AUTODESK. Make anything.

INDUSTRIALIZED CONSTRUCTION
IN ACADEMIA

The secret of change is to focus all your energy not on fighting the old, but on building the new.

—Dan Millman

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FOREWORD

Industrialized construction: how it impacts academia and industry

Industrialized construction (IC) promotes the advancement of construction processes by employing mechanization and automation. There are several intents behind the industrialization of construction, such as increasing labor productivity, substituting labor-intensive processes with machines, fast-tracking the rate of construction, commissioning new projects more quickly, reducing costs, lean construction, incorporating augmented reality (AR) and virtual reality (VR), and improving overall quality.[5] Industrialization is a significant trend of scientific and technical advancement in construction as technology is changing how we design, manufacture, and assemble. It was projected that by 2035 the majority of buildings will be constructed using IC, as manufacturing and construction converge; utilizing manufacturing's expertise in mass production and construction's ability to design and build a highly customized complex product. With these new radical approaches it is imperative that industry, academia, and government unite to help ensure architecture, engineering, and construction (AEC) programs align to produce highly skilled construction professionals with deeper insight in building information modeling (BIM) and IC. Whether academia offers new specializations or master programs, there should be a way to ensure this digital age is equipped for this paradigm shift.

Industrialized construction (IC) is a construction system that uses more innovative and integrated techniques that connect the design-to-make process.

INTRODUCTION

The construction industry is among the least digitized sectors around, with almost all its processes being repetitive and labor-intensive. A study by McKinsey showed that large projects typically extend 20 percent beyond the initial project completion date, and they are usually up to 80 percent over budget. Also, the study shows an industry trend of low or non-existent productivity development as well as low quality and higher costs of building.[1] The slow rate at which the construction industry has adopted process and technology innovations can in part be attributed to these industry problems.

However, the construction industry is ripe for disruption. The industry has progressed vastly through the years, and the future of design and construction will require all project stakeholders—owners, designers, engineers, fabricators, and contractors—to adopt new methodologies in their processes, regulations, and skill sets to thrive in this era of digitization. Industrialized construction has been recommended as an answer to the declining level of productivity and poor quality of assets in the industry.[2]

Currently, construction management schools offer IC courses in upper-division or even masters levels. These schools focus primarily on introducing students to jobsite craft skills, such as manual wood framing to build a house. What if the same amount attention was provided to introducing students to IC workflows?

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CURRENT TRENDS IN IC

The process of IC includes extensive use of advanced technology in activities ranging from the prefabrication of large building elements in off-site factories to the adaptation of construction into a mechanized and seamless process of assembly and installation of these prefabricated assemblies and parts.[3] A combination of several technology advancements can be incorporated into construction processes to transform design and manufacturing by circumventing the issues that define the construction industry today.

GOAL LIST

- Increase labor productivity
- Substitute labor-intensive processes with machines
- Fast-track the rate of construction
- Commission new projects more quickly
- Reduce costs
- Improve overall quality and sustainability
- Make customization affordable

FIVE TRENDS

Prefabrication

Off-site construction of building elements and assemblies in factories

Additive Manufacturing

3D printing of objects by building up structures from small deposits of materials

Robotics

Designing, building, and applying robots to perform work

Big Data, AI, and Predictive Analysis

Predict the future of construction by mining data generated from future projects while integrating lean construction principles

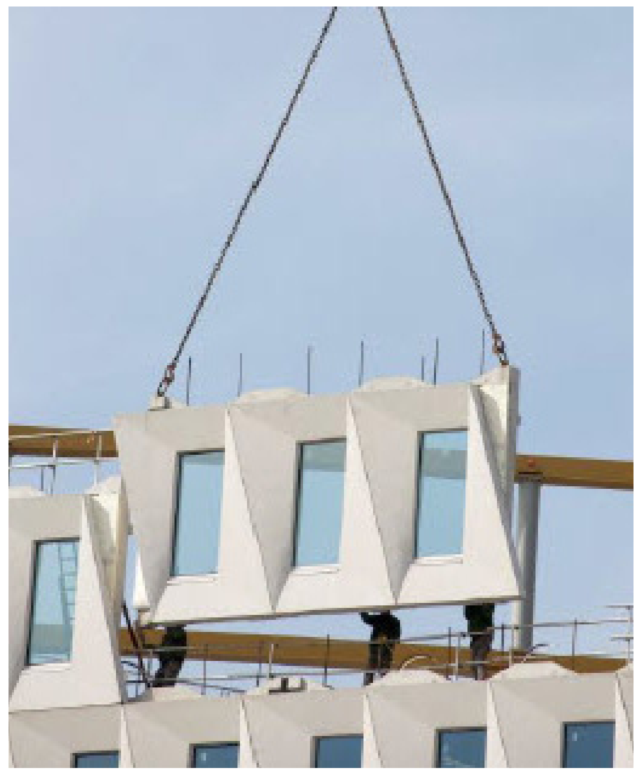
Internet of Things

Network of objects incorporated in the building systems

Prefabrication

Prefabrication is the off-site construction of building elements and assemblies in a factory, which are then transported to a site for assembly and installation. Prefabrication in construction dates as far back as the mid-1800s; however, it has yet to attain widespread adoption in the industry.[4] Prefabrication systems can be split into two categories: modular and panelized construction.[5] In modular construction, the building systems are essentially constructed in a factory as separate box-like modules and then transported and installed on-site. However, in panelized construction, also known as Panelization, the structural components of the building are constructed in a factory and conveyed on-site for assembly.[5]

Modular construction



Panelized construction

The advantages of prefabrication tackle many of the problems associated with traditional construction methods, such as skilled intensive labor, variable quality, product and process inefficiencies, and high environmental impacts. Because the construction of building systems is completed in a factory, it enables the use of automated machinery, which prevents project delays due to unavailability of skilled labor. Also, employing innovative equipment results in improved product quality, improved efficiency, and ultimately reduced costs. Performing construction in such a controlled environment reduces construction waste through environmentally sustainable processes.[4]

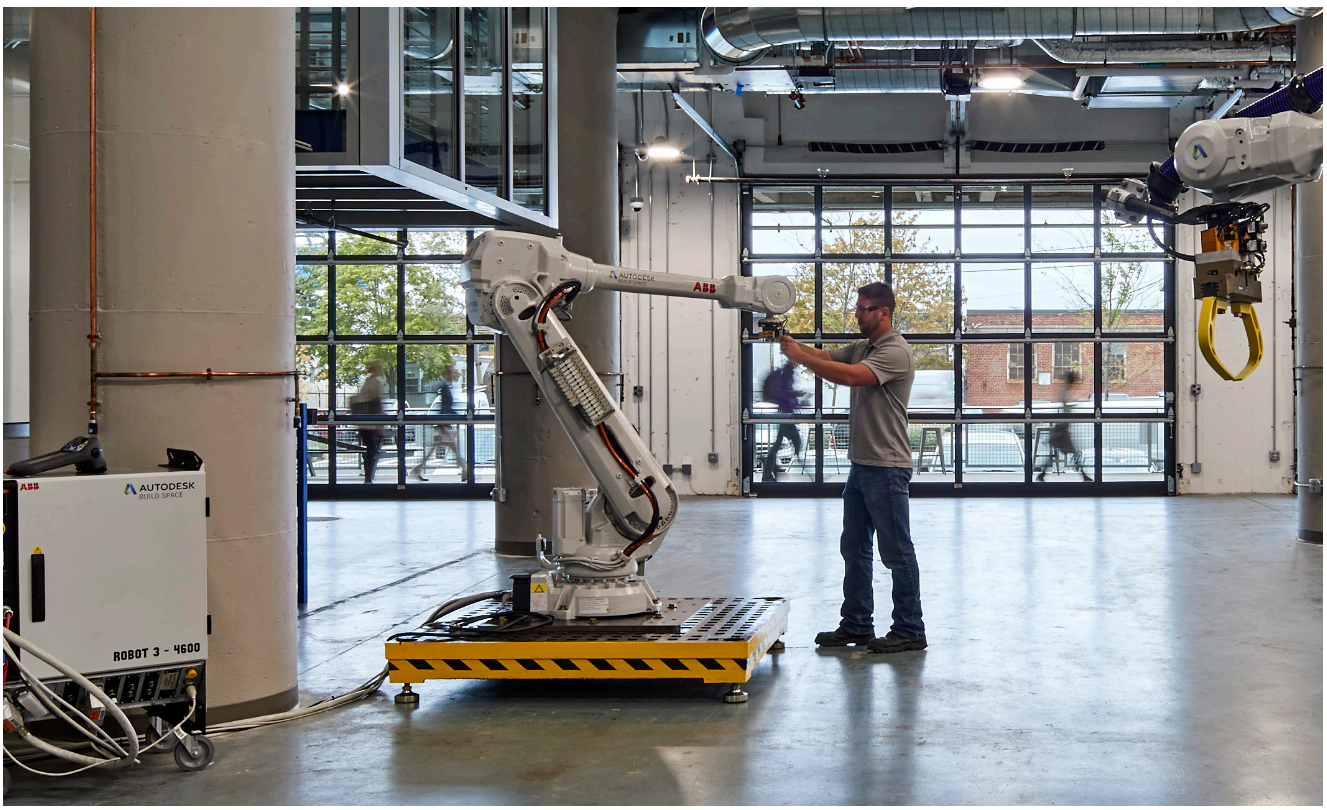
Additive manufacturing

At the front line of digital fabrication is Additive Manufacturing (AM), commonly known as 3D printing, which produces objects by building up structures from small deposits of materials in layers. The construction industry has begun to explore AM as an emerging building technology. With AM, it is possible to go directly from a 3D model of an object to a finished product with one touch and one machine, using a wide range of materials, such as steel, glass, ceramic, polymer, concrete, and more.[6]

One of the inviting advantages of 3D printing is the ability to make custom-built, complex, and unique components. Contractors can deliver ideal solutions for projects with minimal waste without the constraints of standard building components.[6] As the technology advances, it should deliver more aesthetically pleasing structures optimized using generative design, as well as the development of new materials and processes.[7]

Robotics

Robotics is the science of designing, building, and applying robots to perform work by incorporating the background, knowledge, and creativity of mechanical, electrical, computer, industrial, and manufacturing engineering.[8] Robots have customarily been used to do a limited range of monotonous tasks, primarily in materials and components handling. However, emerging robotic technologies used in the construction industry today include demolition robots, 3D printing robots, robotic total stations, rovers and laser scanners, robotic drones, bricklaying robots, welding robots, exoskeletons, forklift robots, roadwork robots, and humanoids.[8]



Robotics employs a synchronized process aimed at improving the lives of human laborers in tasks that are otherwise dangerous, grimy, or demanding. Robots can also be connected to a wide range of sensors, enabling them to acquire data about ongoing processes. This information can then be fed back to the control system, which can then be analyzed to adjust the operation of the robot to drive higher efficiency and accuracy during the process.[6]

Big data and predictive analytics

In the construction industry today, vast amounts of highly structured data are being produced through BIM and other project technology tools.[6] The industry currently deals with an enormous volume of synthesized data, which is only to intensify exponentially as technologies such as sensor networks are commoditized. Big data and predictive analysis are defined by the ability to process large amounts of data and extract useful insights from the data pool.[9] This trend has opened the door to a new discipline in construction called Construction Intelligence.

Construction Intelligence is the ability to predict the future of construction by mining the data generated from numerous projects. Analyzing the data for patterns across several sources could help a contractor identify several project tendencies, such as the basis for overestimation in bids.[6]

Internet of Things

The Internet of Things (IoT) is a network of physical objects that use electronic devices such as sensors and actuators to correspond and update information in order to achieve optimum performance by the overall systems. The network can then create a real-time feedback loop for more informed decision making.[10] This system is commonly referred to as telematics in the construction industry, and it can be incorporated in the building systems to monitor operation conditions, performance levels, or physical states.[11]

IoT changes how we construct, occupy, and maintain buildings. During the operation phase of the building, data from IoT sensors can be integrated with BIM by using the data to model occupancy trends, such as energy usage, temperature inclinations, or people movement.[11] The resulting output from the developed models can be examined to enhance future projects. Also, an essential element of IoT is connectivity, and before this technology can indeed disrupt the industry, it needs to be supported by strong connectivity.[12]

BENEFITS OF IC

By implementing advanced construction technologies, the construction industry can reap several benefits from IC. IC can result in reduced labor costs, improved safety, decreased delays, improved product quality, enhanced productivity, and increased dexterity—none of which traditional construction methods would ordinarily achieve.[13, 14]

SIX BENEFITS

- Reduced Labor Costs
- Improved Quality of Finished Product
- Improved Safety
- Enhanced Productivity Through Optimization and Automation
- Minimized Delays
- Improved Dexterity, Scalability, and Flexibility

Reduced labor costs

IC simplifies the construction process, since it is much less labor-intensive. Because the process employs innovative techniques with mechanization and automation, it reduces the need to use skilled laborers for the demanding tasks that involve strenuous physical work.

Improved safety

With IC, construction tasks at dangerous locations—such as places at substantial height—are conducted with fewer people at risk. Laborers working in a controlled factory environment do not have to worry about jobsite hazards such as exposure to harsh weather elements, threatening access to electricity, or dangerous heights. IC results in better working conditions and reduced material waste.

Minimized delays

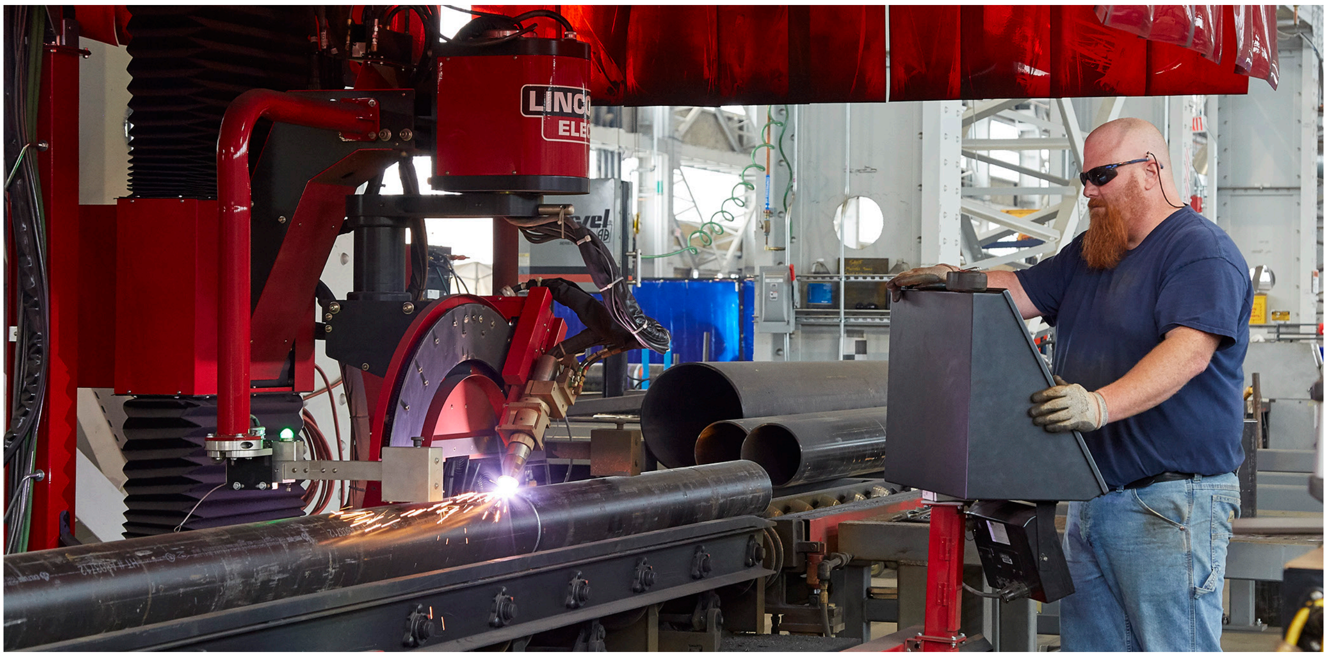
By using automated workflows, IC prevents delays on a construction project and can shorten the duration of each activity involved, helping to ensure adherence to the project completion date. Prefabrication decreases the need for coordination among subcontractors, and with most of the work done in a factory, there will be fewer delays due to weather. Also, with automation and robotics, shift work can be performed around the clock.

Improved quality of finished project

IC results in more precise and uniform product quality, as automation enables the work to be completed more easily. When automation is used in conjunction with IoT, quality aspects can be observed in real time to reduce errors. A significant advantage of working in a controlled and consistent environment, as is the case with prefabrication, is that it allows for higher quality control than is possible on a typical jobsite.

Enhanced productivity through optimization and automation

Optimization of processes and productivity is one of the most apparent benefits of IC. It results in cost savings, increased profitability, waste reduction, error and delay prevention through automation, faster intervention in construction issues, and so forth.



Improved scalability

By taking advantage of advanced technologies such as Big Data, AI, robots, and cyber-physical systems, IC offers improved agility, scalability, and flexibility of construction processes. With these technologies, demand forecasts are made more predictable, and processes can be adjusted for optimal production from a perspective of time and scale.

LIMITATIONS OF IC

IC is still an emerging construction system, and despite its enormous potential to provide solutions to the pressing problems experienced in the industry, certain limitations must be addressed before IC can entirely disrupt the industry. Some of the critical setbacks to the adoption of IC include social acceptance, expensive overall costs of construction, lack of skilled labor workforce, minimal industry-academia collaborations, and lack of compliance and regulatory bodies.[15]

FIVE LIMITATIONS

- Social Acceptance
- Minimal Industry-Academia Collaboration
- Expensive Overall Costs of Construction
- Lack of Compliance and Regulatory Bodies
- Lack of Skilled Labor

Social acceptance

The construction industry has a history of adopting technological innovations at a slow rate, mainly because most contractors resist changing from traditional construction methods that have been practiced for several decades to something that is entirely new to them. Also, trade unions have tended to contest technological change in the industry since the days of the pick and shovel.

Unions have continued to fight back to ensure that the advancement of technology does not leave construction workers jobless. This is a result of robotics and automation often being misinterpreted, with negative perceptions of robots replacing human labor and taking over jobs. Other misconceptions include low-quality buildings, unappealing architectural appearance, and rigid creativity and innovation.

Expensive overall costs of construction

Another limitation to the adoption of IC is expensive overall construction costs of IC projects caused by initial high capital investment. Construction companies have to invest more heavily to acquire these technologies and to train human resources in the skills for implementing the technologies for construction projects.

Lack of skilled labor

IC requires high construction accuracy, and therefore it is required that all parties involved should have competent knowledge about IC processes and the technical knowledge to use required software and hardware, equipment, and machinery. However, the construction industry is confronting a disconcerting skilled labor shortage, with a lack of qualified workers who have the knowledge and exposure to technologies to drive IC processes and higher levels of precision in construction.

Minimal industry-academia collaboration

Integration between industry and academia is key to promoting technological innovations in the industry. However, there are not many established funded research centers to support productive collaboration environments between companies and academia.

Lack of compliance and regulatory bodies

Currently, there are insufficient building code procedures in the industry to make certain that standards are met efficiently regarding the implementation of advanced construction technologies. Also, some of the present regulations and policies do not make allowances for the progression of technology and the emerging needs of the industry.

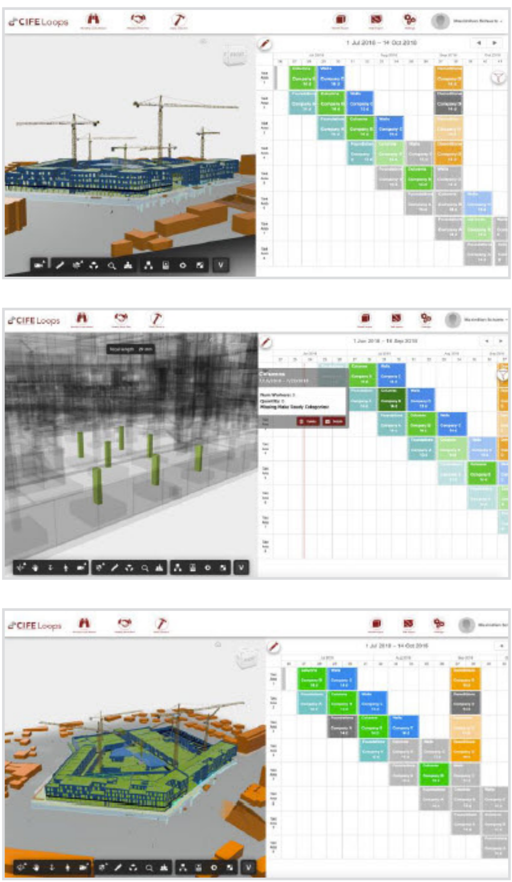
IC IN ACADEMIA

The technological disruption of the AEC industry calls for a change in the pedagogic methods in AEC education to address the Future of Work. The advent of IC technology such as prefabrication, additive manufacturing (3D printing), robotics, big data and predictive analysis, and IoT should have a major influence on AEC education. It is critical for universities to introduce these new technologies and processes in order to adequately equip students with the knowledge and skills required to thrive in the workforce of the digital age.

It is crucial to better understand the role of accreditation agencies in integrating IC and the roadmap of when to utilize these new construction approaches. Construction students will need to learn how to estimate IC costs, schedule, procure, evaluate, and select the right IC methodology depending on the type of project and resources available. Today, a few universities are integrating IC processes into their curricula and are exploring IC via research using robotics, fabrication, and cloud-based technologies. Three leading examples are Stanford University, RWTH Aachen, and the Centre for Information Technology and Architecture (CITA).

Center for Integrated Facility Engineering (CIFE)—Stanford University and Loops software

The Center for Integrated Facility Engineering (CIFE) is a research center at Stanford University, dedicated to issues relevant to the AEC industry. The CIFE mission is to be the world's premier academic research center for virtual design and construction (VDC) of AEC industry projects. The center works with member organizations to document problems, develop and test innovative new ways to model, visualize, analyze, and evaluate the multidisciplinary performance of design–construction projects, and validate results. CIFE is also an educational center that aims to increase awareness of and competence to use the methods and understand the value and costs of VDC for practitioners and Stanford students.[16] Also, CIFE actively strives to digitize construction management through industry–academia collaboration.



Loops: Web-based cloud platform
Source: Dr. Martin Fischer

CIFE Loops

Loops—dynamic look-ahead windows based on project performance feedback loops—is a web-based cloud platform created to support construction project teams by helping them focus on the right aspect of the right tasks at the right time in order to stay close to the optimum schedule. In the field of construction scheduling, research has recently shown that it is possible to automatically generate near-optimum construction schedules and to dramatically reduce the time for such a schedule to be created. By establishing these kinds of feedback loops in a BIM-based and lean-enabled environment, this system can dramatically improve the reliability of monthly Make-Ready meetings and keep the schedule continuously close to optimum.[17]

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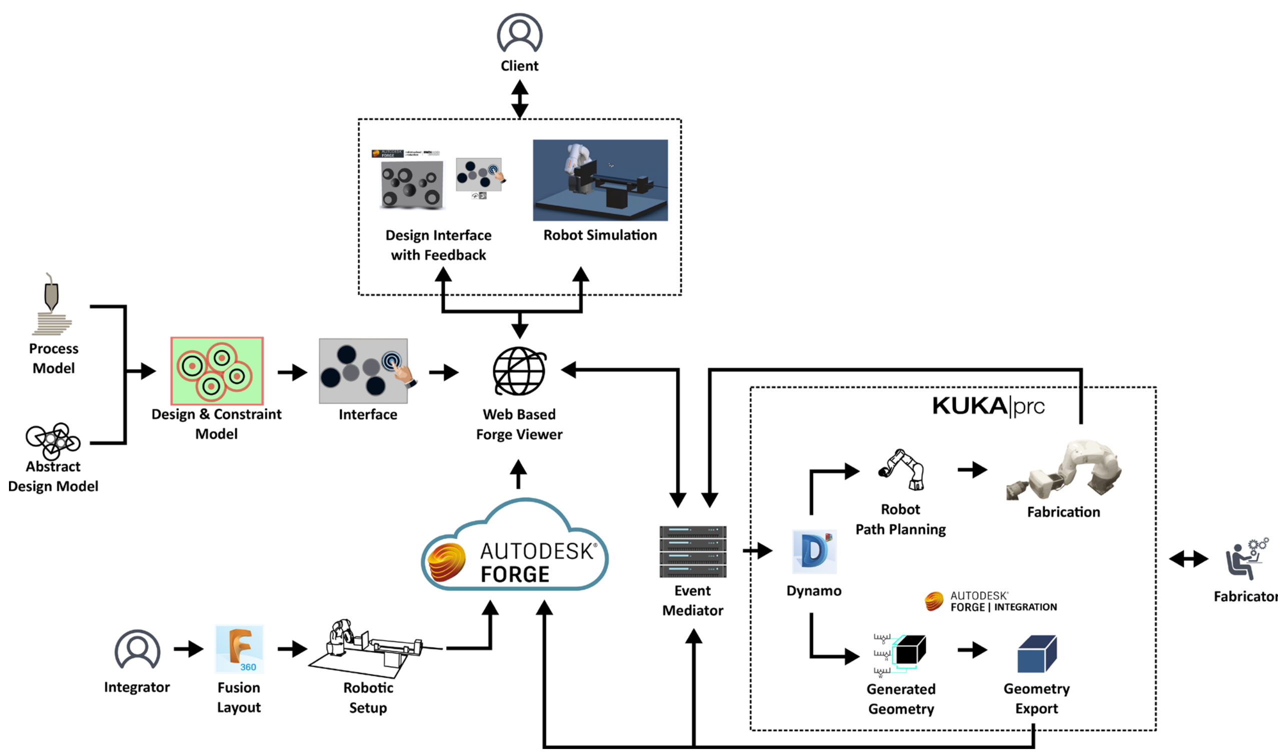
RWTH Aachen University—Autodesk Forge cloud-integrated construction robotics

The current construction industry is slow to adapt to digitalization; specifically, the main gaps in information flow occur in transfer to preproduction and on-site assembly. Employing a cloud-based information flow best suits the new paradigm of decentralized planning and integration of different users to the architectural planning process. By integrating simulation and execution of fabrication strategies through web services, new means of cloud-informed fabrication is possible. Designers can opt for on-demand fabrication, easily obtain feedback about recurring issues, and even fit their designs to fabrication demands before execution.

Application of this approach at Autodesk University



Architecture for a collaborative workflow

RWTH Aachen is focused on enabling users to create their own design based on rules and parameters preselected by fabricators and construction industries. Individual parts design and fabrication becomes an integrated process. This not only allows designers to adapt their design-to-fabrication process, but also enables construction prefabricators to offer their services for accessible, design-oriented, on-demand fabrication.

A number of fabrication technology services already exist and use web interfaces for purchase processing. The required web interfaces used for these kinds of services, however, are created on a case-by-case basis and production parameters have to be transferred separately to prefabrication. RWTH Aachen used Autodesk® Forge cloud services to develop generalized flow from a parametric design model towards a web interface for user feedback and robotic fabrication as a service.[18]

See a full published paper on the project here.

Centre for Information Technology and Architecture (CITA) explores machine learning and digital fabrication: A Bridge Too Far

The building profession is in a radical shift of paradigm from architectural representations of unconnected data to practices with an overwhelming amount of information-rich data. Machine learning (ML) provides architects and engineers with new models and methods to engage in these data-heavy processes in order to synthesize meaningful information for all areas of their practice from design to fabrication.

A Bridge Too Far exhibit in Copenhagen at the Complex Modelling exhibition

Early research into the use of machine learning approaches within architecture was mainly focused on the fields of design generation, shape recognition, and design space exploration and categorization.

In its practice with ML, CITA has been interested in shifting from a focus on analysis of existing data towards applications concerned with creative use and synthesis. They have been conducting research into the intersections between ML and fabrication. ML is here identified as a next step in the paradigm of fabrication-informed design.

The use of digital data to control a fabrication process bridges the gap between design and making by giving control over the construction and fabrication process. Current fabrication-informed design keeps a design within production limits by establishing an a priori understanding of these limits within the design space. However, the limits of this approach are apparent in many real-world cases where fabrication engages with non-linear material behavior and production setups, which require feedback and online decision making.

Connecting ML to fabrication is an opportunity to rethink this sequential relation between design information and the process of making—to extend the scope of design beyond previous stopping points and into the making process, and to consider design information that is only generated during construction. This supports a new paradigm of production processes where the aim is not precise replication, but higher levels of flexibility, adaptability, and integration.

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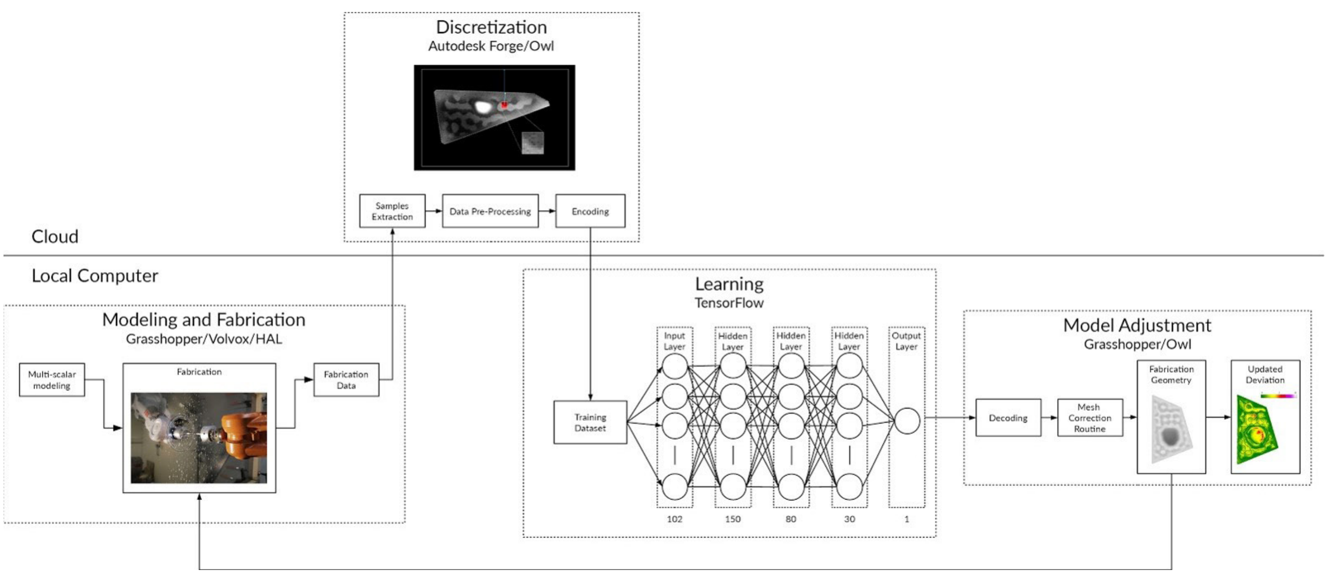
The exhibit A Bridge Too Far (Fig. 1) was undertaken as part of the CITA research project Complex Modelling that tests integrations of ML into design, simulation, and fabrication. A Bridge Too Far investigates ML to extend the adaptation of design and fabrication information into the fabrication process. This project finds context in Robotic Incremental Sheet Forming (RISF), a free-form fabrication approach that offers mass customization for metal architectural skin. It provides an alternate technology through which to extend, exploit, and vary the material capacities of architectural skins.[19]

Incremental Sheet metal forming at CITA using two synchronized robotic arms



Machine learning workflow including local and cloud based (Autodesk Forge) steps

See a full published paper on the project here.

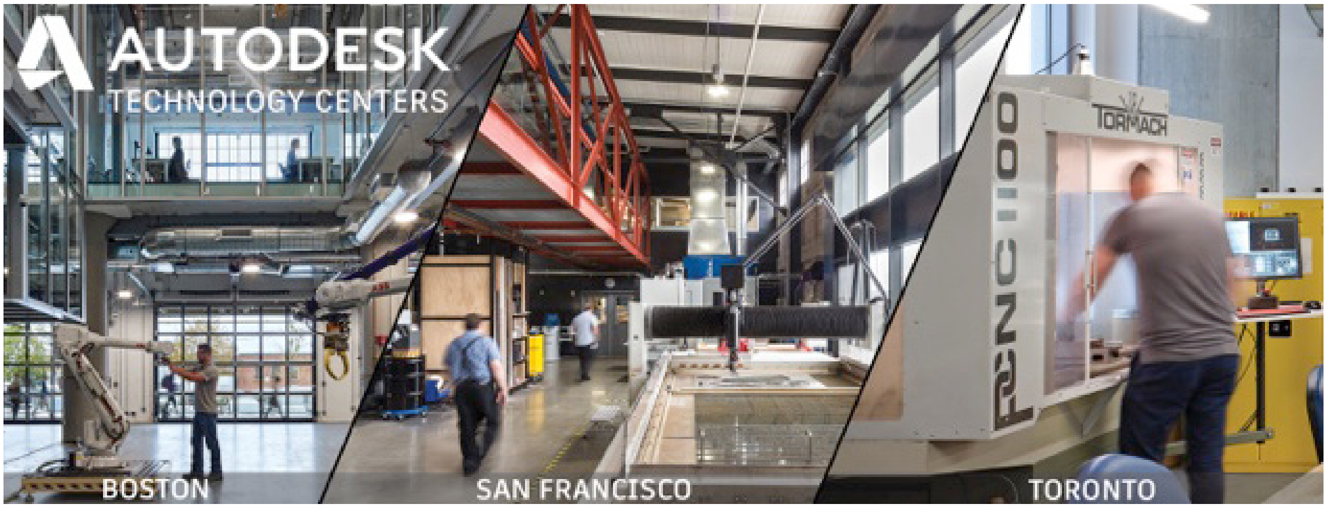
AUTODESK COMMITMENTS TO IC

The technological disruption of the AEC industry calls for a change in the pedagogic methods in AEC education to address the Future of Work. The advent of IC technology such as prefabrication, AM (3D printing), robotics, big data and predictive analysis, and IoT should influence CM education. It is critical for universities to introduce these new technologies and processes into curriculum early, in order to adequately equip students with the knowledge and skills required to thrive in the workforce of the digital age. Several universities have great digital fabrication labs and construction robotic research programs, and slowly the larger pedagogy will reflect this paradigm shift.

Autodesk Education Community

Through an established relationship with students and educators, Autodesk is committed to equipping students with free* access to software and resources to help them achieve academic and future career success. Students and educators also have access to pertinent learning content designed to engage students. As a company, Autodesk is passionate about educating and inspiring the next generation of designers, engineers, and makers through software, learning resources, and programs that build students' skills, and inspire them to make anything![20]

*Free Autodesk software and/or cloud-based services are subject to acceptance of and compliance with the terms of use or other applicable terms that accompany such software or cloud-based services. Software and cloud-based services subject to an Educational license may be used solely for Educational Purposes and shall not be used for commercial, professional or any other for-profit purposes.



Autodesk Technology Center Residency Program

Autodesk Technology Centers are where the future of making takes shape. With locations around the world, Autodesk invites industry, academic, and entrepreneurial communities to reimagine what it means to design and make, and create a shared vision of the future that will enable people to do more and make better things with less negative impact.

The Residency Program at the Autodesk Technology Centers in Boston, San Francisco, and Toronto provides open workspaces for teams from industry, academic, and startup communities doing forward-looking work in the areas of construction, manufacturing, and emerging technologies.

Autodesk provides the facilities, technology and equipment, training, and expertise for these communities to explore ideas that will shape the future. Each location explores different aspects of the future of making, but all the spaces are designed to foster open innovation and advance the industries that help imagine, design, and make the world around us.

The Technology Center in Boston focuses on industrialized construction, digital fabrication, automation and robotics in construction, and other ideas that are transforming the built world.

Located in Boston's Seaport Innovation District, the 34,000 sq. ft. BUILD Space offers teams access to large-format fabrication equipment and project space, as well as training and expertise from Autodesk personnel. The center's equipment supports nearly any material used in the construction process: steel, wood, stone, concrete, ceramics, glass, composites, and more.

Resident teams test and develop solutions that will improve how we build the places where we live and work and the infrastructure we rely upon. More than just a workspace, the center fosters an open community where industry thought leaders can collaborate on a shared vision of the future of construction.

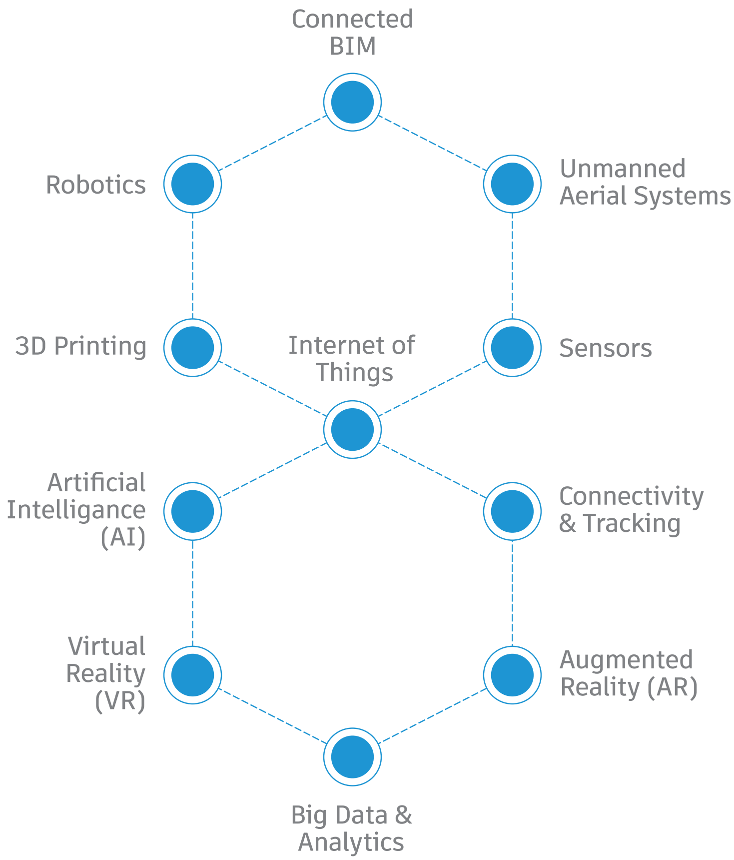
Residency proposals are reviewed on a rolling basis, and selected participants are provided with dedicated project areas in a technology center, access to advanced fabrication machinery, training, and connections to industry experts and the technology center community. The program can be tailored to meet individual goals and availability. Residencies can last anywhere from two weeks to a year or more.

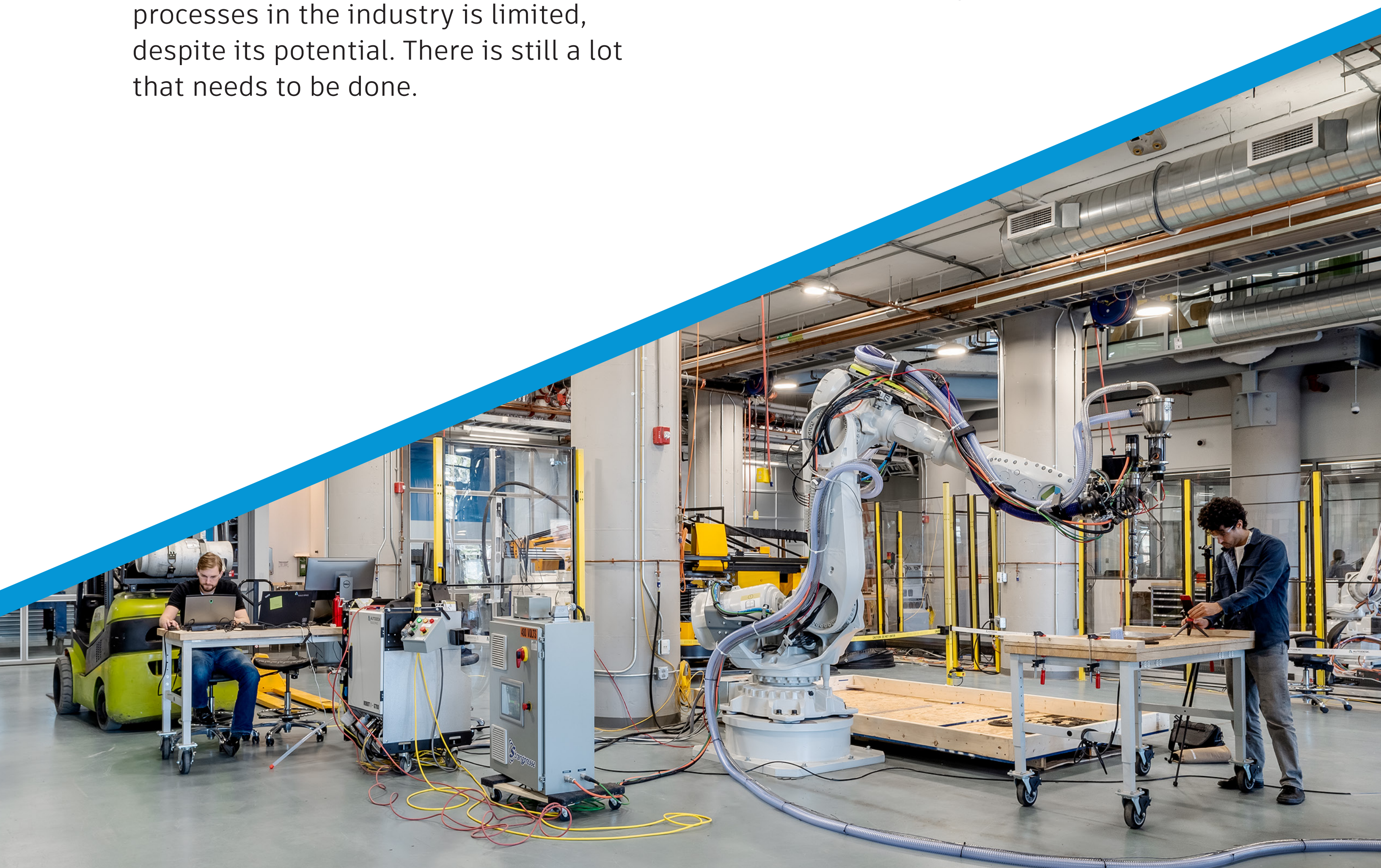
The Autodesk Technology Centers exist to create a shared vision of the future of making with a community of innovators and thought leaders, and the Residency Program is a vital part of bringing that vision to life.

THE FUTURE OF IC

The digitization and industrialization of construction have been identified as the key to addressing the declining level of productivity and poor quality of assets in the industry. Construction companies are increasingly incorporating advanced construction technologies, such as digital sensors, smart machines, and new software applications integrated with a central platform of connected BIM in construction projects.

The new era of digitization in construction offers immense benefits for the construction industry, the environment, and the economy. Although advanced construction technologies are already being integrated into construction, the widespread implementation of IC processes in the industry is limited, despite its potential. There is still a lot that needs to be done.





Call to action

All stakeholders in the construction industry—academia, private companies, and the government—need to act to move the industry forward.

Academia and accreditation bodies

The future of the industry is highly dependent on the competence of workers entering the workforce. In the face of troubling skilled labor shortages, it is crucial for new employees to enter the industry with the abilities and exposure to technologies to drive IC processes and higher levels of precision in construction. Deans and members of the faculty in AEC-related programs should evaluate their curriculum to ensure students are exposed to advanced construction technologies and knowledge of interdisciplinary skills required to thrive in the digital age.

Private companies

The adoption of advanced construction technologies is crucial for construction companies that want to remain economically feasible and competitive. Private companies should evaluate the prospects of new technologies and materials and then actively modify their operations, processes, regulations, and business model appropriately to thrive in the technology-driven world.

The government

Integration between industry and academia is key to promoting technological innovations in the industry. The government should establish productive collaboration environments for transformation in the construction industry, such as funded research centers and high-profile projects.

The industry should agree on common goals and standards for implementing advanced construction technologies and IC processes. It is imperative for all stakeholders to collectively collaborate to attain a widespread adoption of IC and assure an exciting future of the construction industry.

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