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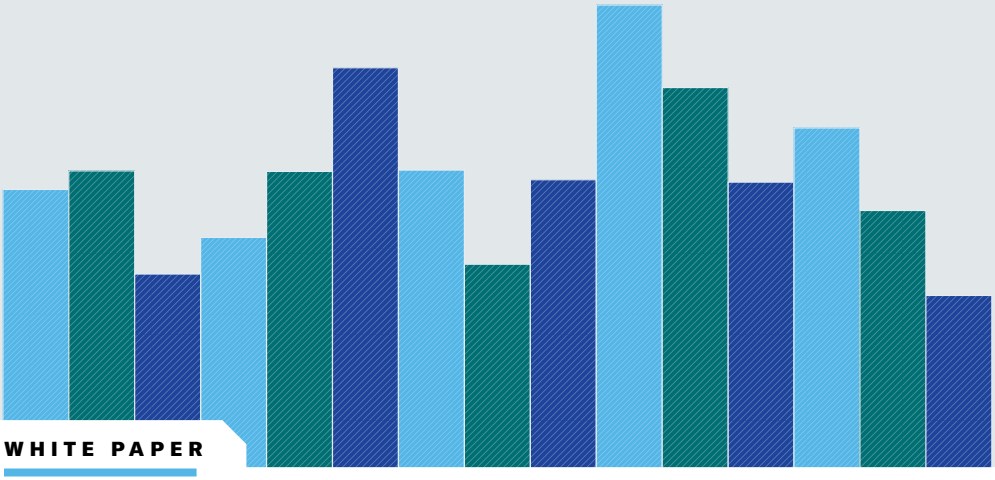

WHITE PAPER

Leveraging Artificial Intelligence and Automation for Return on Investment in Innovation

Architecture, Engineering, and Construction Sector

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The Business Imperative for Automation

Mike Haley
Vice President
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What stands in the way of innovation? It's often the old ways of doing things—repeating old patterns because that's what worked before. It's predictable and measurable, but it doesn't break you out of the status quo. Innovating can feel like walking on a tightrope without a safety net, but with the help of automation, it's like having an amazing mentor sitting right next to you, guiding you through new possibilities. Whether your business is architecture, infrastructure, construction, or manufacturing, automation transforms the way you work because it helps your teams explore and discover new ways of doing things.

When people ask me if automation and artificial intelligence are going to take away jobs, I always ask them, "Have we solved all the world's problems?" There are an enormous number of challenges. The architecture, engineering, and construction and manufacturing industries have low margins, face an aging workforce, and strain to adapt to new patterns of manufacturing, such as industrialized construction and reshoring of manufacturing.

Automation is your friend because it allows you to spend more time solving problems rather than focusing on tedious tasks and interpreting volumes of data. The human brain is not able to absorb the increasing deluge of data that everything—even a sensor-filled concrete beam—collects. People need computational help to see patterns and gain insight.

All that help is possible with the automation provided through digital twins, generative design, and innovative construction processes such as design for manufacture and assembly (DFMA). A digital twin—which is a dynamic, up-to-date replica of a physical asset like a car, a building, or a bridge—can absorb and exchange data throughout an asset's entire life cycle. With the addition of real-time operational data, digital twins acquire the behavioral awareness necessary to simulate, predict, and inform decisions based on real-world conditions.

With generative design, you're expressing what outcome you're looking for and letting unbiased, raw computation create, test, and evaluate options by itself. Even if you don't use exactly what comes back, this approach shows you things you weren't thinking about, triggers innovations and ideas, and helps you make informed decisions for complex design problems.

Meanwhile, DFMA—a set of design principles that helps connect the design-to-make process—is a game changer for the built environment. Through automation, you and your teams can become more productive and adaptable to change, and it can help you meet sustainability goals, including the 2021 United Nations Climate Change Conference pledge to make all buildings net zero by 2030.

All of this innovation shows the promise of automation. It's not a luxury. To solve the world's complex problems, it's absolutely essential.

Leveraging Artificial Intelligence and Automation for Return on Investment in Innovation

Architecture, Engineering, and Construction Sector

Innovation capabilities are essential in today's marketplace. Forrester Research calls a tech-driven and sustainable innovation strategy "mission critical" to stave off disruption and weather continuous change—and finds that organizations that adopt this type of innovation strategy grow 2.6 times faster than those that do not adopt it.[1]

Artificial intelligence (AI) and automation are often seen as key enablers of innovation, allowing organizations to work better, faster, and more sustainably and efficiently while reducing costs. A 2021 survey of 1,843 global cross-industry organizations by McKinsey & Co.[2] showed that 87% reported a cost decrease as a result of using AI in manufacturing and 69% experienced a cost decrease in product and/or service development in 2020. Fully 63% and 70%, respectively, saw revenue increases in manufacturing and product and/or service development as a result of AI adoption in 2020.

"The business environment, whether it's supply chain or energy or climate or customer expectations, is continually changing. I think by almost that alone innovation is a necessity to ensure business growth," says John Suh, vice president, Hyundai Motor Group, and head of New Horizons Studio, a team developing an ultimate mobility vehicle (UMV) based in Fremont, Calif. "Because of change, you have to do things in new ways."

The design and manufacturing (D&M) and architecture, engineering, and construction (AEC) industries are turning to AI and automation to fuel innovation by streamlining processes, discovering new patterns and insights, and automating data-based decision making. AI and approaches such as digital twins, generative design, and design for manufacturing and assembly (DFMA) offer the potential to unleash worker creativity and move innovative activity

HIGHLIGHTS

Organizations in the construction and manufacturing ecosystems sometimes **struggle to identify and monetize innovative ideas**.

Organizations investing in the innovation required to **approach old problems in new ways enjoy greater growth**.

Artificial intelligence and approaches such as digital twins, generative design, and design for manufacturing and assembly **offer the potential to unleash worker creativity**.

beyond niche-use cases to impact the larger organization and its strategic direction.

Beyond competitive and customer pressures, factors such as sustainability and a need to attract digitally savvy younger workers are increasing the need to become more innovative to fuel future growth. But organizations in the construction and manufacturing ecosystems sometimes struggle to identify and monetize innovative ideas. Common obstacles to fostering and operationalizing innovation include cultural resistance, entrenched business practices, and uncertainty about how to instill innovation-enabling processes.

Organizations seeking to monetize innovation in the D&M and AEC industries must learn what changes they need to make to nurture and embrace innovation so they can successfully navigate tomorrow's marketplace. This transition requires understanding why innovation is so important and how innovative firms are gaining an advantage by embracing AI and related technologies. It also means increasing collaboration, identifying factors that may be holding back innovation, and leveraging the best practices that have helped early adopters in D&M and AEC transition toward innovation-nurturing business practices and cultures. Successful moves include establishing diverse, cross-functional teams and formalizing structure around innovation.

"Innovation is not just driving growth for AEC and D&M; it's somehow disrupting the industry from the bottom up," says Angelo Yu, founder and CEO of PIX Moving, a Guiyang, China-based multidisciplinary developer and manufacturer of modular smart vehicles. "Like how Henry Ford nurtured the mass adoption of cars and how Apple initiated the big bang of the digital age, innovation in design, engineering, and manufacturing will eventually change how we work, live, and play."

The Pressure to Innovate

Gartner reports that innovation requires three key elements: novelty, execution, and a useful outcome.[3] In the AEC and D&M industries, the useful outcomes of innovation include being able to sharply reduce time, cost, and risk while increasing the sustainability of construction and manufacturing processes.

Take Bryden Wood, a London-based architecture, engineering, and design company focused on innovation in the construction industry, as an example. The company is automating various AEC processes and implementing design for manufacturing and assembly, which have enabled the firm to reduce capital costs by 20% to 30%, trim schedules by 20% in many projects, and configure designs in two days that would take a traditional design team 15 months. Similarly, PIX Moving has used AI-driven design algorithms to reduce the components of a 3D-printed, autonomous-driving skateboard chassis platform to a tenth of what was needed before and apply digital fabrication to trim lead time by 75%. These are just two examples of organizations that moved more aggressively than their competitors to adopt processes, technologies, and mindsets that enable innovation and are enjoying significant benefits as a result.

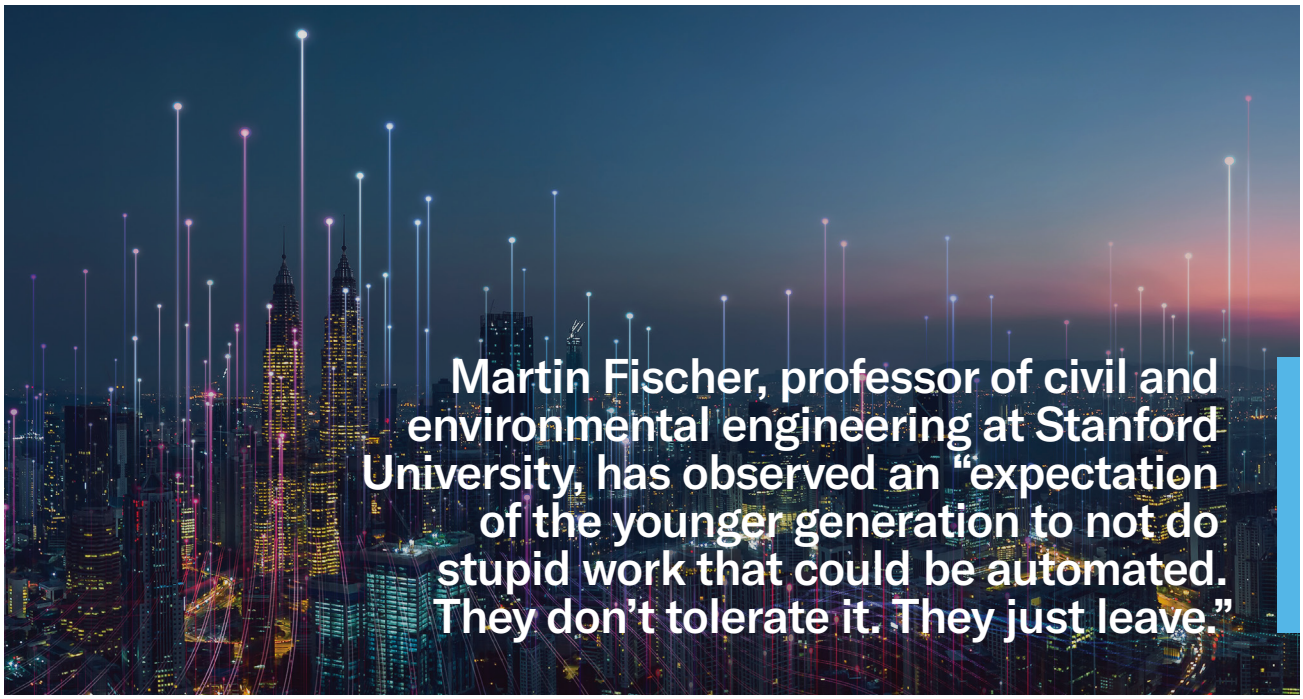
The ability to significantly reduce the resources needed to design, engineer, and build something, whether it's a scooter or a skyscraper, offers a clear competitive advantage over traditional methods. As Forrester's findings confirm, organizations investing in the innovation required to approach old problems in new ways enjoy greater growth. But signs suggest such innovative capabilities will also become a means of survival in the D&M and AEC industries. According to "Winning the Race for Survival," a May 2020 World Economic Forum white paper, "We may be on the precipice of 'Operational Darwinism,' wherein mere reductions in costs may not be enough to compete against leaders who make manufacturing a rapid and key part of their digital innovation edge." Pressure to innovate is coming from customers, competitors, and organizations' own workforces.

While competitive and customer demand are nothing new, pressure to innovate from the workforce is being felt across many industrial sectors as they struggle to attract new talent. "Everywhere in the world right now [there] is the need for more talent, better talent," says Martin Fischer, professor of civil and environmental engineering at Stanford University. Fischer has observed an "expectation of the younger generation to not do stupid work that could be automated. They don't tolerate it. They just leave."

"The 2021 Future Manufacturing Workforce Study," a survey of 882 Gen Z manufacturing employees by workforce management company UKG, found that 94% called working on fulfilling projects important, very important, or extremely important to their job satisfaction. Three-quarters agreed, somewhat agreed, or strongly agreed that manufacturing has unfavorable working conditions.

Attempts to attract new talent to industrial organizations lead to a culture clash of sorts when established workers steeped in manufacturing expertise encounter young, digitally savvy talent without that background. "And that causes quite a lot of disconnect and cultural dysfunction in some cases where the newcomers are not easily welcomed," says Jo Geraghty, cofounder of Culture Consultancy, a London-based culture change consulting organization. Organizations need ways for new hires to learn from the experience and knowledge of long-term workers while using their data skills to update and transform processes.

Sustainability goals are also upping pressure to bring innovation to sourcing, materials, and processes, with stakeholders, including investors, customers, and employees, increasingly focused on goals beyond simply driving revenue. "There's been a growing recognition, particularly around



sustainability, that it's not acceptable now not to have some strategy of how you are going to reduce materials or increase material efficiency and other things," says Jaimie Johnston, director and head of global systems at Bryden Wood.

Mandates and incentives from governments, such as the tax incentives offered to innovate in Singapore, are also dialing up the heat. Governments from the United Kingdom to Brazil to Mexico are mandating or heavily pushing the use of building information modeling (BIM), a holistic process of creating and managing information for a built asset, typically starting with government-funded projects. Sustainability requirements are finding their way into building codes, such as California's new requirements for the use of solar panels, batteries, and electric heat pumps in some new homes and commercial buildings.[4] European Green Deal proposals include new rules to make almost all physical goods more environmentally friendly and implement stronger regulations around sustainable construction. Outcomes from the 2021 United Nations Climate Change Conference in Glasgow included a focus on achieving zero global carbon dioxide emissions by 2050, impacting both AEC and D&M organizations. For the cement and construction value chain, for example, this goal will require tripling the current pace of decarbonization. Participants in a construction industry panel convened by McKinsey & Co. at the event determined that creating a culture of innovation is a strategy key to achieving that goal.[5]

Responding to this complex web of pressures will require pronounced changes to business as usual in both AEC and D&M. To stave off disruption, weather continuous change, and achieve faster growth in these industries, organizations will need to rethink processes and culture, both internally and across their ecosystems, identifying and committing to new ways of working.

Key Levers of Innovation

Technology is proving a key enabler of innovation, applying increasingly sophisticated algorithms and models to data and automating the iteration of design choices. Sources of essential data are proliferating across manufacturing and construction, thanks to increasingly affordable sensors and cameras and the ability to collect and amass data via wireless and cellular networks and the cloud. Beyond simply digitizing existing analog processes using this data, organizations are increasingly digitalizing them—rearranging business processes by sharing and collaborating on digital information in new ways, with information at the center of this new operating model. AEC and D&M organizations are leveraging automation, AI, digital twins, generative design, and DFMA to foster innovation and create business value by streamlining processes, discovering new patterns and insights, and automating data-based decision making.

AI promises to have a profound effect on the entire global economy. McKinsey created a model simulating the potential cumulative impact of the use of AI on the world economy by 2030, including an analysis of how it could affect companies.

Nonadopters [of artificial intelligence] "might experience around a 20% decline in their cash flow from today's levels," according to a 2018 McKinsey & Co. report.

In its report, "Notes from the AI frontier: Modeling the impact of AI on the world economy," published in September 2018, McKinsey analysts found front-runners in AI adoption could double their cash flow (economic benefit captured minus associated investment and transition costs) by 2030, with a 122% cumulative change. **FIGURE 1** Nonadopters "might experience around a 20% decline in their cash flow from today's levels, assuming the same cost and revenue model as today," according to the report.

The ability to leverage AI techniques to perform tasks that normally require human intelligence—often at a scale and speed that are beyond human capability—is enabling organizations to create new ways of working across design, engineering, and production processes. PIX Moving, for example, is leveraging AI and automation to develop systems that can rapidly produce a manufacturing-ready customized product. PIX Moving's Yu says the use of AI-driven design and digital fabrication techniques leads to fewer components, shorter lead time, less dependence on the supply chain, a faster response to customization needs, and a mold-free approach, all of which reduce costs significantly for the organization.

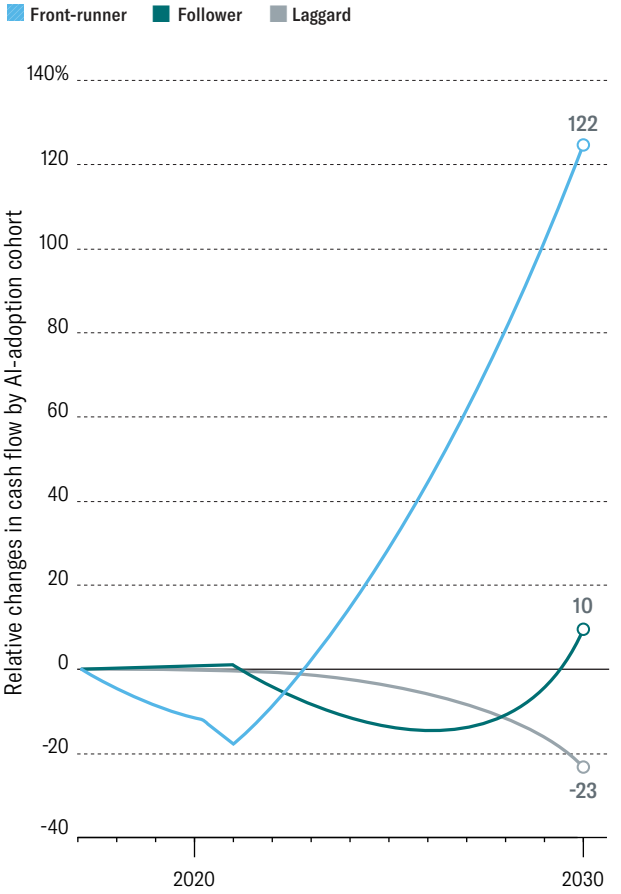
According to Yu, such software-defined manufacturing systems free PIX Moving from the factors that limit innovation for traditional automotive manufacturers. These factors include extra-large factories, heavy investment, high barriers to entry, longer lead times, and time-consuming processes, such as tooling and production line setup, which slow iteration and impose risk. When the same task—car design and production—is enabled by tools such as AI, the process "is distributed, user-participated, and decentralized, and no more molds are required, reducing tooling fixtures and [enabling us to] respond flexibly to market changes," he says.

Some of the most widely used applications of AI in construction are in progress tracking and safety. By analyzing image data captured by cameras mounted on cranes—and, increasingly, drones—construction companies are substantially reducing the many hours and people it takes

FIGURE 1

Advantages Accrue to Early Adopters

By 2030, front-runners in adopting artificial intelligence could double their cash flow



Source: McKinsey & Co., September 2018

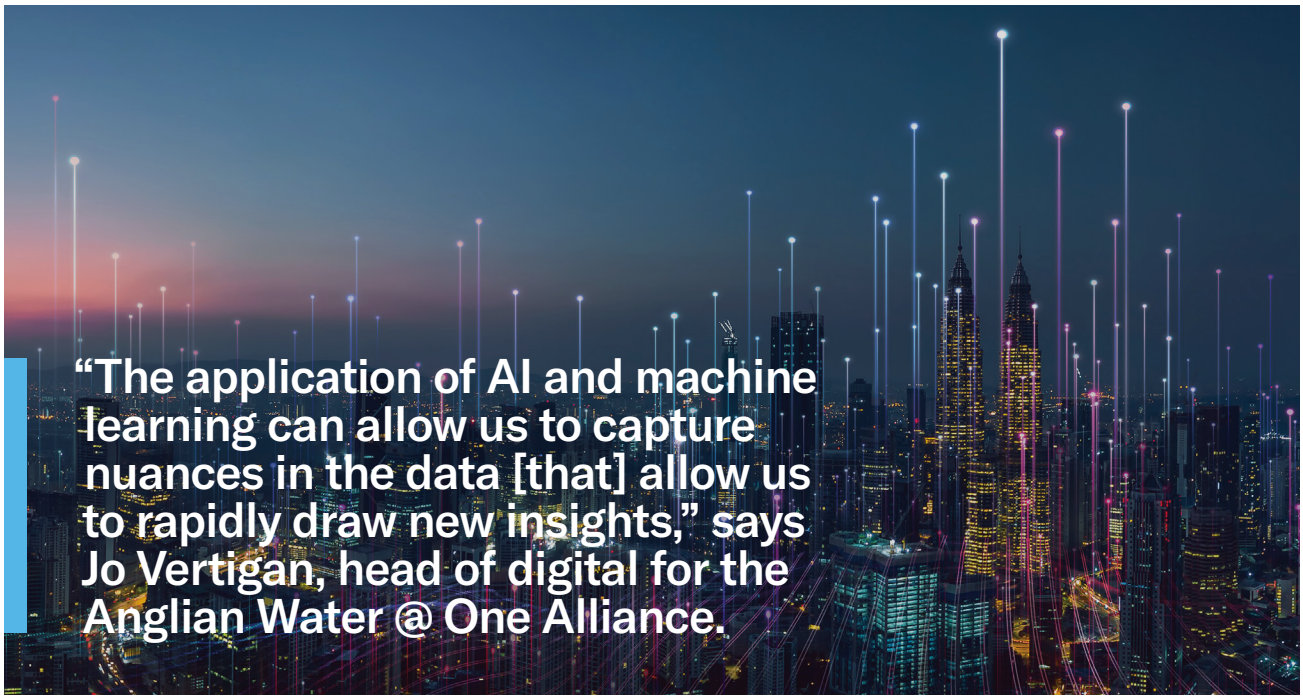
to prepare reports on the current status of work, a key metric, down to just minutes.

"With integrated digital technologies, our project managers can objectively assess project status, productivity, and any risks, and [can] make data-based decisions more quickly to improve safety, performance, and outcomes," says Francesco Tizzani, group manager of digital construction at Leighton Asia, an international construction contractor headquartered in Hong Kong and part of CIMIC Group. "The technologies also reduce manual reporting, enabling our people to focus on analyzing intelligent data to improve project delivery."

Digitization is being used to innovate in all areas at Leighton Asia, including safety, Tizzani says. For example, a safety solution from Nexplore, the wider group's internal software innovation company, has been trialed at a Leighton Asia

McKinsey analysts found front-runners in artificial intelligence (AI) adoption could double their cash flow (economic benefit captured minus associated investment and transition costs) by 2030, with a 122% cumulative change.

"Notes from the AI frontier: Modeling the impact of AI on the world economy," McKinsey & Co., September 2018



construction site. An AI-powered proximity detection camera system monitors exclusion zones (no-go areas around high-risk activities) and raises an alarm if, for example, an operator or worker enters an exclusion zone established to protect them from moving equipment.

But many see these applications as only the beginning. AI is well suited for a wide range of innovative use cases across AEC and D&M design and production processes, from filtering big data to identifying opportunities for sustainability to capturing knowledge from an aging workforce to running simulations. “It can be the codification of human knowledge and intellect,” says Jo Vertigan, head of digital for the Anglian Water @ One Alliance, a partnership of seven companies collaborating on a significant proportion of the British water company’s capital investment program. “The application of AI and machine learning can allow us to capture nuances in the data [that] allow us to rapidly draw new insights.”

Quickly sorting through a multidimensional problem, such as optimizing the parameters for the most sustainable version of a design, frees people to focus their attention in the right places.

“There are so many things where we could make innovations,” says Stanford’s Fischer. “That’s where I see AI being able to give us the insights so we can prioritize what really matters and [what] has the biggest impact.”

As these examples illustrate, AEC and D&M organizations are adopting AI to uncover new insights and optimize choices across a wide range of disparate variables, innovations that would be otherwise very difficult to achieve. These benefits promise to multiply as organizations begin to collect more and better data. Indeed, according to Deloitte’s 2020 “AI Enablement in Smart Manufacturing” survey, 54% of respondents agree, and 39% strongly agree, that AI will be key to growth and innovation in manufacturing. The survey respondents were senior managers at 110 Chinese manufacturing companies.

Digital Twins Bring New Ideas to Life

Digital twins are also increasing their role as a tool of innovation in AEC and D&M. Organizations are tapping digital twins’ ability to create a virtualized version of a product or structure to enable designers and engineers to experiment with designs, materials, and other variables as part of the initial design process. The dynamic nature of digital twins and their ability to represent real-world data and performance on top of a virtual model create a feedback loop between physical and virtual environments. This loop helps users and organizations make better decisions, improve their business practices, and access benefits such as reduced downtime and increased ROI during construction and manufacturing. Digital twins also benefit the ongoing usage of products and buildings.

The global digital twin market is projected to grow at a 58% compound annual growth rate (CAGR) from 2020 to 2026, from $3.1 billion to $48.2 billion, respectively, according to a report from Markets and Markets.[6] The Asia Pacific

INDUSTRY INSIGHT

Overcoming Innovation Obstacles in Architecture, Engineering, and Construction

The architecture, engineering, and construction (AEC) industry has a complex relationship with innovation, often embracing new ideas in theory while hesitating to actually innovate due to practical and cultural limitations that disincentivize experimentation. Regulatory and contractual barriers often stand in the way of innovation, and the industry is highly fragmented, operating with low margins, high risk, and complex demands stemming from urbanization, population growth, labor shortages, and limited resources.

AEC's project orientation, where an array of separate contractors comes together for one-off builds, often means every activity must be billable, contracts must focus on avoiding risk and litigation, and razor-thin margins give leadership further reason to stick with what's proven. Cultural and business practices built around these conditions reinforce conventional ways of working.

The pressure to embrace innovation must be strong to overcome the obstacles. There's a lot happening in the current marketplace to ramp up that pressure, and AEC firms are responding. It takes organizational, cultural, and technological changes to drive greater adoption of innovative ideas and mindsets. Experts interviewed for this report recommend the following steps for AEC organizations to overcome obstacles and increase innovation.

Learn from example. One strong force is proof among an organization's direct peers. "This industry is exceptionally peer influenced," says Stephen Jones, senior director of industry insights research at Dodge Data & Analytics, a New York construction research firm. There's also a fair bit of wariness around vendor claims, so it takes enough data about results and what it actually takes to achieve them to drive the belief that failing to adopt new technologies and approaches will harm the business. "That's what's going to begin to pull things in," he says.

Lessons from the past suggest that more aggressive adoption of new technologies and approaches can pay off. Most AEC firms were reticent to adopt what's now known as building information modeling (BIM) in the 1990s, recalls Martin Fischer, professor of civil and environmental engineering at Stanford University. One Finnish mechanical engineering firm, Granlund, that did embrace BIM early on went on to become one of the few to thrive through a subsequent economic downturn and, in turn, expanded its role to become a primary consultant to building owners, Fischer says. "They dramatically expanded their footprint in the project and building life cycle. You can put it directly back to that strategic decision to invest in this innovation."

Restructure contracts. Structural changes can also address the disincentives to innovate. Integrated project delivery, a collaborative approach to building that includes multiparty contracts, has been highly effective at encouraging greater collaboration across subcontractors, says Dodge's Jones. Other experts point to insurance and other legal vehicles to share the risk that otherwise makes AEC organizations hesitant to try something new.

Improve data collection. Improved data collection and analysis are key to AEC innovation, particularly to fuel artificial intelligence and machine learning, but when projects are one-offs, data ownership becomes unclear. Data repositories, such as the one University College London (UCL) is helping create for Homes England, a major social housing provider, can amass the critical, unbiased data needed to fuel innovation. UCL is also testing production control rooms, leveraging data to monitor all aspects of an ongoing construction project. The first live site applications have taken place on commercial projects in London, says Jacqui Glass, vice dean of research and a professor in construction management at UCL. With a production control room in place, "You've suddenly got a very different environment to bring in other technologies—it's like opening a door to new ways of working and thinking about AEC," she says.

Work cross-functionally. Successful strategies to put more focus on innovation also include establishing more diverse, cross-functional teams, including collaboration with third parties such as startups and academics. And in-house labs and innovation teams using sprint cycles and other fast development techniques have also been effective—but only if AEC leaders do the cultural work to enable their ideas to

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INDUSTRY INSIGHT

CONTINUED FROM PAGE 7

migrate successfully into the broader organization. Staff need time, resources, and permission to fail in order to generate new ideas that transform old ways of working.

Restructure around innovation. Jo Vertigan, head of digital for the Anglian Water @ One Alliance, a partnership of seven companies collaborating on more than 50% of the British water company's capital investment program, uses an innovation-focused iteration of McKinsey & Co.'s "Three Horizons Framework," a structure that enables organizations to explore potential opportunities for growth without neglecting current performance, to guide the transition of innovative ideas from concept to adoption. "Innovation and exploring new ideas take time and effort; [they] can't just be slotted in in your spare downtime," Vertigan says. "You've got to support [them] with robust commercial underpinnings but also be mindful of having the time and space to learn. You should be careful of customer-led innovation, as it is not always best placed to articulate a future world, especially in traditional business sectors."

region is expected to experience the fastest CAGR, with the manufacturing industry predicted to be the earliest adopter.

According to a global survey conducted by London's Royal Institution of Chartered Surveyors from September to November 2021, 26% of respondents are using digital twins and 18% have started taking the first steps to implementation. The top use cases are facilitating data sharing to deliver performance efficiencies for all stakeholders and gathering real-time site data for decision making and collaboration (each 54%).

"Digital twins will help reduce the developmental cost of some parts of design and demonstration [processes], which can help improve profitability," says Yuya Kajikawa, a professor at the School of Environment and Society at the Tokyo Institute of Technology and at the Institute for Future Initiatives at The University of Tokyo.

Hyundai's New Horizons Studio is putting digital twins of its concept UMV into digitally simulated worlds. The long-term goal is to evaluate the performance of the vehicle in that environment. Because of the complexity of emulating realistic traction of the vehicle on simulated surfaces, New Horizons' shorter-term goal is to show how a UMV might be used in various scenarios in which the physics of the vehicle

The dynamic nature of digital twins and their ability to represent real-world data and performance on top of a virtual model create a feedback loop between physical and virtual environments. This loop helps users and organizations make better decisions, improve their business practices, and access benefits such as reduced downtime and increased ROI during construction and manufacturing.

performance is simplified. That insight gives potential customers a way to understand what a future product could do and provide their feedback, which engineers can then use to iterate new designs without ever having to build a physical prototype.

"If you have a new product type with new capabilities, it's hard to even articulate or even absorb what is the benefit of something that they've never touched before," says New Horizons' Suh. "But if they're interacting with it virtually, they can." Simulating designs and material usage is also helping AEC organizations throughout the building process.

Leighton Asia's Tizzani is excited to see the company leading the way in the use of digital twins. "We are building the asset and its digital twin for our clients. A digital twin begins with a dynamic BIM model of what has to be built. We integrate a project's multiple workflows into the model and input data as the project progresses," he explains. Because Leighton Asia is not locking data into spreadsheets and 2D drawings, the team can use the model and visual reporting to collaborate on change management. Then, they can use simulation and machine learning to help decision making, improve efficiency, and reduce rework. "When construction is completed, the digital twin is invaluable for operations and maintenance across the asset's life," Tizzani adds.

While current progress is encouraging, the potential for digital twins to transform much of the process of designing and producing goods and structures in AEC and D&M still lies ahead. By increasing the volume and variety of their data collection activities, organizations can lay a foundation to reap insights and drive experimentation in the future.

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Innovation through Next-Gen Design Approaches

The need to elevate organizations' capacity to innovate is also driving increased use of generative design and design for manufacture and assembly. Generative design is a design exploration process that takes into account design goals, parameters, and constraints to quickly generate and test design alternatives. DFMA enables engineers to incorporate construction into early design phases, when changes are less costly. It also enables designers/architects, engineers, fabricators, contractors, and subcontractors to work hand in hand in the design process and collaborate on goals, such as reducing time and total project costs. Architects, for instance, can know how each part will be fabricated and assembled so they can optimize their designs consequently. And manufacturers and fabricators can share their constraints in advance so that architects or designers can take them into account. Efficiency in the design process provides huge benefits in cost and efficiency downstream as projects progress.

Bryden Wood uses generative design in several ways to infuse innovation into its processes, including helping "serial" builders that need to erect variations of the same asset on multiple sites. Instead of designing each location as a one-off using conventional approaches, generative design can quickly produce 100,000-plus proposed variations, which can be "down selected" according to a client's value drivers to arrive at the ideal design for each individual site. That success enabled Bryden Wood to take the generative design concept to the next level by asking what *else* the organization could do by having an optimized design in hand. The company used automated design to develop a rapid-assembly, highly accurate set of parts for the superstructure of The Forge, a net-zero carbon commercial office project in South London.

"We then [asked] the mechanical and electrical contractor, 'If you knew that the superstructure was super precise, all your fixing points are already in the slab, and they're also very accurate, what would you do with that?'" says Bryden Wood's Johnston. In a conventional project, the mechanical and electrical contractor would install electrical components manually on-site as a series of individual trades due to the inevitable variation in, say, the placement of a column. But because the superstructure was built to the design's exact specifications, the electrical contractor was instead able to create multiservice cassettes containing mechanical and electrical components in a factory, then wheel those into position and quickly raise each one into place. Essentially, the contractor could design for manufacturing and assembly. "The install time collapsed from hours to minutes," says Johnston. The same concept, applied to pieces of the façade, cut the time required to install each panel from an hour to seven and a half minutes.

The ability to consider manufacturing and automated assembly processes in the design stage will particularly bring value as more production processes are handled by robots, notes New Horizons' Suh. "We'll link our digital models of the components designed for automated assembly; then

Efficiency in the design process provides huge benefits in cost and efficiency downstream as projects progress.

that file will go straight to the robot that makes and joins the components," he explains. "Then on-site, people will use simple automation to support final assembly of the subassemblies quickly and accurately."

By adopting generative design and DFMA, AEC and D&M organizations are increasing their ability to generate, test, and collaborate on ideas early in the design process, enabling them to develop innovative approaches to how they work while also minimizing cost and increasing efficiency. As the use of generative design and DFMA continues to expand, they promise to bring far greater collaboration and cohesion to end-to-end processes in both AEC and D&M.

Stimulating New Approaches to Sustainability

There is perhaps no greater need for innovation than in increasing the sustainability of design, production, and construction processes. As the aforementioned pressure from governments and clients to create more sustainable products, processes, and structures continues to rise, AEC and D&M organizations will increasingly leverage AI and modeling tools and techniques to arrive at new designs that balance purpose, sustainable design and materials, and economic factors.

"There is generally a trade-off between environmental sustainability and economic efficiency," says The University of Tokyo's Kajikawa. AI and modeling can be tuned to help humans make those decisions in a complex trade-off, he says.

A Capgemini Research Institute survey of 480 global manufacturing executives conducted in February and March 2021 found that organizations are already seeing sustainability benefits from scaled digital technologies including automation, AI/machine learning, and data analytics. **FIGURE 2** For example, respondents report an average 15% reduction in waste over the past two years and another 20% expected over the next five. According to the report, "Innovation, driven by technology and data, can help manufacturers address both sustainability and economic concerns simultaneously."

"When you look at building structures and you're trying to remove carbon from your building, you're trying to reduce energy in use, but you also need to look at the embodied carbon within the building itself, the materials," says Jacqui Glass, vice dean of research and a professor in construction management at University College London.

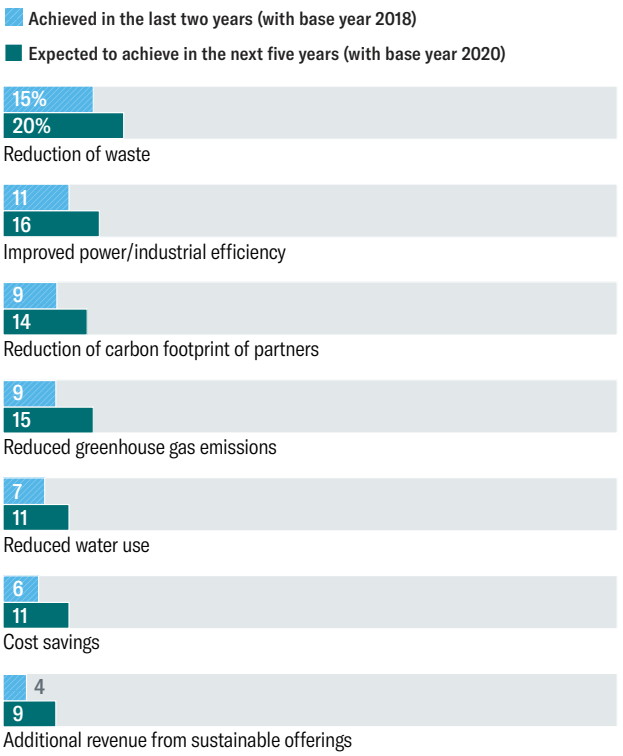
One example of innovation in sustainability, she notes, is the Automating Concrete Construction project at the U.K.'s University of Bath, which seeks to dramatically improve sustainability and productivity in construction by defining a holistic approach to the manufacture, assembly, reuse, and deconstruction of concrete buildings. Machine learning, a subset of AI that allows a machine to automatically learn from past data without specifically being programmed for

FIGURE 2

Digital Investments Deliver Sustainability Benefits

Manufacturers report payoffs from scaled use of digital technologies including automation and artificial intelligence/machine learning

What are the average sustainability benefits from scaled digital technologies?



Source: Capgemini Research Institute, 2021

that purpose, is being used to design smart slabs that are then created using concrete frames, cutting material use by up to 50% by ensuring concrete is placed only where it is needed to provide sufficient stability and strength. Then 3D printing and robotic production improve the efficiency of the production process. "That's a really nice demonstration of how you're bringing together the technologies to drive innovation in how construction processes can be made more sustainable," Glass says.

As the need for greater sustainability in manufacturing and construction processes and materials has gained urgency, AEC and D&M organizations are turning to innovation to break through the limitations of traditional practices. Approaches incorporating AI, digital twins, generative design, and DFMA promise to enable new ways of working that remove waste, speed processes, reduce costs, and create far more cohesive, integrated ways of working.

Discovering new ways to remove time, materials, and other costs from the design and production of goods and buildings requires overcoming some considerable obstacles. AEC and D&M companies must tackle the organizational, cultural, and technological challenges unique to their industries to successfully lay the groundwork for more innovative practices.

Addressing Complex Challenges with Innovation

AEC and D&M industries have always faced challenges, of course. But today's competitive and customer pressures, sustainability and workforce challenges, and rising mandates are being felt more intensely than before. Many see innovation as the key to unlocking the new materials, processes, and creative energy required to meet this moment.

Increased focus on innovation is driving AEC and D&M organizations to explore tech-enabled ways of working. AI and approaches including digital twins, generative design, and DFMA are automating rote processes and helping people discover, test, and implement better ways to achieve organizational goals. Early adopters of these technologies, including Bryden Wood and PIX Moving, are seeing marked reductions in capital costs and design and production time frames and discovering more sustainable materials and methods.

"In this day and age, there is no option other than to innovate in order to grow," says Jo Geraghty, cofounder of Culture Consultancy.

To truly reap the benefits of new tech-enabled approaches to innovation, organizations are also changing how they work. In AEC, successful strategies include changing how contracts are structured, improving data collection and analytics, and creating a more formal structure for infusing innovation into day-to-day work. In D&M, fostering more diverse, cross-functional internal teams, collaborating with universities and startups, and making room in the culture for innovation are helping organizations successfully nurture and monetize new ideas. Experts are confident that those able to clear the hurdles to adoption are poised to benefit from embracing innovation across their ecosystems.

"In this day and age, there is no option other than to innovate in order to grow," notes Culture Consultancy's Geraghty.

Endnotes

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