwide that will shape the design of buildings. The UK Government, for example, has announced a ban on gas and oil boilers in any new homes built after 2025, requiring developers to look to new methods of heating, including low carbon heat pumps and heat networks powered by alternative forms of energy.

Prioritizing sustainability as a driver for change ranked in the top three responses for all countries in the survey, except for Switzerland, where it ranked fourth. China, which continues to undertake massive building programs as part of its transformation, was the country to place the most emphasis on the environment as a catalyst.

—
Sustainability is becoming an increasingly important factor in China's massive program to develop its cities to accommodate rising urban populations.

Did you know?

China will account for almost half of the world's new construction projects in the next

10 years*

The country adds around

+

two billion sq m

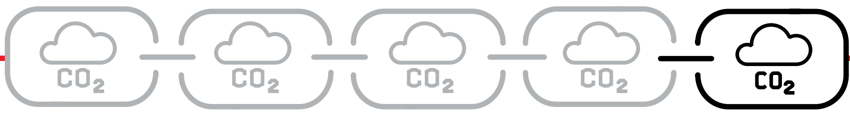
of new floorspace each year

2001 **2016**

Between 2001 and 2016, energy consumption in China rose by over

50%

The carbon cost of constructing new buildings, including extracting and processing raw materials and the energy consumed by the supply chain accounts for approximately one-fifth of China's carbon emissions



China has set a target to become a leader in green construction

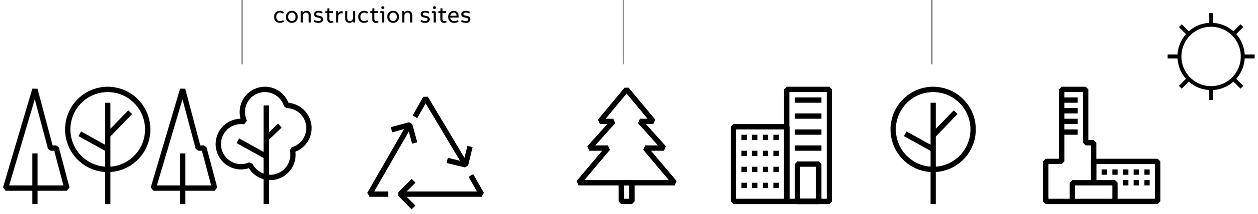
How is China making its construction industry more sustainable?

Vertical forests', comprising of tree covered buildings⁺

3D printing using recycled materials instead of cement, recovering waste from steel mills, coal plants and urban construction sites

Repurposing existing buildings

Using passive building design to maximize available natural light and heat



* (https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22761.pdf)

[+] https://www.stefanoboeriarchitetti.net/en/news/nanjing-vertical-forest/

(All stats sourced from https://www.bbc.com/future/article/20200610-how-china-can-cut-co2-emissions-with-sustainable-buildings and https://www.worldgbc.org/news-media/world-green-building-council-and-china-green-building-council-announce-partnership-0)

How can robots help build the sustainable homes of the future?

With the industry facing increased environmental regulation and the need for more high quality, lower cost homes, robotic automation reduces waste by improving quality and consistency, which is significant when it's estimated that the amount of waste generated by construction and demolition will reach 2.2 billion tons per year by 2025[28].

Developments in robotic automation for construction can help reduce this, with techniques such as 3D printing and improved accuracy in timber modular construction, for example, both allowing greatly improved control over the application of materials used in construction.

Added possibilities are also being enabled by the combination of robots with digital 3D CAD modelling software, which allow builders to effectively design waste out at the beginning of a project through effective building design and construction processes.

—
Combining 3D building modeling software and robotic automation can ensure better control of the building process, improving aesthetics and quality and reducing wastage.

CASE STUDY - INTELLIGENT CITY

Sustainability from the ground up

Canadian company Intelligent City is on a mission to transform the way the construction industry operates. With automation and robotics, Intelligent City thinks the time is ripe to vastly improve the sustainability of an industry that is the world's number one source of greenhouse gas emissions.

Based in Vancouver, the company has become an expert in offsite construction of timber-built modules that can be connected to produce buildings up to 18 stories high. Making use of Canada's large timber resources, Intelligent City can deliver fully integrated mass timber based turnkey products with passive housing certification to meet the highest energy standards. This product-based approach allows 'urban densification', promoting sustainable city living by infilling small or brownfield sites rather than building on greenfield areas.

The use of a common platform, based on modular floor panels with integrated services, and modular façade panels gives a full structural system that can be erected rapidly, and which meets all the requirements of a high performing building.

Intelligent City can also model the building in a digital twin that allows the performance of the project to be tested before it even arrives on site.

On the shop floor, ABB's robots are used to process, handle and assemble large sections of timber in the prefabrication production line. Three robotic systems are used, including several robots integrated with tracks. Operating in cells, the robots produce timber components according to designs created in Intelligent City's Platform for Life (P4L) design software, enabling customized structures to be built according to specific customer requirements.

ABB's RobotStudio offline programming software is also used with P4L to plan tasks and movements for the ABB robots. Every component gets its own file and can be simulated and executed directly.

Key benefits of using the robots include manufacturing flexibility, improved production efficiency, a 38% improvement in project delivery times and a 33% reduction in the cost of producing a home. Wastage has also been significantly reduced as the robots can be used to optimize the production process to minimize things such as off-cuts.

RobotStudio has also been very valuable in helping to model cells as well as the layout of the factory to help optimize the production line.

Oliver Lang, co-founder and CEO of Intelligent City, believes automation is fundamental to the company's whole sustainable approach to construction: "Automation allows a range of solutions, allowing people to embrace it. It also ensures quality control and repeatable processes to improve the performance of buildings. We simply can't do this without robots or advanced software."

For Lang, three things connect sustainability and robotics. Firstly, improving the quality of a building through automation means the building will last longer so it doesn't have to be replaced with a new building after a few years, using more energy and resources. "The second is the material itself," says Lang. "Wood really lends itself to robotic automation because of its malleability and processability. It is easy to add to or subtract from without much penalty. It is also extremely lightweight for its strength and so production is therefore much easier to automate."

The third is the adaptability of a developed product. "Building housing as a product means you have figured out everything from design to manufacture and that we can adapt every building element and component. The only repetition is in the logic of the workflow – the system is pre-engineered to work through all the possible permutations.

"Variability is also important. A building is far more than just its components, it also about how you site it and make the best use of light and heat. Buildings are typically built generically and must be retrofitted with equipment to suit their environment. We don't have to do this with a passive structure."

Lang appreciates the support of ABB in helping the company grow and develop its production system. "It is absolutely fantastic to be able to work directly with a large company like ABB with all its knowledge and experience," says Lang. "This is hugely valuable. It is very reassuring that a small start-up company like Intelligent City can work and innovate with ABB. Working together, we are pushing the boundaries of the software, discovering a lot of functionality in RobotStudio and how to integrate it with our own software. "

—
Intelligent City's product-based approach allows 'urban densification', promoting sustainable city living by infilling small or brownfield sites rather than building on greenfield areas.

3. The construction industry currently lags behind other industries in adopting robotic technologies, but this is likely to accelerate quickly

According to the survey, 55 percent of construction companies say they use robots, compared with 84 percent in Automotive and 79 percent in Manufacturing[29]. The findings show that there is appetite within the construction industry to accelerate adoption, with 81 percent of construction businesses saying they will introduce or increase the use of robotics and automation in the next decade:

Is your business likely to introduce or increase your use of robotics and automation for your workplace in the next decade?	Yes, within the next 2 years	21%
	Yes, within the next 2-5 years	24%
	Yes, within the next 5-10 years	20%
	Yes, but in more than 10 years' time	9%
	Yes, but we are unsure of the timeframe	6%
	No	6%
	Unsure	13%
	NET Yes	**81%**

Most construction companies intend to either invest in robotics, or increase their investment within the next 10 years, with only 6% stating that they had no intention whatsoever. The weighting of survey responses that answered yes within the next 2 or 2-5 or 5-10 years suggests that more widespread implementation of robotics is likely to happen sooner rather than later and that in 10 years more than two thirds of construction businesses will be using robotics and automation in their businesses.

"Much of offsite construction today consists of building in much the same way as on a conventional building site, with some small gains and climate control. We need to redefine this. Onsite construction surrounded by four walls and a roof is not manufacturing."

Brent McPhail, Founder & CEO, Brave Controls

The expected benefits from the use of robots were also varied. Reducing project times and improving the working environment for employees were cited by the most respondents as ways in which automation and robotics could help the industry, with consistent quality and increasing possibilities for building design also seen as key ways in which robotic automation could help deliver improvements.

Expected benefit	Ranking
Remove workers from unsafe tasks / improve health & safety	#1
Reduce project times	#2
Relieve workers from tedious tasks	#3
Help to tackle skills shortage	#4=
Increase possibilities for building design	#4=
Improve worker productivity	#5=
Ensure consistent quality	#5=
Reduce costs	#6
Reduce wastage / breakages of materials	#7
Improve profit margins	#8
Ensure compliance with COVID restrictions (e.g. social distancing)	#8
Improve competitiveness through greater choice	#9
Off-site fabrication	#10=
Automate on-site fabrication / construction	#10=

4. Uncertainty, a lack of understanding of robotics technology and its benefits and a current lack of skills in automation are some of the reasons why investment in robotics has been slow in the construction industry

Historically, the construction industry has been slower to embrace new technologies than other sectors. The most cited reason for not investing in robotics was a lack of belief that either the business or the industry was not suited to robotic automation. The question was answered only by respondents who had indicated that their business does not currently use any robotics.

What has stopped your business from investing in robotics so far?	Lack of belief that my business / my industry is suited to robotic automation	32%
	Belief that robots are too expensive and therefore the investment isn't justified	25%
	Belief that robots are too difficult to use	14%
	Uncertainty / lack of knowledge about how robots or automation could help my business	26%
	Lack of in-house experience and/or technical knowledge around working with robots	20%
	Unsure of where to start with regards to choosing and then setting up robots in my business	17%
	Distrust in the technology	9%
	Lack of space	6%
	My employees / customers would prefer to work with people	22%
	Don't know	7%
	Other (please specify)	3%

The key takeaway from the responses to this question is that there is a lack of education and awareness surrounding the potential benefits of robots with almost a third claiming that their business is not compatible with them.

26 percent of respondents identified a lack of knowledge about how automation could help their business, while 14 percent said that robots are too difficult to use. Robots are an advanced technology, but innovations in recent years have made them more accessible, more efficient and more versatile than ever before.

Advances in user interfaces and ease of use, along with developments in machine vision and CAD systems, mean that it now takes comparatively little training to be able to program and operate modern robots, while their adaptability makes them suited to an extremely wide range of tasks and duties on a typical construction site, particularly those where there are health and safety risks for human workers. There are very few tasks in the construction industry that modern robotics and automation technologies cannot carry out or assist with.

These innovations open new possibilities for the construction industry. Robots allow buildings to be constructed more quickly and at a lower cost, allowing more projects to be completed in less time, with greater accuracy and less wastage. This in turn allows construction businesses to be more agile and flexible in the design of buildings and can help to provide more choice for the end customer. This added flexibility means that there no longer needs to be a "one size fits all" approach to housing design, allowing greater input from the customer and greater freedom to design and build customized structures utilizing different designs and materials that can help to make future homes more energy efficient and sustainable throughout their lifetime.

Robots can also directly help to address the skills shortage by freeing workers from high risk or repetitive tasks, improving health and safety. This helps free up labor to be deployed more effectively elsewhere and can also make construction a more attractive career prospect for young people especially.

More education is clearly required to generate awareness of the capabilities of modern robotics technologies. With some survey respondents reporting that they were unsure where to start with introducing robotics and automation to their business, it seems that robotics manufacturers should do more to smooth the path towards adopting the technology, while highlighting the wide range of applications in which robotic automation can be used.

New technologies, new possibilities

Recent years have seen a massive expansion in the capabilities of robotic automation which has led to robots being used in an increasingly broad range of applications. Many of these advances have helped to address some of the lingering concerns around the technology, including factors such as complexity, lack of flexibility, safety and collaboration, quality control and questions around leaving them unsupervised.

Examples of specific technologies that have been developed to address these concerns include:

Simplified programming and operation

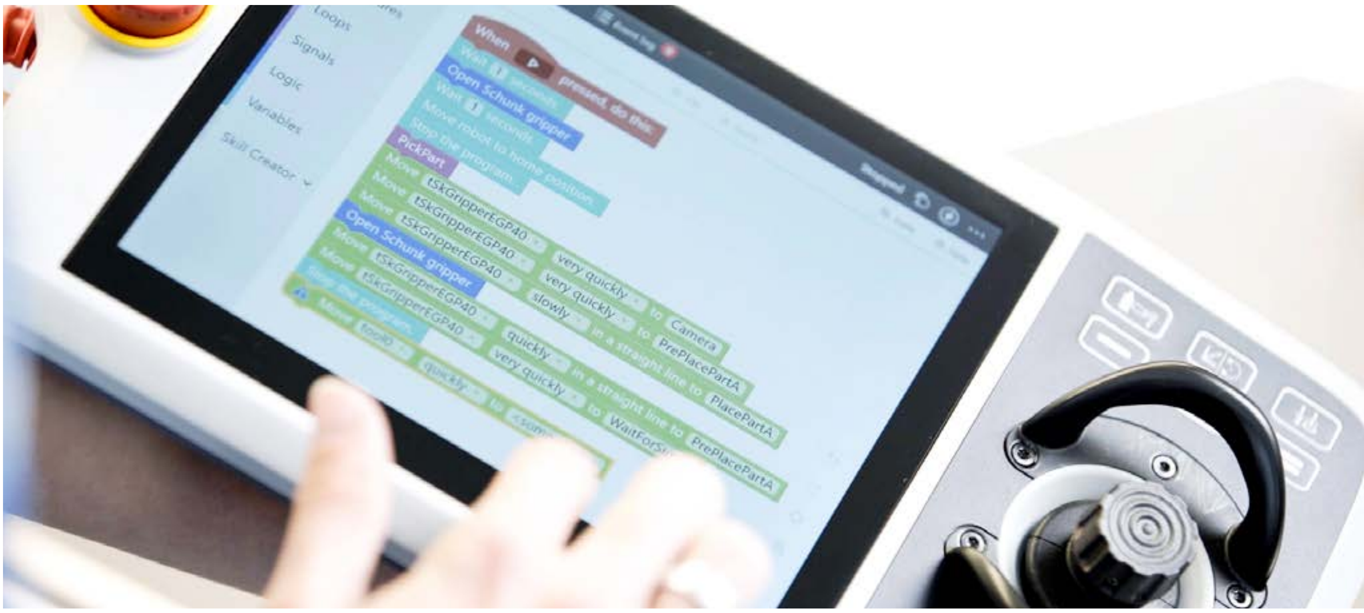
- **Handheld controllers** – ABB's FlexPendant handheld controller offers a quick and convenient way of programming robots with the movements needed to perform a specific task. Using FlexPendant, an operator can 'teach' the robot the paths needed to perform a particular action by jogging the robot arm into the positions required. Once all the positions have been entered, the controller can be used to run the complete program, with the operator able to carry out further modifications if required. With an easy-to-follow visual interface and controls, the FlexPendant can be used with ABB's full range of robots.

- **Easy programming software** – available with ABB's new range of collaborative robots and its IRB 1100 industrial robot, the Wizard Easy Programming software tool presents commands as pre-programmed visual blocks, which operators can simply drag and drop into place to create an entire operating program. With no need to learn programming code, the tool helps to extend the benefits of robots to users with little or no experience required in robotic automation.

- **Lead through programming** – also used on ABB's new range of collaborative robots, lead through programming makes it possible to program a robot by simply moving the arm into the location required and setting the required action using either a controller or, in the case of the new GoFa™ cobot for applications up to 5kg, by pressing a button on the robot arm.

- **Offline programming and visualization tools** – ABB's RobotStudio® offline programming tool is an engineering tool for configuration and programming ABB robots both on the shop floor and virtually via a PC. The software can be used to create, test and simulate a specific set up on a PC without disrupting the factory floor or production operation. This software can also be used to import CAD models of the products that need to be made or handled with the robot, which can be tested as part of the program before the installation is put into action for real.

  Once a setup has been created, it can be stored as a digital twin that can be used as either a template and/or benchmark for future changes. As such, it offers a powerful tool for developing robotic solutions, helping to reduce the time, cost and troubleshooting that can often arise in automation projects.



—
ABB's Wizard Easy Programming software is one example of how new technology is being applied to help make robots easier to use by removing the requirement for specialist programming knowledge.

Enhanced flexibility

- **Dedicated function packages and tailored solutions** – the result of ABB's extensive experience in the development, implementation and support of robotic solutions for a wide range of industries and applications, ABB's Function Packages and tailored solutions bring together all the technologies needed to carry out key tasks found in many manufacturing applications in a single integrated package, helping to cut the time, cost and potential error that can be incurred when trying to integrate solutions from scratch.

Safety and collaboration

- **Collaborative robots** – developments in collaborative robotics are opening new opportunities for being able to safely use robots alongside people. Collaborative robots fall into two categories – inherently safe 'cobots', which feature soft padding and integral sensors that prevent injury arising from contact and collaborative robots that feature additional features such as safety scanners and software that enable them to 'react' to a human presence, either slowing them down or stopping them completely depending on how close the person is to the robot.

Quality control

- **Robot vision** – ongoing developments in robotic vision have led to breakthroughs in areas including 3D and color vision, enabling robots to assess objects in greater detail and use the resulting data to modify their movements, including responding to unexpected situations such as products or parts being in different orientations.

- **3D quality inspection** – advances in 3D quality inspection are opening new opportunities for greater precision and accuracy in quality control. ABB's latest generation inspection robot uses a 3D sensor to capture multiple images of the product and compare it to a master CAD model. This contact-less technique allows operators to test for quality at a much faster rate and with more information than traditional tools and manual inspections.

Performance

- **Motion control** – developments in motion control software mean that a robot can keep to the programmed path regardless of its speed. The improved precision that this delivers ensures that robots can be used to deliver reliable, predictable and consistent performance while reducing cycle times and helping to speed production without affecting product quality.

- **Force measurement** – if robot vision is a robot's sense of sight, then force control is its sense of touch. Normally robots are position controlled with a predefined path and speed. With ABB Integrated Force Control, the robot reacts to its surroundings and deviates from the programmed path or speed based on feedback from the force sensor.

The adapted movement of the robot is determined by constraints that are specified to suit the particular application. Integrated Force Control technology includes powerful functionality that allows the robot to maintain a constant force between itself and the objects it is working with. The technology also can be used to adapt the robot's speed upon input from the force sensor. This allows it to follow edges and other contours efficiently, such as in deburring of complex shapes. The tactile functionality of Integrated Force Control can also be used in assembly to search for correct positions using advanced search patterns.

Scope for automation: 'Automate like automotive'

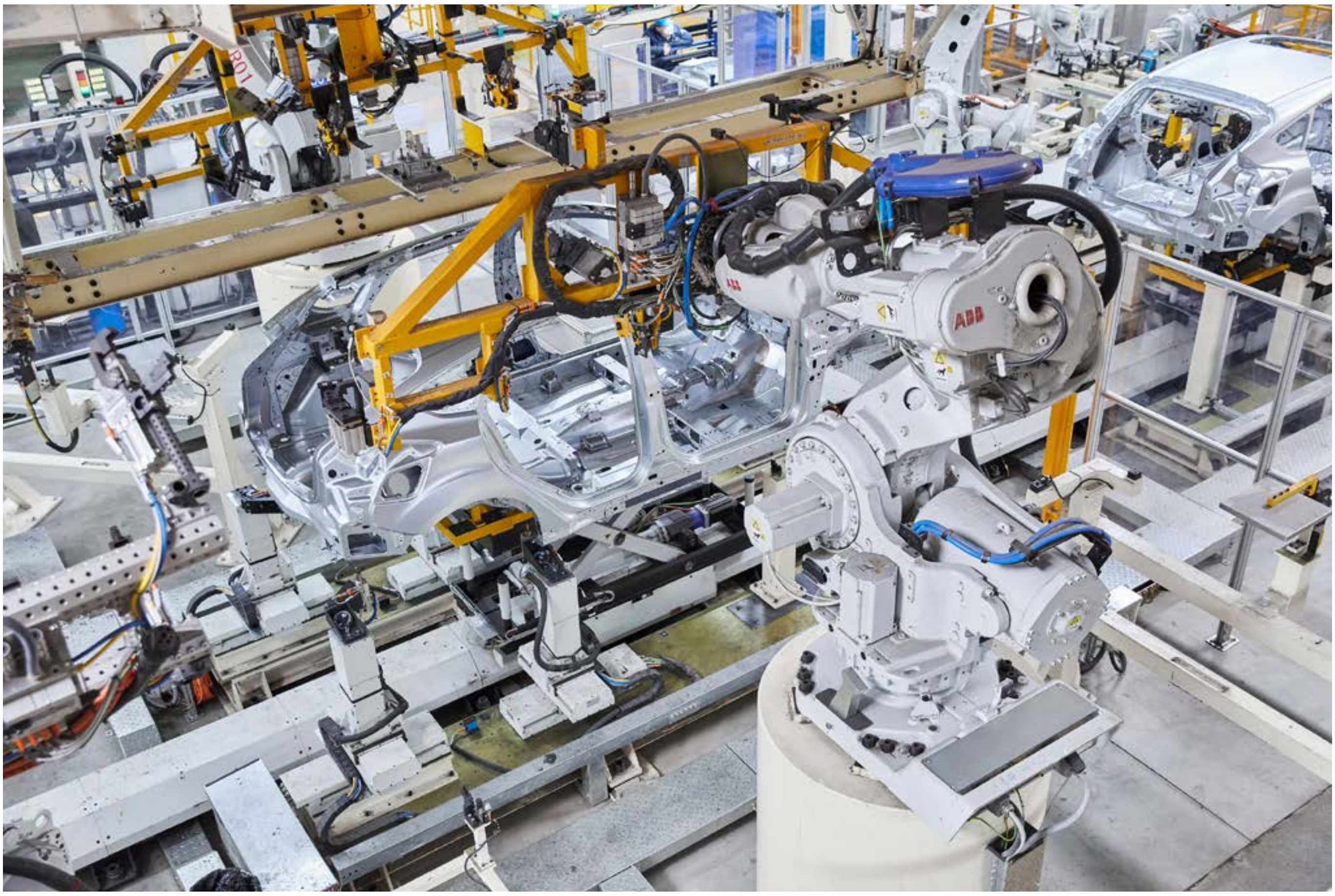
The experience of the automotive industry in automating its production processes has been noted by many players in the construction industry, with some companies using it to guide their own efforts in finding ways to attempt to achieve the efficiency levels enjoyed by automobile manufacturers.

Ever since the introduction of the first car production line by Henry Ford in 1913, the automotive industry has been characterized by its embrace of the latest technologies and techniques that have led to it becoming a leader in productivity and efficiency, while simultaneously finding ways to shave production costs to produce a greater variety of affordable vehicles.

While the construction industry does not currently match the automotive industry for innovation or productivity, the two sectors have many essential similarities. Both have products requiring the assembly of a basic frame which is then augmented and developed by attaching a variety of component parts to produce the finished item. Many of the basic processes, such as attaching doors, fitting windows, lining up screws and attaching electrical equipment, are common to both car building and housebuilding, albeit at a different scale.

The key production stages are also consistent in both industries, with each product going through a set sequence of operations before they are completed.

Both industries also have a product that can be customized to meet specific customer demands, with many areas of similarity such as panel configurations, paint finish and overall shape.



—
The automotive industry has led the way in applying robotic automation to handle a wide range of production tasks, resulting in significantly improved productivity, efficiency and flexibility.

Common manufacturing tasks used in the automotive and construction sectors

While the nature of the products being built in the automotive and construction industries is very different, there is considerable overlap between many of the processes involved, enabling robotic techniques developed for car manufacture to be applied to many of the operations involved in manufacturing components used in building, with the same benefits of improved part quality, higher levels of consistency and higher throughput/productivity. The following are some key examples of where techniques developed for automotive can be applied in construction:

Robotic trimming
Robotic trimming of interior trim in automotive has long been a common operation. Knowledge gained from this application has been applied in other industries such as the example shown, where robots are used to trim fiberglass baths and hot tubs. Both products are relatively straightforward as the product comes from a mold with little deviation. As long as the fixturing and molds are consistent, the robot will follow the same path.

With the introduction of sensors and probes, it has been possible to expand the use of robots to trim and cut more products made from other more variable materials such as plastics and wood or even stone, with the robot able to adjust the cutting paths to the actual surface of each individual piece to ensure that all the relative features are consistent. Furthermore, in the stone slab example, the robot also handles the part using a tool changer.

Robotic arc welding
Although the origins of arc welding lie in automotive, developments in joining techniques in the sector mean that it is no longer used as widely. Nevertheless, many of the principles developed for automotive can and are being applied to the construction industry, either directly, such as for joining bridge components, or indirectly in the construction of earth moving machinery.

In particular, techniques developed for automotive manufacturing enable robots to handle an almost infinite variability of product sizes with excellent levels of accuracy, precision and repeatability. The development of smart laser and searching technologies, for example, makes it possible to search for the edge of a part and follow the edge or join as the robot welds, ensuring a good, clean join. To achieve this quality of weld manually, whilst not impossible, can be challenging and unlikely to be anywhere near as consistent requiring potential rework. Using a robot for arc welding tasks can also help to improve both health and safety and quality of the working environment.

Riveting and joining
The advent of self-piercing rivets in automotive was a real game changer and allowed mixed material to be joined together without the need for welding. This same technology is now used in many different applications in construction-related industries such as the scaffold manufacturer pictured. In this example, the wood boards and aluminum frames are riveted together using the same technology pioneered by Jaguar Land Rover for its XJ series nearly 20 years ago.

The capability of the technology means it can be readily applied to the building wall panels in construction, fixing plasterboard to metal framework.

Credit: Gramazio Kohler Research, ETH Zurich

—
With developments in path and force control, coupled with advances in areas such as robotic vision, robots can be used to reliably handle a variety of construction-related tasks for everything from individual parts through to complete structures.

A guide, not a template

Whilst there are significant similarities between the two industries, there are also significant differences as well. A key difference is the quantity and complexity of components entailed in building a house, with limited scope for the type of standardization employed in automotive manufacturing. Brent McPhail, CEO of Brave Controls in Canada, a system integrator specializing in automated manufacturing for modular prefabricated construction applications, likens the processes involved in pre-fabricating a home or other building to a snowflake.

"In traditional manufacturing, you first design a product then design a factory to mass produce it. In construction, the approach is what we call 'snowflake manufacturing'. You design a building then you build a factory that can accommodate changes in designs to build that 'snowflake' – before you have completed the first project you are already designing a multi-unit residential snowflake to run in the factory you have already built. Current manufacturing doesn't work that way."

Consequently while many of the processes used in automotive can be applied to construction, the actual way in which they are used will need to be carefully considered to ensure the correct end result can be achieved and that any variations in design can be realized during the manufacturing process.

"The automotive industry builds products, not snowflakes. For this reason, automotive manufacturing should be used as a guide, not a template."

Brent McPhail, CEO and founder, Brave Controls

Another important factor to remember is that while the automotive business is held up as the epitome of an automated production process, these plants are more than just automation. They have a full supporting infrastructure of roles including process engineering, industrial engineering, maintenance, production supervision and quality analysis, among others. It is these aspects that transform offsite production from a simple process of pre-fabrication in a large shed, into properly organized offsite manufacturing with the scope to replace manual work with structured automation and gain all the benefits of quality and productivity that it promises.

For a construction company to be able to make a similar transition into this space requires a fundamental shift in both mindset and behavior, moving them from the current norms associated with the building site to the brave new world of factory manufacturing.

How to achieve this shift is explored on page 42.

Benefits of robotic automation

Ultimately, the construction industry's ability to meet the challenges outlined in section 1 of this study will require a new approach that combines the possibilities of new technology with the imagination and inherent abilities of human workforces.

Capable of handling a wide range of tasks involved in construction applications, robots offer several advantages that can help to tackle many of the issues that are currently facing the industry. The first three factors listed below highlight the key point that robotic automation is not about replacing people, but rather finding ways to make their roles more productive, safer and interesting.

Enhanced productivity
A key benefit of robots is their ability to increase productivity. Enabling tasks to be carried out more quickly and efficiently, robots can help to substantially reduce production times, enabling more units to be produced within a given timeframe.

Using robots to either take over or assist with labor-intensive tasks can also help to improve worker productivity. Actions such as lifting, handling and processing can be carried out with the minimum of supervision, enabling workers to be deployed to other higher-value tasks that make better use of their abilities.

A good example is the building of reinforcement bar cages, which involves placing steel rods and tying them with steel wire. The time taken to conduct this traditionally manually intensive job can be greatly reduced by using robots – Swedish construction company Skanska, for example, has reduced time from 16 hours to just one hour per ton (see Skanska case study on page x). The result of this is that fewer people are now required to carry out rebar construction, allowing them to be used to carry out other work.

"A good automated project augments the capabilities of humans."

Brent McPhail, Brave Controls

The opportunity to use robotic automation to enable more effective utilization of existing labor resources workers will become increasingly more important as companies face the growing impact of worker shortages, especially for carrying out dirty, dangerous or tedious tasks that fewer and fewer people want to perform.

Another potential benefit of the improved productivity that can be achieved by using robots is the opportunity for companies to handle more projects. With more work carried out in less time, project times can be optimized, potentially allowing workers to be released to the next or other projects earlier.

Increased safety
The inherently dangerous nature of many construction-related tasks can present significant risks to workers. As a live production environment, a construction site presents a wide variety of risks, which can at best only ever be minimized.

With the lifting of heavy loads accounting for a significant percentage of worker injuries in construction applications, using robots can provide an ideal means of making working conditions safer. Loads can be safely lifted and transferred between stages without workers having to become involved, greatly minimizing the risk of being 'caught in, under or between' type injuries which accounted for 1,059 deaths in the industry between 2003 and 2015[30].

Using robots can also improve safety in other tasks as well. Operations such as cutting, welding and grinding can all be safely conducted by robots, with workers able to be used to supervise the processes and/or be used to perform other operations in the construction process.

The safety benefits of robots are valid for both off-site and on-site construction applications.

To help improve the safety of workers for example, Schindler Lifts recently deployed a robotic solution to carry out the installation of bolts and other essential fittings in elevator shafts. Elevator installations require large numbers of anchor bolts in the elevator shaft to fasten guide rails and access doors precisely and safely. The taller the building, the greater the number of bolts required.

Known as the Robotic Installation System for elevators (RISE), the solution, developed in conjunction with ETH Zurich, features an AI-enabled robot that travels up and down the shaft to carry out its work. After selecting the appropriate places to insert the bolts and fittings, the robot first drills holes and then fits the bolts into the walls of the shaft. With potentially hundreds of bolts that need to be inserted, the use of the robot helps to improve both safety and working conditions by reducing the need for workers to operate at extreme heights in confined spaces, which can quickly become dusty from the drilling operation.

Worker recruitment
The continued recruitment of workers into the construction industry is key to ensuring that it will be able to meet the demands placed on it, especially when it comes to meeting the challenges of urbanization and mass customization. With negative industry perceptions a major cause of the growing gap between people leaving the industry and new recruits entering it, either because of factors such as on-site safety, lack of innovation or lack of interest, young people especially need to be convinced that working in construction can offer an interesting, varied and safe career path.

For a generation that has been raised with technology and electronics, the use of robotic automation and building design and modelling software can present an attractive option that compares with the best that other industries such as automotive, aerospace and general manufacturing can offer.

By finding more ways to utilize this technology into its processes and generating new roles that allow its potential to be explored and exploited to the full, construction companies can successfully recruit new talent into the industry, creating a new breed of construction workers, engineers and architects who can help to bring new ideas and approaches to transforming sustainability and innovation.

Credit: Schindler Lifts / ETH Zurich

—
Developed in conjunction with ETH Zurich, Schindler Lifts' Robotic Installation System for elevators (RISE) solution features an AI-enabled robot that fits bolts and other essential fittings for elevator systems. Benefits include improved safety for human workers who no longer have to work at height in dusty and confined conditions.

Flexibility for mass customization
The flexibility and adaptability of robots makes them ideal for meeting the growing trend in mass customization. In comparison to fixed machines that can only be used for specific purposes, such as those used for cutting or drilling for example, robots can be set up with a variety of different programs that can be changed over as and when necessary to suit the specific requirements of a particular design or the varying characteristics of different types of workpiece.

This flexibility can make it possible to customize or adapt standard components, providing customers with a greater range of options and saving time and cost by eliminating the need to transfer items between different dedicated machines or make design modifications or alterations by hand.

For construction companies, having the capability to enable mass customization provides a much greater degree of freedom in terms of what can be made. This is particularly the case where robots are combined with building design software, with the robot's movements guided according to the specifics of the design.

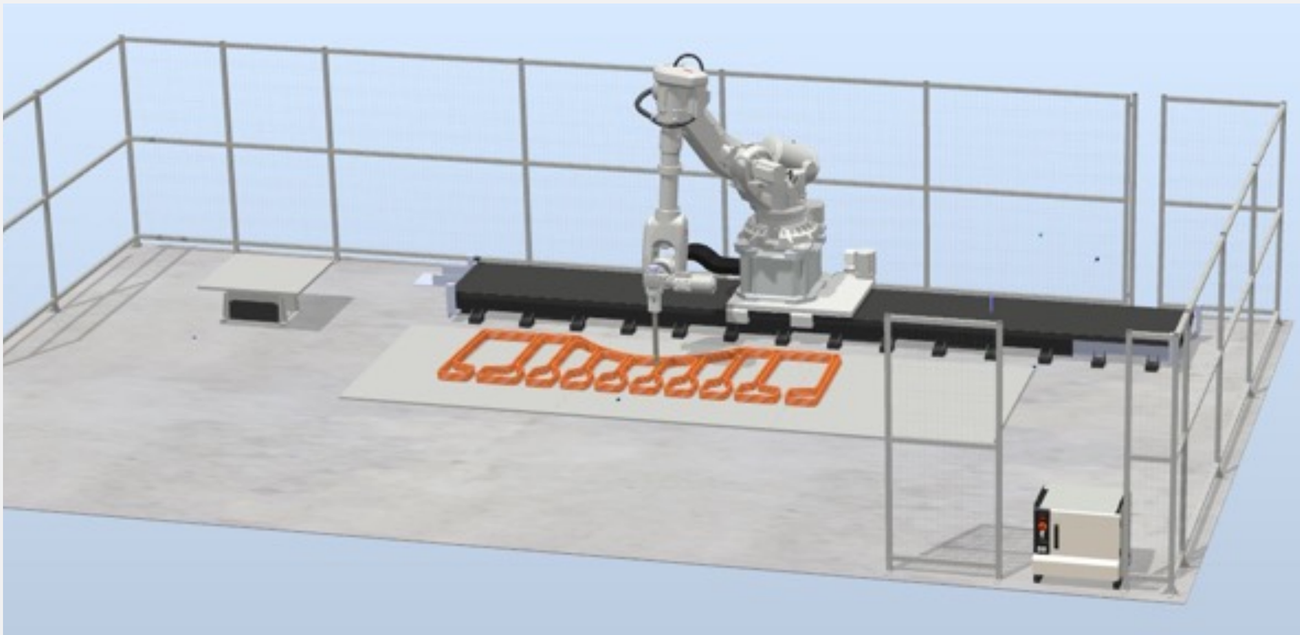
By using ABB's RobotStudio offline programming software, users can upload designs from their building design software, with the information being turned into commands that guide the movements of the robot. For companies this delivers the benefits of a design for manufacture operation, in which the design is directly translated in the product built by the robot, with no risk of error that can arise where workers misinterpret designs or variations appear due to imperfect measurement.

About RobotStudio®

ABB's simulation and offline programming software, RobotStudio, allows robot programming to be done on a PC, enabling tasks such as training, programming, and optimization to be carried out in a virtual environment without disturbing production.

The tool is built on the ABB Virtual Controller, an exact copy of the real software that runs ABB's robots in production. This allows very realistic simulations to be performed, using real robot programs and configuration files identical to those used on the shop floor.

RobotStudio comes with a full package of features and add-ons allowing for perfect offline simulation reducing risks, fastening the start-ups, shortening the changeovers and at the end increasing the productivity.



—
ABB's RobotStudio® offline programming software enables complete installations to be modeled and tested before they are applied in a real life manufacturing environment.

The benefits offered by ABB RobotStudio software is key to enabling companies like modular fabricated building manufacturers Intelligent City and Z Modular and companies such as XTreeE, which specializes in 3D printing, to test and refine set ups that will enable them to optimize their production set ups.

CASE STUDY - XTREEE

How XTreeE is using RobotStudio to help construction companies to think differently

In only five years, French company XtreeE has developed an industrialized solution to equip constructors with the technology to produce 3D printed buildings – and not just hardware. XtreeE offers a full solution, from digitalization of the project through to production.

The company uses ABB six-axis robots and RobotStudio® software as part of industrialized 3D printing solutions, used by construction companies to produce new types of design-led building elements and components that cannot be achieved using normal construction methods.

XtreeE's 3D printing solutions allow construction companies to produce unique designs that can be incorporated into building projects. This provides new possibilities for design for manufacture and new scope for the mass customization of structures at a competitive price.

The flexibility provided by the robots and RobotStudio® software is fundamental to meet the requirement for mass customization, with the robots able to be programmed to produce a range of different designs. This extreme flexibility is seen in XtreeE's eclectic range of projects, from a reception desk in Dubai, to artificial reefs off the coast of France.

Although some buildings have been printed directly on site, for Mallet, the era of complete on-site printing is not yet here: "For now we are just doing offsite production for it easily brings productivity, safety and quality, reducing onsite operations as much as possible Although we are looking at on-site 3D printing, it is not currently possible to get the necessary quality, productivity and security, as you would need to protect all elements around the 3D printer to secure and proof it against the weather."

—
XTreeE uses ABB's robots and RobotStudio® software as part of its industrialized 3D printing solutions, which it supplies to construction companies to help them explore new design and building possibilities.

Improved quality

A major benefit of robotic automation is its ability to improve quality. Once a robot is programmed and set into motion, it can continue to perform the same actions repeatedly with maximum consistency. Developments in robot motion control technology enable the robot to maintain accurate path control regardless of its speed, enabling high precision performance with reduced cycle times.

This technology, coupled with recent developments in robotic 3D quality inspection, has been key to the quality improvements witnessed in the automotive sector in particular, both in terms of vehicle assembly and the components produced by automotive tier suppliers. By ensuring that every part that is used in the production of vehicles is defect-free, automotive manufacturers have been able to deliver significantly improved levels of product quality.

In the context of modular fabrication or 3D printing processes, the tight control provided by motion control technology ensures that the robot follows the exact instructions from the building design, eliminating errors that could otherwise lead to deviations in measurements that could result in issues such as misaligned joints or defects in the shape of a finished product such as a façade or interior wall. By enabling this performance to be maintained and repeated for every component that is handled or every process, overall efficiency can be improved with fewer stoppages needed to correct performance or identify potential faults.

The application of robotic quality inspection techniques and technologies can also provide similar benefits as those achieved in the automotive industry, checking the quality of components and completed structures to help identify any defects.

The ability to achieve consistent and repeatable processes is a key enabler for sustainable construction, particularly when it comes to the minimization of waste. By ensuring that components or structures are produced right first time, the need for reworking is eliminated, producing savings in cost and time that can help to increase the likelihood of a project being completed on budget and to the required deadline – two areas where the construction industry has been traditionally weak.

> “If you want to build sustainably then you have to develop scalable processes”
>
> **Oliver David Krieg, Intelligent City**

—
Robotic 3D quality inspection is one example of a technology originally developed for the automotive industry that can be applied to help improve quality and productivity in construction applications.

Improved cost control and margins
The extent of the cost savings that can be achieved by using robotic automation will vary by application, depending on what is being built and the processes being used to build it.

In the case of Intelligent City, which uses robots guided by its Platform4Life (P4L) design software through ABB's RobotStudio® offline programming software, the improved performance that has been achieved translates to a 10 to 15 percent saving on its total build cost, with projected estimates of approximately 30 percent in longer term savings.

The cumulative impact of the various benefits outlined in this section can all help to make a significant contribution to improving cost control and increasing margins.

A more productive workforce assisted by robots can help to improve efficiency and reduce project times, thereby reducing project over-runs and enabling people to be deployed to perform tasks where they can maximize potential revenue per worker.

A good example is to compare the relative performance of the automotive and construction industries in terms of the labor cost as an overall percentage of the overall price charged for the completed product. With its advances in productivity, largely achieved through the application of the latest production technologies such as robots and 3D CAD software, the automotive industry has achieved a position where labor accounts for just 9 percent of the per unit price that can be charged for a vehicle. By comparison, the figure for the construction industry, which has a much lower take-up of new techniques and technologies, is around 50 percent.

From this example it can be seen how the application of robots to assist workers could help to improve labor productivity, offering the opportunity for greatly enhanced margins with labor accounting for far less of the chargeable price of a building.

Similarly, the ability to utilize production lines more effectively through increased flexibility and efficiency could help to achieve improved economies of scale, increasing choice for customers while helping to reduce the cost per unit produced.

The reduction of wastage and improvement in build quality can also have a major bearing on reducing costs and improving margins – in the case of quality, companies that can ensure a consistently high build quality are in a much better position to benefit both from improved reputation and the ability to command a higher price premium.

Credit: Intelligent City

—
Using robots has enabled Canadian modular fabrication company Intelligent City to achieve a 10 to 15 percent saving on its total build cost, with projected estimates of approximately 30 percent in longer term savings.

Changing mindset – moving from construction to manufacture

Steps for introducing robotic automation

With robotic automation still in the early stages of adoption in the construction industry, it can be difficult to know exactly where or how to start when it comes to deploying robots. This section aims to provide some outline advice for how to approach the use of robots, with tips on the steps to take and how to work with partners and technology providers such as ABB to achieve the best result.

Tip #1 – Think like a manufacturer

The many benefits of off-site construction make it an attractive proposition for meeting many of the challenges facing the construction industry. However, it is important to remember that it also requires a fundamentally different approach, requiring meticulous planning of all stages of the production set up to ensure that things run as smoothly as possible.

As such, it can pay to look to the manufacturing industry for inspiration. A conventional manufacturing production set up utilizes a structure that ensures that all aspects of the production process are understood and taken care of, with teams comprised of people responsible for specific aspects covering key areas such as:
- Process engineering
- Industrial engineering
- Maintenance engineering
- Material, planning and logistics (MP&L)
- Automation engineering
- Production supervision
- Quality analyst

Dividing the production process into these stages can help to ensure that all parts of the process are optimized to work together, avoiding issues such as bottlenecks that can occur in automated processes when products are processed quicker than the next stage can handle. Equally, having an effective maintenance regime in place, backed up by technical support, can help to minimize disruption caused by unplanned downtime by keeping equipment in good working order.

Another area that can be adopted from the manufacturing industry is the use of lean manufacturing principles to help optimize production performance. These principles define eight classic wastes that provide a useful guide when designing a factory set up:

Defects
Defects in a production process can have a significant impact on the time, cost and resources consumed in performing a particular task or set of tasks, as well as the overall quality management of the process itself. Potential sources of defects can include poorly designed processes, unclear or inadequate documentation around standards, quality and/or design changes, and incorrect inventory levels that do not match the demands of the production operation.

Excess processing
Excess processing is another sign of a badly designed process. Potential causes can include management or administration issues that can result in poor communication, overlapping responsibilities, and duplication of effort, increasing the likelihood of errors that can result in items having to be reprocessed or rejected as waste. It can also include the equipment being used to perform the task, which may not be adequate to achieve the required levels of quality or speed of production.

Over-production
Over-production is effectively caused by imbalances in the production line, resulting in parts reaching the next stage before they are needed. Potential sources can include poor or unreliable automation, delayed set-up times and badly managed production schedules.

If such problems are not addressed, issues including bottlenecks and excess work in progress can occur. In addition, there is also the increased risk of quality issues and excessive waste, as potential defects could end up being spotted later than they otherwise would if the production flow was correctly balanced.

Waiting
The problem of waiting occurs where the next stage in a process is ready before the one preceding it, effectively resulting in a situation where the production line becomes starved. As such, the situation can be caused by various factors, including people taking too long or being unavailable, downstream machinery taking too long to produce parts, or upstream machinery sitting idle.

Aside from delaying production, excessive waiting can incur additional time, cost and resources, with workers potentially having to work overtime to finish production of the outstanding components.

Also, in a similar way to over-production, imbalances in the production line that can lead to waiting can increase the risk of errors and increased wastage, as defects can easily get overlooked in the rush to compensate for lost time and production.

Transportation
An optimized production process should facilitate the easy movement or transportation of parts between different stages, allowing smooth processing of raw materials into finished goods, which can then be taken to a storage or distribution point for dispatch to the point of use.

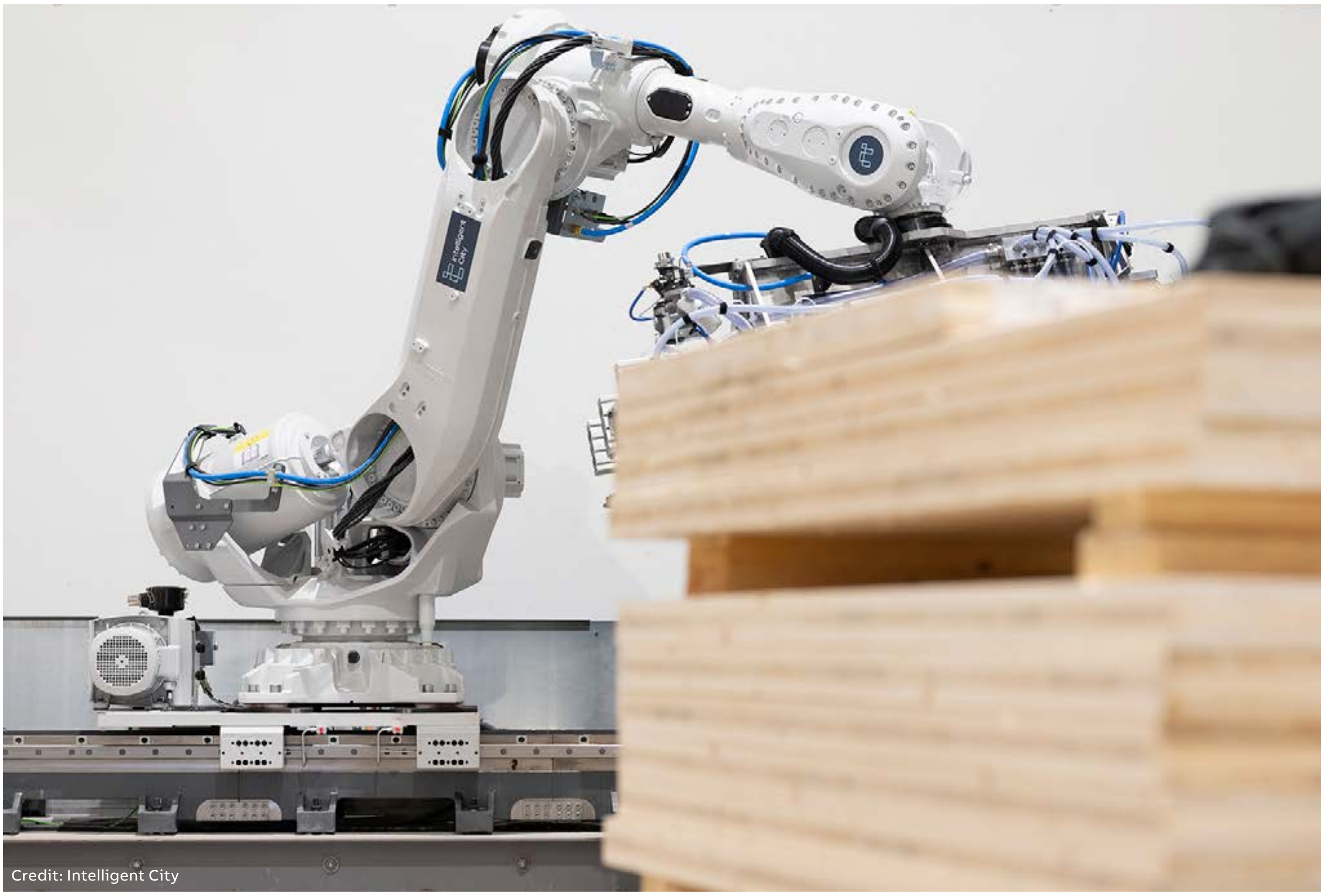
Poorly designed transportation processes often lead to production operations being too dispersed, which can result in issues including excessive wear and tear on conveying equipment and the costs involved in using additional labor to operate equipment such as forklift trucks.

Motion
Like automotive, a poorly designed production process can incur additional time, cost and resources by increasing the overall level of motion between stages, whether in terms of conveying parts between production stages or unnecessary or excessive physical movements such as reaching, lifting or bending. Ideally, a production line should be designed to ensure that elements are positioned in a way that makes best use of the space available and reduces the amount of effort needed for tasks to be carried out.

Inventory
Excessive inventory is also considered a waste as it represents additional costs in terms of purchasing and holding stock and the use of space for holding stock that could otherwise be utilized for production. Common causes include miscommunication between purchasing and manufacturing functions and poor forecasting that can lead to over-estimating and over-purchasing raw materials. It can also arise where more products are manufactured than are required, leading to excess stockholding of work in progress or finished goods.

Non-utilized talent
The effective utilization of a person's skills can be key to address many of the wastes listed above. In the context of automation, maximizing the talent of a particular individual or team of individuals can include giving them access to technologies such as robots that they can use to perform their roles more effectively, enabling them to develop their skills and allowing them to be more productive.

Using these principles as a guideline when designing a production line and all the associated processes that go with it can help to identify and minimize any functional or performance issues, increasing the likelihood of achieving an optimized manufacturing operation.


Credit: Intelligent City

—
Robots can be used to help enable fast and easy movement or transportation of parts between different stages.

Tip #2 –Know what you want and keep it manageable.

The need to prepare for the challenges facing the construction industry – particularly the onset of skills shortages – coupled with the need to keep up with companies that have already started to realize the benefits of using robots in construction applications, could make it tempting to try to jump ahead with a robotic automation project without first gaining the direct experience that can help maximize the chance of success.

In the words of Brent McPhail of Canadian systems integrator, Brave Controls, 'automation for construction is a paradigm shift at the highest level of how manufacturing is to be understood'. For this reason, it is important to make sure that you have the right production process in place from the very beginning with the processes and equipment, including robots, needed to achieve a successful operation.

In the context of construction, where the shape, size and design of structures can change from unit to unit, this involves not only finding ways to streamline production but also to build in the potential to handle as much additional variety as possible.

Central to this is the need to both understand from the outset what you want to achieve and to keep things manageable. For those who are new to robotic automation, this should include ensuring that the scale and ambition of an automation project is related to the level of experience they have in using robots.

For those with little or no experience in robotic automation, the best approach is to start by identifying which aspects of their operation can be automated most easily. The experience and expertise that is learned can then be used to develop more sophisticated solutions that either expand the utilization of the robotic solution or add further robots to other stages of the operation. This is the approach being taken by companies such as Skanska, which is exploring how robots can be applied to different construction tasks to help improve productivity, reduce costs and speed up project times.

For companies with more experience in using robots, additional possibilities can be explored, including looking for ways to combine robots with digital technologies such as building design software to enable them to adopt a complete end-to-end design for manufacture approach where all stages of the production process are automated.

Tip #3 – Reach out

The journey to robotic automation doesn't have to be undertaken single-handed. The steady emergence of projects looking for ways to utilize robots in construction applications means there is a growing ecosystem of organizations able to transfer their knowledge and experience.

Potential sources of information include academic institutions such as ETH Zurich University and Italian research laboratory, IndexLab, both of which have carried out extensive research and testing of a wide variety of robotic construction methods, from 3D printing to modular assembly and sustainable building techniques. Both organizations regularly advise construction companies and architects on how to use robots to help design and build new types of structures and how robotic technology can be used to achieve improved sustainability and reduced waste through the more effective use of materials.

Systems integrators with experience in implementing robotic solutions in manufacturing applications can be another great source of information and assistance. An example is Canada-based systems integrator, Brave Controls. As a developer and supplier of manufacturing automation solutions, Brave Control Solutions has a wealth of experience building such facilities as robotic welding cells, transfer presses and even automated parking garages. It is now bringing its expertise to bear on the automation of construction tasks, combining robotics and automation to streamline production of modular buildings. The company's solutions combine material handling, variable fixturing, mechanical fastening, welding and dispensing of adhesives and insulation to produce prefabricated construction modules with minimal human interaction.

CASE STUDY - BRAVE CONTROL SOLUTIONS

The brave approach to construction automation

As a developer and supplier of manufacturing automation solutions, Brave Control Solutions is now bringing its expertise to bear on the automation of construction tasks, combining robotics and automation to streamline production of modular buildings. The company's solutions combine material handling, variable fixturing, mechanical fastening, welding and dispensing of adhesives and insulation to produce prefabricated construction modules with minimal human interaction.

For Brave, a good solution for its construction industry customers is one that matches the needs and capabilities of the company: "The right solution is the one you can support. We aim to match automation technologies to where the company is in its readiness for automation – this ensures we don't deliver a solution that a user can't use or find application for."

It's not just the fabric of the buildings themselves that is feeling the impact. All the services that bring life to the hotel or home are also part of the potential of automation. "Mechanical, electrical and plumbing suppliers are now doing sub-assemblies to build their installations. We are looking at pipe cutting machines and fitting/assembling machines and are working with ABB to develop solutions using CAD2FAB to enable this - things that can be made in a factory using techniques that are available now but in a much more flexible way."

Working with ABB provides Brave with the ability to prove to clients what automation can do: "ABB's RobotStudio is an enabling technology to help demonstrate techniques to clients. For example, for inserting windows, we can use RobotStudio to demonstrate how you are going to make it work. This is important because the construction worker won't be able to envisage what an automated system could do.

ABB is a major part of the Brave approach to automation. "Our main reason for choosing ABB was the RAPID programming language – robots were designed to be customized. It enables users to create and issue commands that allow the robots to do new things, to try crazy things and do things that other robotic packages wouldn't allow. Essentially, we feel that Brave cannot scale without ABB."

Another option is partnering with a company or companies that already have experience in applying robotic automation to construction tasks. Working with these companies can provide an alternative to developing solutions in-house. Furthermore, given the temporary nature of construction projects, having the option of using a partner helps to answer the problem of what to do with the robots once the project is completed. A good example of a company that works in partnership is French 3D printing specialist, XTreeE.

Since 2016, XTreeE has developed an industrialized solution to equip constructors with the technology to produce 3D printed buildings, supplying both the robots and the software needed to create a wide variety of different structures. XTReeE's 3D printing solutions allow construction companies to produce unique designs that can be incorporated into building projects. This provides new possibilities for design for manufacture and new scope for the mass customization of structures at a competitive price.

For off-site modular prefabrication applications, there is also the growing option of 'factory in the box' solutions, where companies that have successfully built robotic production lines to produce modular buildings provide other companies with access to their know-how to allow them to leapfrog the process of researching and developing their own robotic production lines. An example is US-based company Z Modular, which specializes in manufacturing modular steel frame structures for residential, commercial and healthcare developments. Part of Zekelman Industries, Z Modular has created a fully-integrated, open-source building ecosystem that provides access to its production process, technology and expertise for other companies to use in their own operations.

"We need big construction companies to believe in the future of modular and prove it, but architecture is usually very slow to change. Once big players are on board, then it can grow by getting other smaller companies involved – a cottage industry of smaller builders, developing new ways of streamlining. However, first we must prove the ground."

David Warne, VP Architecture and Design for Zekelman Industries

Finally, for ideas about what robotic solutions are available, robot manufacturers such as ABB can provide an invaluable source of information. With experience gained from thousands of manufacturing applications across a wide range of industrial sectors, ABB can help to identify the best type of robotic solution for your application, with a wide range of hardware and software options that can be applied for tasks on a building site, in a modular fabrication plant or for a 3D printing project.

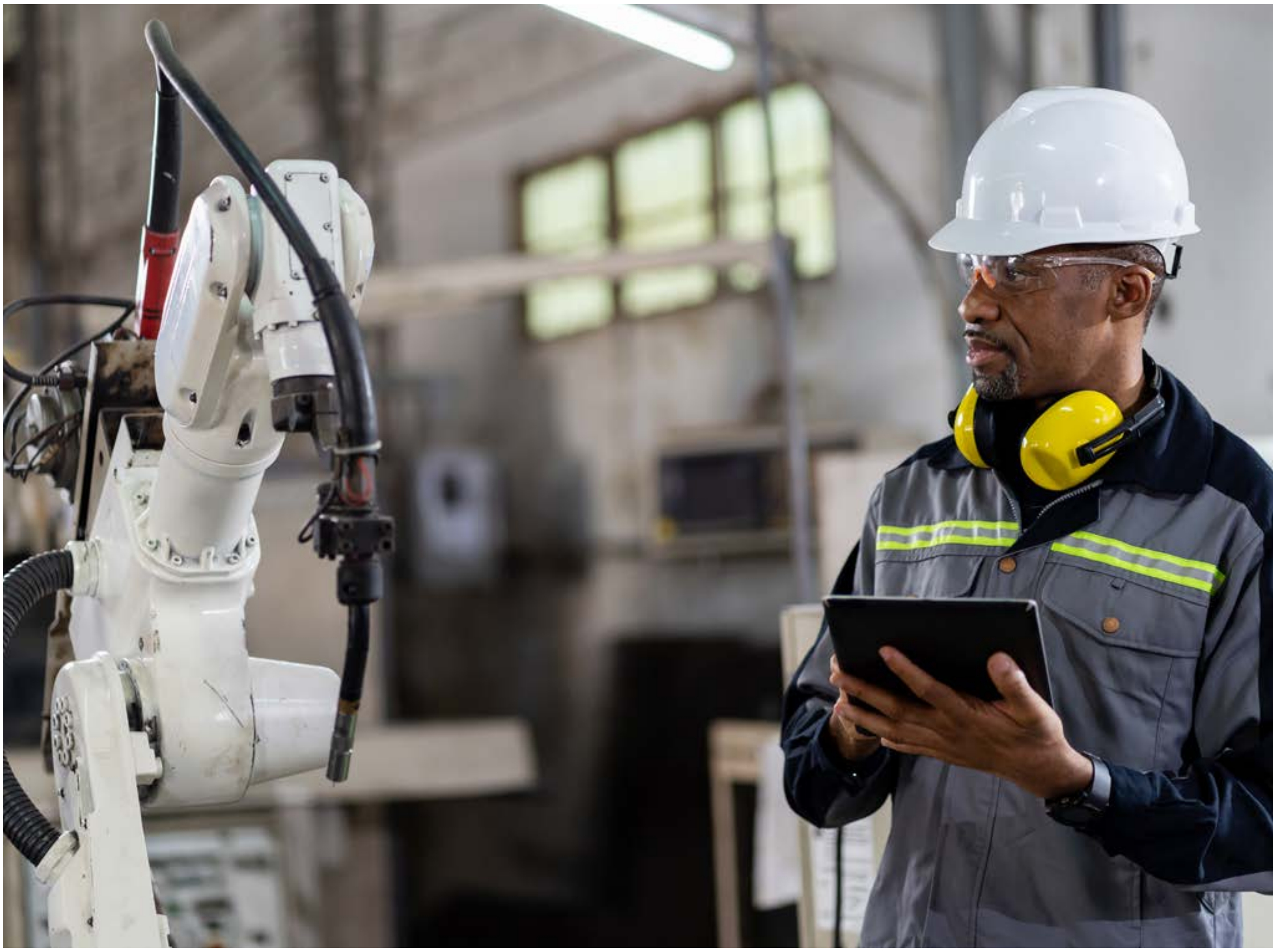
Tip #4 – Automate responsibly

The best robotic automation projects are ones that combine the inherent benefits of robots such as speed, flexibility accuracy, consistency with the adaptability, imagination, and intelligence of human workers. The ability of robotic automation to enhance the productivity of human workers has been well proven by the automotive industry, which has used the technology to help carry out tasks that people find either difficult or tedious to carry out.

"The best automated solutions are the ones where the humans do the work that humans do best and the robots do the work that robots are the best at. When you mix those up is usually when you run into issues."

Brent McPhail, CEO and founder, Brave Controls

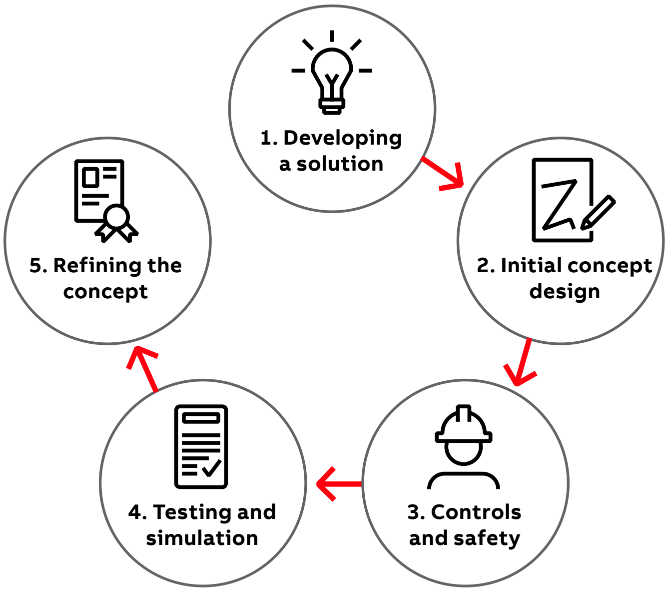
When introducing robotic automation, it is important to see how automation can be used to address both the strengths and weaknesses of your people. The chosen solution should ideally augment their capabilities and empower them, giving them both a tool that they can use to do their job more effectively and a potential avenue for improving their skills, such as through programming the robot or working on other tasks.



—
A well-designed robotic solution should augment the capabilities of manual workers by enabling them to do their job more effectively and develop their skill sets.

Tips for specifying and designing a robotic solution

In matching an automation solution to the demands of an application, it can be useful to adopt an iterative process to help guide the specification, design and implementation stages. The diagram below outlines the recommended steps for gauging the potential for robotic automation and selecting the appropriate solution for an application.



Step 1 – Develop your solution

A successful robot installation starts with a proper specification. Knowing exactly what you need, and communicating it to a supplier, will help to avoid problems caused by miscommunication or a mismatch in the capability of your system versus your requirements.

Factors to consider at this point include the types of products you need the robot to handle, how long you want it to operate and any special conditions relating to the application itself, such as whether the robot will be operating in a sterile environment, for example.

It can also be helpful to speak to anyone involved with the process that you are seeking to automate. Doing this can often reveal nuances in the production process that you might not be aware of that could have a material impact on the specification and eventual efficiency of a robotic system.

Once equipped with this information, a target cycle time can then start to be calculated, which can be used to assist in the overall design of the system.

If this is your first experience of robotic automation, help is available from both ABB and its system integrator partners through the ABB Value Provider network to help you develop a robot solution that meets your needs.

Step 2 – Create your initial concept design

Very often the information you need for this stage will already exist, either in your own organization or in the wider market. In such cases, it is relatively easy to get an idea of what is being asked for and to start to devise a solution by developing an outline concept based on the desired installation. This can then be tailored to meet the requirements of the application being addressed.

Where additional equipment may be needed, or where a different or bespoke solution may be required, it is worth consulting with experts and / or suppliers who can advise on the best way to tackle a particular problem. These organizations represent a fount of knowledge and can often use their experience to recommend the best way to tackle a given problem.

Again, you should consider enlisting the help of a manufacturer such as ABB and/or a systems integrator to provide expert advice and input on shaping the concept.

Step 3 - Consider safety and control

Recent developments in robot control technology have enabled greater collaboration between robots and manual workers. The latest proximity detection software technology, for example, enables operators and robots to work safely in the same area by replacing mechanical safeguarding equipment with electronic motion detection and prevention measures, which can be reconfigured if required. In the event of an unanticipated obstacle being detected, the robot is automatically brought to an instant stop. By reducing the requirement for conventional guarding equipment, this technology helps to cut both the cost of an installation and the overall footprint, making them particularly ideal for locations where space is at a premium.

Another point to consider is the type of control equipment that will be used to control the robot. Many manufacturers, ABB included, offer application software packages that can help to greatly simplify the process of installing and setting up a robot. Features such as drag-and-drop equipment selection and offline simulation and testing, for example, help to remove much of the complexity and risk at the set-up stage.

Developments in HMI and integration technology are also presenting new methods for robot control. Many robot controllers feature their own easy-to-use HMIs, either built into the controller itself or using hand-held teach pendants, which allow operators to easily program and configure a robot without the need for specialist programming skills.

Step 4 - Testing and simulation

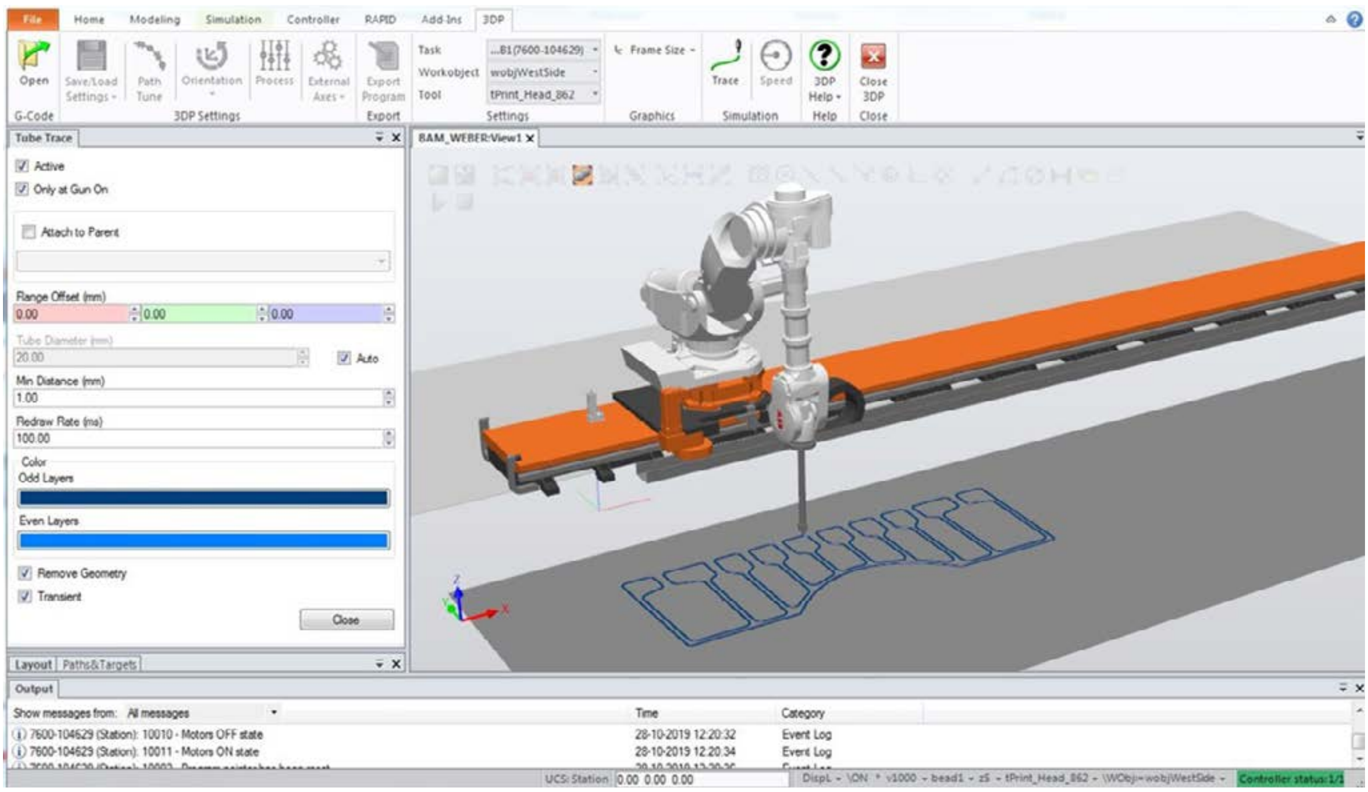
A lingering concern when it comes to robotic automation has always been the ability to prove that it can deliver real benefits, both in terms of performance and return on investment. Offline simulation tools, such as ABB's RobotStudio® software, enable entire installations to be created, tested, and refined in a virtual environment before they are put into action. This software can be used to model anything from an individual robot or complete robot cell through to an entire installation, showing the potential impact of a robot with other processes and enabling the development of solutions that will fit comfortably within the space available.

Step 5 - Refine the concept

Conducting the steps detailed above should start to give some idea of the efficiency of the robot installation, including whether it will be achieved or whether anything further needs to be done to achieve it. Using the information gathered, it should be possible to begin to calculate some potential cost savings, which in turn can be used to derive a likely return on investment figure.

In many cases, the process outlined will invariably reveal scope for changes or improvements that can be used to help further refine an initial concept.

A key factor to bear in mind is the need to cope with any future changes. Wherever possible, it is advisable to anticipate and plan in any likely changes from the outset to maximize the effectiveness of your installation and ensure that your robot will be fully utilized. This will help to provide the flexibility both to accommodate future changes and to add extra tasks if required.



—

The ability to test and simulate virtually is a key benefit of ABB's RobotStudio programming software, enabling operators to find the optimum solution before applying it in a real-life production environment.

The new construction ecosystem
How can the industry work together to make robotic automation happen?

For an industry that has remained largely unchanged for decades, the construction sector will need to reshape itself to adapt successfully to the challenges it now faces, both in terms of meeting the megatrends identified at the start of this document and in adapting the new technologies that will help to achieve this.

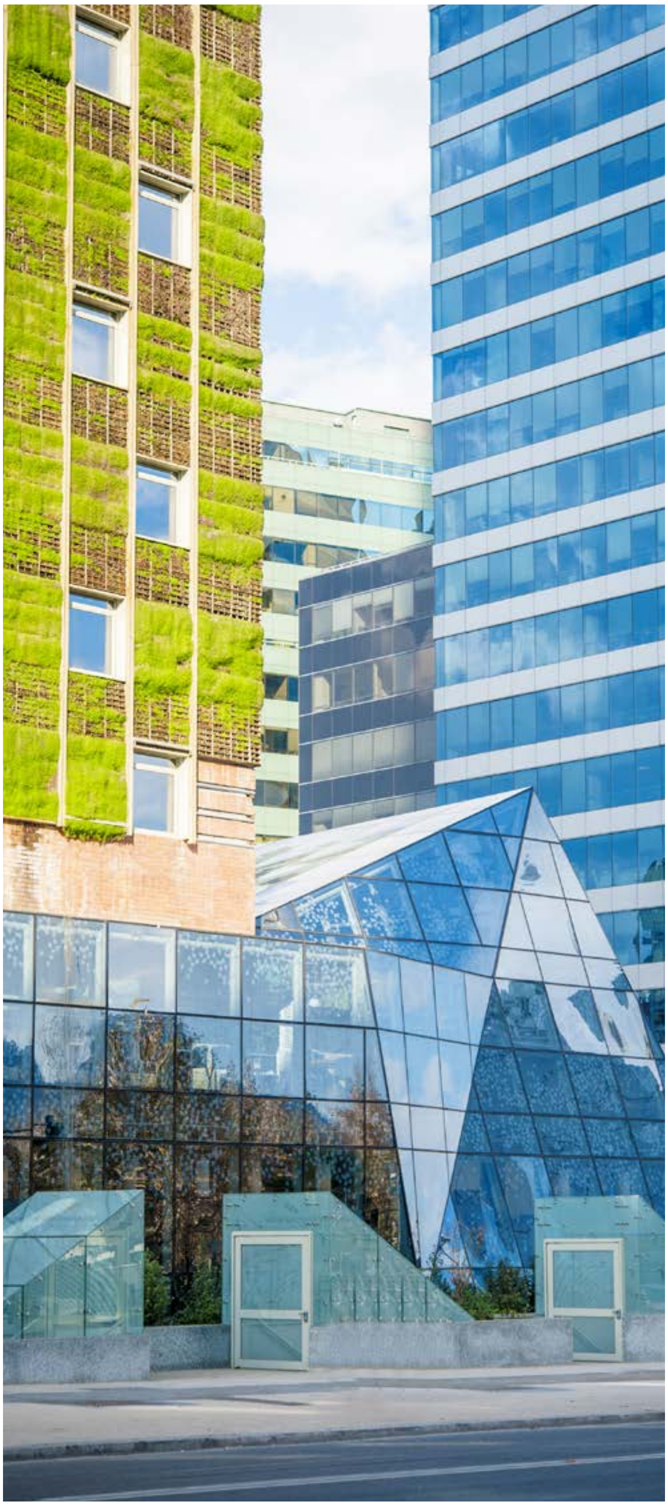
As such, the old model of divided disciplines of architects, contractors, sub-contractors, trades and component and technology suppliers is likely to be replaced by one where parties collaborate in a symbiotic and mutually beneficial relationship, combining their expertise and resources.

French 3D printing company XTreeE, for example, uses the approach of creating specific ecosystems for the different projects it works on. With a major cement producer and construction company as key investors, the company utilizes the skills of different parties including architects, civil engineers, constructors, academia and technology providers, including ABB, to help deliver the right solution for a particular project.

"We don't want to be disruptive. Instead, we need to help architects evolve and understand, to learn how to use the solution and how to make the profession itself evolve. That is why we are working with architects, civil engineers, and constructors – because that's the way the market is. We prefer to teach them what we know and to learn from them, changing the industry from the inside."

Alban Mallet, XTReeE

As the industry increasingly looks to robotic automation, such partnerships are likely to become more widespread with a greater range of collaboration between different parties, potentially including ones from outside the conventional industry mix such as tech companies like Google[31], to help achieve the quantity and quality of sustainable buildings needed to meet steadily growing demand.



—
Greater collaboration between the different parties involved in the construction value chain will be key to delivering the sustainable buildings of the future.

Enabling knowledge transfer

A key enabler for collaboration is the transfer of specialist knowledge and experience between parties. As outlined above, key parties in the construction mix are already starting to find ways to work together as they also find ways to tackle their own challenges.

Part of the reason for the cement major's investment in XTreeE, for example, was to find ways for it to adapt the application for its product in a market that is being changed by regulation. As a major energy user that accounts for around five percent of global carbon dioxide emissions, the cement industry has been tasked with reducing its CO_2 emissions by 20-to-25 percent by 2030, requiring it to find new ways to reduce the energy it uses.

With 3D printing able to use a variety of supplementary substances to create more sustainable cement mixes, working with a 3D printing specialist to find new applications for its product can help it to find a new way forward as the industry moves towards achieving greater sustainability.

As a technology provider, ABB can also help to facilitate the transfer of knowledge by helping companies throughout the construction value chain find ways to utilize robotic automation. This can include not only providing robot hardware and software, but also helping to establish the necessary ecosystems needed to help develop them into solutions.

- **Universities** are now adding robotics and automation into their learning programs to help students understand how to produce smart designs and turn them into real solutions that take advantage of efficient manufacturing processes and enable standardization and modularity.

- **Architects & designers** are partnering with automation companies to help them understand the manufacturing processes involved in producing advanced and new shapes, for instance moving away from traditional squared walls, cylindrical pillars and creating more sustainable components that use less material.

- R&D teams of **raw material suppliers** such as cement companies are looking into new concepts of how their materials can be used more efficiently through the use of robotics, such as concrete 3D printing, to help reduce the CO_2 emissions footprint in their own manufacturing processes.

- **General contractors** must become more efficient and more profitable, increase quality and reduce delivery times. All of these can be achieved by the use of robots both on and offsite, while also helping to less disrupt the surrounding communities where houses and buildings are erected.

- **Machinery manufacturers** are adding vision guidance and Artificial Intelligence (AI) to their machinery enabling autonomous vehicles to do the work, reducing risks and accidents for workers in this very often dangerous environment.

- And last, but not least, **software companies** are developing digital tools to help the construction industry have a better control of assets and processes, leading to a "Just in Time" manufacturing concept, tracking material coming into the construction sites, generating Digital Twins and CAD-to-Path processes in an efficient way. This strengthens the concept of quality control and assurance, so every component can be checked for integrity of shapes, geometries, sizes, location of holes.

CASE STUDY – ETH ZURICH

Research lays the foundations of robotic construction

The site of the world's first architectural robotic laboratory, which is now helping transform the way architects think about construction, ETH Zurich (Swiss Federal Institute of Technology) started by looking at the changes in architectural production requirements that result from introducing robotic fabrication techniques. How does robotic fabrication with bricks, concrete, steel and timber components expand the possibilities for construction and how does it establish a unique architectural expression?

Dr Ammar Mirjan, at the Chair of Architecture and Digital Fabrication (Gramazio Kohler Research) at ETH Zurich, says: "Contrary to production machines that are designed for specific applications, as for example with CNC milling machine, a robot offers flexibility and versatility. Instead of having to operate in predefined tasks, robotic fabrication can be freely designed to a given material or construction system.

ETH Zurich is a leader in the development of robotic solutions for construction and architecture. It uses ABB robots to help create and test new approaches and teach the next generation of architects, engineers and builders. Its aim is to spread the word about how robotics can be used to build new types of structures and enable new approaches to design and building.

One result of the research at ETH Zurich is the DFAB HOUSE, a dwelling that it is not only digitally designed and planned, but also built using predominantly digital processes, both on-site and off-site.

The house brings together novel digital building processes from different chairs at ETH Zurich for the first time: The In situ Fabricator, a versatile autonomous on-site construction robot; Mesh Mould, a formwork-free, robotic process for steel-reinforced concrete structures; Smart Dynamic Casting, an automated concrete slip-forming process; Smart Slab, integrated ceiling slabs fabricated with 3D-printed formwork; and Spatial Timber Assemblies, a robotically fabricated timber structure.

Bringing these processes together into the construction of one building gives access to the benefits from digital design, planning and fabrication: design flexibility, economy in materials, time and cost efficiency, and improved quality control.

Credit: Gramazio Kohler Research, ETH Zurich

—
ETH Zurich's DFAB HOUSE melds a variety of different construction techniques into a single structure to demonstrate what can be achieved by combing digital design with robotic automation.

Mirjan sees architecture and construction as very closely interlinked, with the way things are built also changing the aesthetics of the design. “The possibility of directly fabricating building components described in the computer expands the spectrum of possibilities for construction and, by incorporating the constructive constraints, actually connects the design process directly to the later physical realisation. The implementation of the production logic into the design process can lead to new forms of architectural expressions.”

As an educational institute, it is not just architects and the industry that ETH Zurich is helping today learn new possibilities – the next generation is equally, if not more important.

“Introducing robotic fabrication processes to architecture students has developed a lot in the last ten years,” says Mirjan. “Back then, custom processes and design tools needed to be developed which required a lot of technical knowledge. Today, with new interfaces such as visual programming, robotic system are more accessible to students, allowing them to prototype, experiment and link their designs with the robot.”

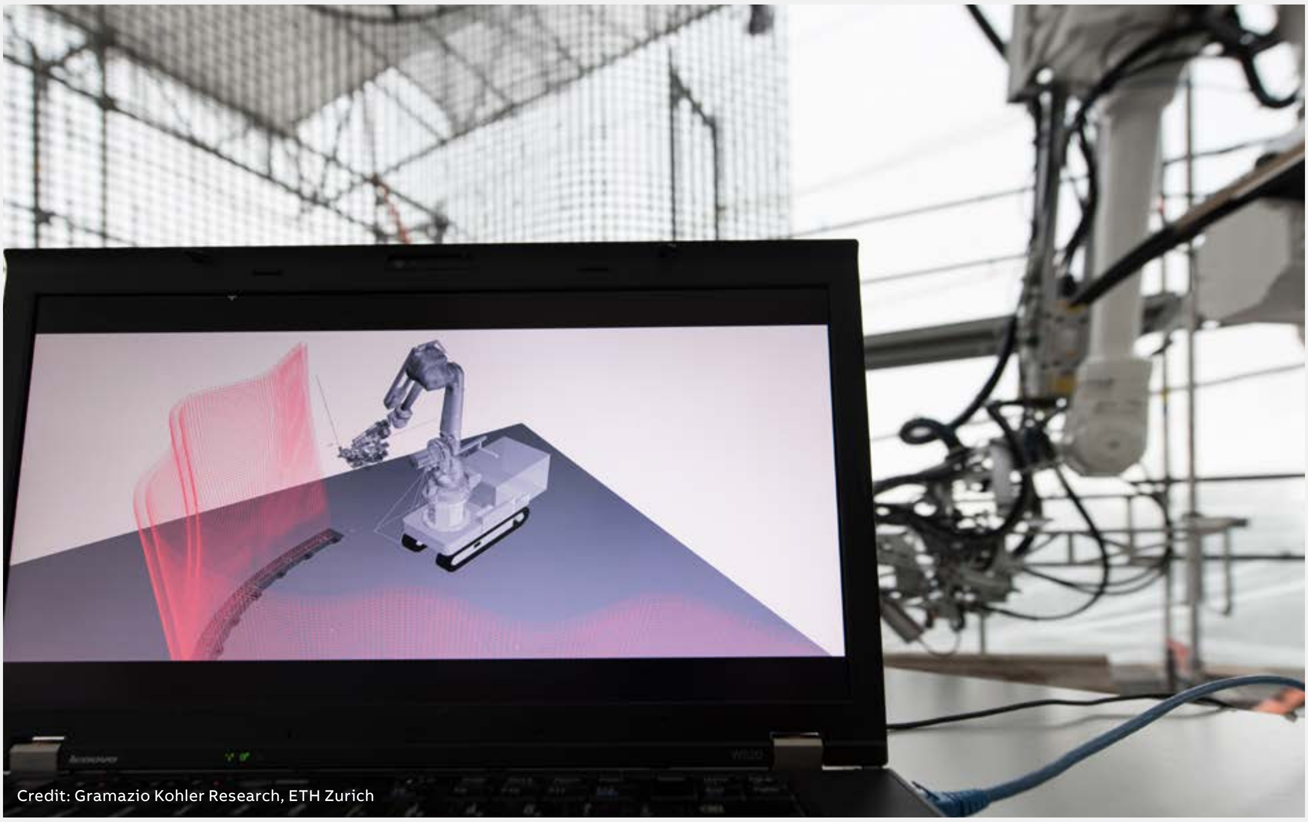
Describing how he sees the current state of play of robotics in automation, Mirjan recognises that certain techniques, such as timber prefabrication, are applied in the construction industry already - using robots on the construction site is starting to happen but is still very much a topic being researched at moment.

One area that Mirjan does see as promising is the use of more sensing and feedback in fabrication processes. “Working with real time observation will change the way we build. For example, we could have a 3D model sent to the robot, allowing it to use feedback to adapt its tasks while building and correcting errors.”

“It is also possible to equip existing construction machines with additional sensors in order to digitalize them and allowing them to be directly linked to a computational design blueprint,” adds Mirjan.

Thinking of the future, Mirjan is convinced that robots can only play a growing role in construction but warns they are not a panacea: “The cheaper robots get, the more they can be applied but there is also the factor of the human involvement in the processes. The two are complementary and mutually supportive and it is an illusion that you could construct a building using robots alone.”

ETH Zurich and Mirjan see the future as one of continuous digital workflow through planning and construction, where all stakeholders are involved. “There are still a lot of gaps between stakeholders in the construction process,” he adds. “Rather than standardising buildings to make them more manageable, the digitalisation of the construction industry using robotic fabrication processes and computational design should foster creativity, flexibility and open-ended architectural expressions.”



Credit: Gramazio Kohler Research, ETH Zurich

—
Tomorrow's architects will increasingly be able to achieve an exciting new range of possibilities delivered by digital technologies and robots.

Summary – a change waiting to happen

Sources from academia, architecture, and construction as part of the research phase of this document generally agreed that while change is necessary for the industry to adapt, the take-up of robotic automation in the construction sector will initially involve different companies trialing different solutions and using their experience to guide their future projects. Importantly, there are still several hurdles that also need to be overcome before robots can enter the mainstream, particularly with respect to their application for on-site construction.

What is certain is that as the megatrends of labor shortages, changes in consumer demand, environmental pressures and the need to house more people more quickly conspire to challenge the industry, robots will present an increasingly attractive option for handling a growing range of tasks. As the need to embrace robotic automation becomes greater, it will provide the incentives for the development of new solutions to address existing hurdles and drive greater innovation in the industry.

With the potential to transform productivity, reduce waste, increase choice and enable construction of a wide range of sustainable structures, robots represent the future of the global building industry.

By **2030**

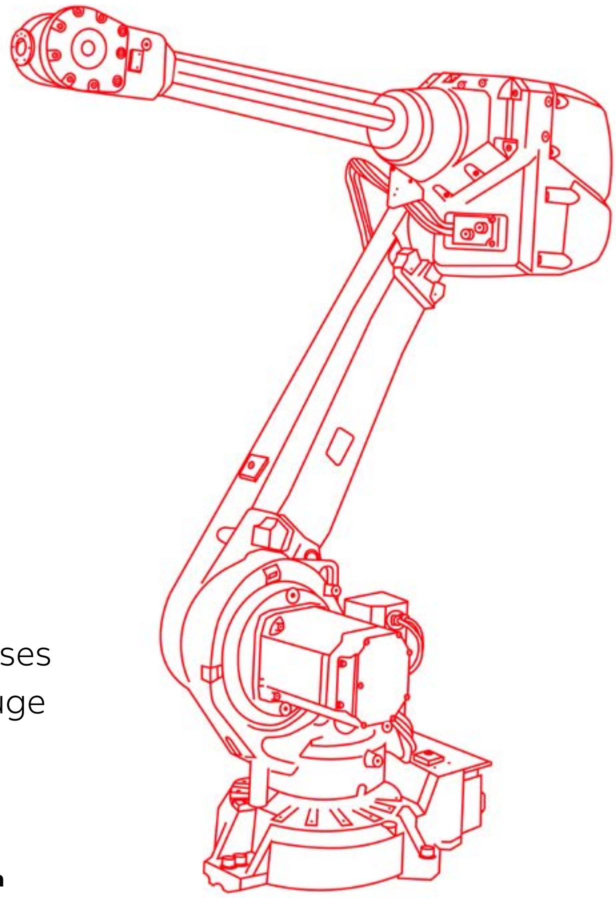
ABB predicts a significant change

81%

81% are likely to introduce, or increase, their use of robots in the next 10 years.

"With so few construction businesses using automation today, there's huge potential for us to transform the industry through robotics."

Sami Atiya
President of ABB Robotics & Discrete Automation



Sources

1. Global Construction Perspectives and Oxford Economics – Global construction market to grow $8 trillion by 2030: driven by China, US and India

2. United Nations – Department of Economic and Social Affairs – 68% of the world population projected to live in urban areas by 2050, says UN

3. Chartered Institute of Building (CIOB) – The real face of construction 2020

4. United Nations – Department of Economic and Social Affairs – World Population Prospects 2019

5. McKinsey & Company – The next normal in construction: How disruption is reshaping the world's largest ecosystem

6. Turner & Townsend – International construction market survey 2019

7. Juricic, Galić, Marenjak, published Buildings, 22nd Dec 2020 – Review of the Construction Labor Demand and Shortages in the EU, pp. 12.

8. International Labor Organization – Construction: a hazardous work

9. ADP Spark – Construction grows, but baby boomers retiring leaves gap

10. UK Government Migration Advisory Committee – EEA workers in the UK labor market: interim update

11. pwc – A new urban agenda: accommodating 2 billion new urban citizens

12. International Energy Agency (IEA) – Global status report for buildings and construction 2019

13. United Nations Environment Program (UNEP) – Energy efficiency for buildings

14. Construction Online – How can we make construction sites more sustainable?

15. Construction Executive – Ten benefits of sustainable construction

16. McKinsey & Company – Reinventing construction: a route to higher productivity

17. Science Direct – Waste: A handbook for management

18. Boston Consulting Group (BCG) – The offsite revolution in construction

19. Charted Institute of Building (CIOB) – Improving quality in the built environment

20. Turner & Townsend – International construction market survey 2019

21. Building magazine, 23rd September 2019 – The sky's the limit: See the world's tallest modular tower in Croydon

22. McKinsey & Company – The impact and opportunities of automation in construction

23. Boston Consulting Group (BCG) – The Offsite Revolution in Construction

24. Boston Consulting Group (BCG) – The Offsite Revolution in Construction

25. Statista.com – Number of robots per 10,000 workers in the construction industry in selected European countries in 2017

26. International Federation of Robotics (IFR) – Robot race: the world's top 10 automated countries

27. GovInsider, 19th July 2019 – Exclusive: Singapore plans for construction robots – how the Building and Construction Authority is going for a digital push

28. Low Carbon Buildings, 26th March 2019 – Global efforts to cut construction industry waste and improve sustainability

29. ABB – ABB robotic automation survey 2020

30. Safety & Health, 27th January 2019 – Prevent caught-in, caught-between incidents

31. Triumph, 1st July 2019 – Google to invest $1 billion in Bay Area. What does this mean for modular housing?

ABB Robotics
For your local ABB contact, visit:
www.abb.com/contacts

For more product information, visit:
www.abb.com/robotics