AUTODESK.

CONSTRUCTING WITH THE POWER OF DIGITAL

Foreword

Welcome to Autodesk's digital manifesto for the construction industry. In this report, you will find a vision for how technology can deliver a more profitable, resilient, and agile industry, and a better built environment.

Predicting the future is never an easy business; aligning the fast-paced world of technological change with the conservatively natured $10 trillion construction industry can be especially tricky. Yet, investing time to explore that future is something all construction professionals must now do. Having not just informed positions on the range of opportunities that new technologies hold, but incorporating those positions into corporate strategy, will soon be just as much a pre-requisite for success as a strong balance sheet, a social license to operate, and a skilled workforce.

New technology, by its nature, is disruptive. It breaks and remakes business models, reshapes definitions of value in markets, and creates not only new forms of competition, but new competitors too. Today, the number of new technologies emerging is breathtaking: *3D printing, infinite computing, crowdsourcing, robotics, machine learning, drones, big data, the Internet of Things (IoT), predictive analytics, augmented reality, generative design, gaming engines, and reality capture*, to name a few. These trends are transforming how we design, build, and operate buildings and infrastructure.

From work pipelines driven by sensors to estimates designed by algorithms; from printed buildings to big data-driven scheduling; from new forms of project funding to a new era of digitally driven localism for our built environment, the implications for the industry are profound. The potential to transform so many facets of construction is up for grabs. Unlocking this potential will become critical for contractors over the coming years. The rewards are significant: Improved levels of productivity, reduced risk, greater resilience, and better margins. But we'll also see a new competitive landscape emerge, as democratic access to such disruptive technologies makes it easier for firms to innovate. A competitive landscape where traditional barriers to entry—capital, knowledge, efficiencies, relationships—might be swept away.

Alongside this shift, the world wants and needs more buildings and infrastructure. By 2030, population growth, urbanization, and economic expansion are forecast to increase worldwide demand for construction output by 85%[1]. Fulfilling this pipeline will not be a case of 'more of the same.' Growing sustainability requirements, constrained finances, increasingly complex urban landscapes, skills shortages, and shifting expectations of asset owners, end users, and society will all require the construction community to develop new ways of thinking about and delivering buildings and infrastructure. Perhaps the application of these emerging technologies to the grand challenge of ensuring tomorrow's built environments are economically viable, socially inclusive, and environmentally sustainable will deliver the ultimate benefit to industry and society alike.

Dominic Thasarathar
Industry Thought Leader
Construction, Energy, Natural Resources
Autodesk

Image: sursad//Shutterstock.com

“Si monumentum requiris, circumspice.”

If you are searching for his monument, look around.

Epitaph of Sir Christopher Wren

Image: Spcruciatti/thinkstockphotos.co.uk

Time for Change

Construction is important. Consider the numbers: 6% of global GDP, $10 trillion in revenues[2], and a powerful stimulant for growth—in the U.K., every £1 invested in construction delivers £2.84 of economic activity[3], with similarly impressive figures for other markets. But, more fundamentally, construction is the progenitor to every other industry; it delivers the residential, social, and economic infrastructure that underwrites so many aspects of our daily lives.

And that importance is only set to increase. By 2030, worldwide construction output is forecast to reach $17.5 trillion ($2014), some 85% greater than 2014 levels[4]. The scale of the task ahead is intimidating. By 2020, China will have constructed 31,000 miles of high-speed rail networks[5]; by 2030, India will need to build homes for an additional 165 million urban dwellers[6]; and by 2040, 4,400 GW of additional power generation infrastructure[7] must be created to meet worldwide demand for electricity. Just a few of the many statistics that highlight the generational nature of the challenge the industry faces.

Achieving success in tomorrow's market isn't going to be a simple case of scaling up today's practices. Against a backdrop of rising project complexity, levels of risk, uncertainty over the flow of money into projects, skills shortages, the growing globalization of construction, and other factors, securing a profitable place in tomorrow's market is increasingly going to be linked to a contractor's ability to innovate.

Today, the construction market is still frequently burdened by an emphasis on risk and money. This has habitually suppressed productivity levels, kept margins low, introduced cost and waste, and reduced the industry's ability to add value to the built environment. The root causes are many, varied, and well-documented: Opposing business goals of project participants, the manner in which projects are procured, fragmentation of the supply chain, lightly capitalized balance sheets, the uniqueness of each project, and the variable cost nature of contracting, to name a few. With the cyclical nature of construction providing only limited windows in which to address these issues, the challenge of changing the industry can seem insurmountable.

If technology is to help the industry, then it needs to do more than just tweak a process or incrementally increase productivity, it surely must have grander aspirations. This manifesto then seeks to position technology in support of:

- A sustainable and predictable **margin** that appropriately reflects the level of skill and professionalism that firms bring to the table, and the level of risk they take with them
- A greater **resiliency** across and throughout the sector, affording a degree of insulation from the extremes of the 'boom and bust' cycle, the inefficiencies and uncertainties of discrete procurement, and rising levels of risk and complexity
- Agility to **grow and transform**, to take advantage of new markets, new relationships, and new business opportunities, to counter new competitors with a strong reputation
- A fostering of greater **cooperation and collaboration** between all stakeholders to deliver better outcomes for our built environment

Construction represents

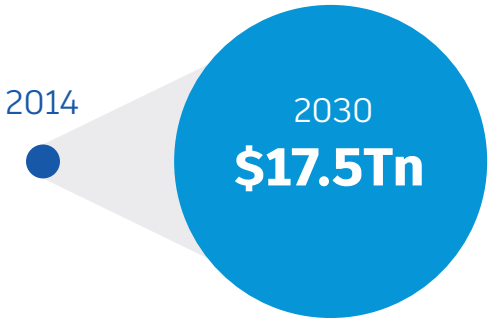
6%

of **global GDP**

Source: World Economic Forum[2]

In the UK, every £1 invested in construction delivers £2.84 of **economic activity**

Source: LEK Consulting[3]



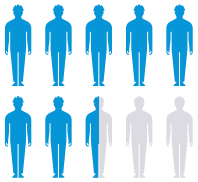
By 2030, worldwide **construction output** is forecast to reach $17.5Tn ($2014), some 85% greater than 2014 levels

Source: Global Construction 2030[4]

There are up to

180 million

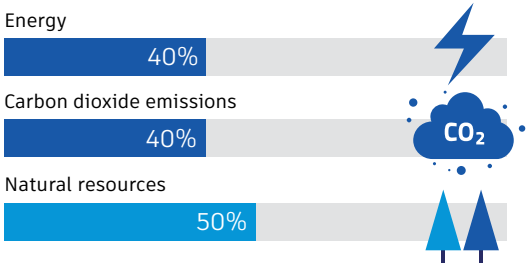
construction workers worldwide



are in developing countries

Source: Building and Woodworkers International, accessed http:www.bwint.org/pdfs/WCProcurementFiona.pdf

Today, our **built environment** utilises the world's:

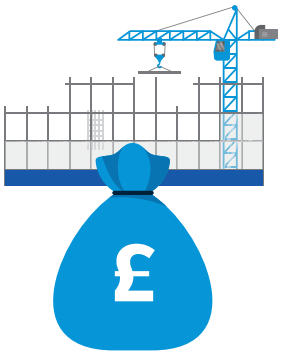


Source: Global Construction 2030[4]

Average global construction **project margins** fell from an already low 6.3% in 2015 to

6.1%

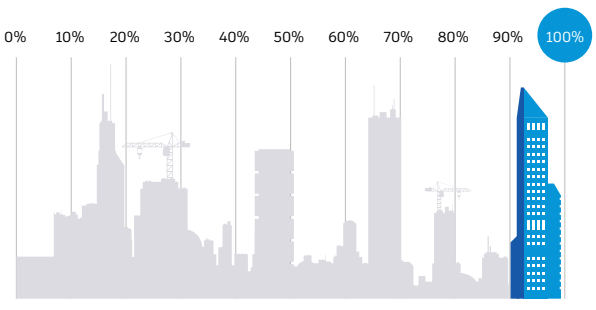
in 2016



Source: Turner and Townsend International Construction Market Survey 2016

Skills shortage is common in many construction markets, with only the above **four** having excess labour due a downturn in those markets

Source: Turner and Townsend International Construction Market Survey 2016



Just **a quarter** of construction projects in the last three years came **within 10%** of their original deadlines

Source: KPMG, Climbing the Curve, 2015 Global Construction Project Owner's Survey

Technology: from the Past to the Future

When we think of technology, the future can seem daunting. Reading the headlines makes it seem like we could all be out of a job within a few years—replaced either by smart algorithms out-thinking us or by robots outworking us.

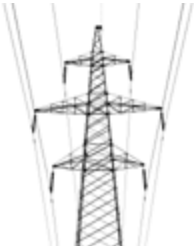
Behind the headlines, there's certainly an element of truth, as the nature of work will be changed significantly by technology over the next decade. But technological change is as old as human history. And construction professionals can take comfort in the fact that their industry has a rich heritage of adapting to and driving this change.

To illustrate the case, jump back two thousand years and consider the Pantheon in Rome. Completed in around 126 AD, it is home to what is still today the world's largest unreinforced solid concrete dome—weighing over 4,500 tons, with a diameter in excess of 43 meters, and without a single piece of reinforcing steel. This was made possible by the innovation of a Roman contractor who created a new form of lightweight concrete, containing volcanic ash, which allowed the build to span such large distances.

In recent times, we've become accustomed to an increased pace of change. Consider for example, Building Information Modeling (BIM). The benefits of BIM are now too compelling to ignore: In 2013/14, was a significant contributor to over £800 million savings in construction costs in the U.K. alone[8]. It's a poster child example of how technology can affect construction, and how early adopters can gain an advantage.

The breadth of change that we're currently experiencing, however, is broadening, and the pace is accelerating. For instance, a roll call of digital trends piquing your attention today might include:

Individually, each of these has the potential to change one or more aspects of the industry. Collectively, the interaction between these trends is giving rise to something bigger. They're fundamentally disrupting the very way in which we design, build, and operate buildings and infrastructure assets. And those disruptions are about to transform the industry.



100 AD — Invention of concrete and the dome by the Romans

1756 — First use of Portland cement

1760 — First industrial age, iron and steam

1777 — Ironbridge is the first large cast-iron structure built

1800s — General contractors are established

1818 — Tunnelling shield

1839 — Steam shovel

1853 — First reinforced concrete structure

1855 — Brick-making machine

1880 — Second industrial age, steel and electricity

In 2013/14, **BIM** was a significant contributor to over

£800 million

savings in construction costs in the UK alone

Source: G Paterson, J Harty and T Kouider, 2015[8]

Within

10 years

full-scale **digitalisation** of the construction industry will lead to huge **annual global cost savings**.
For non-residential construction, those savings will be:

Design & Engineering and Construction phases

$0.7 trillion → **$1.2** trillion

Operations phase

$0.3 trillion → **$0.5** trillion

Source: World Economic Forum[2]

Technologies

such as

Robotics

Mobile

IOT

Cloud

Big data

are the main drivers of change in employment between 2015 – 2020, accounting for

2.02%

change, compared to an overall flux of 1.73%

Source: World Economic Forum, Future of Jobs 2016

1895 Mature high-rise building technology emerges

1900s Prefabrication becomes more widely used

1905 Emergence of project planning

1960s Development of CAD

1985 First concepts of on-site automation & robotics emerge

1993 Laser scanners are first used by engineers

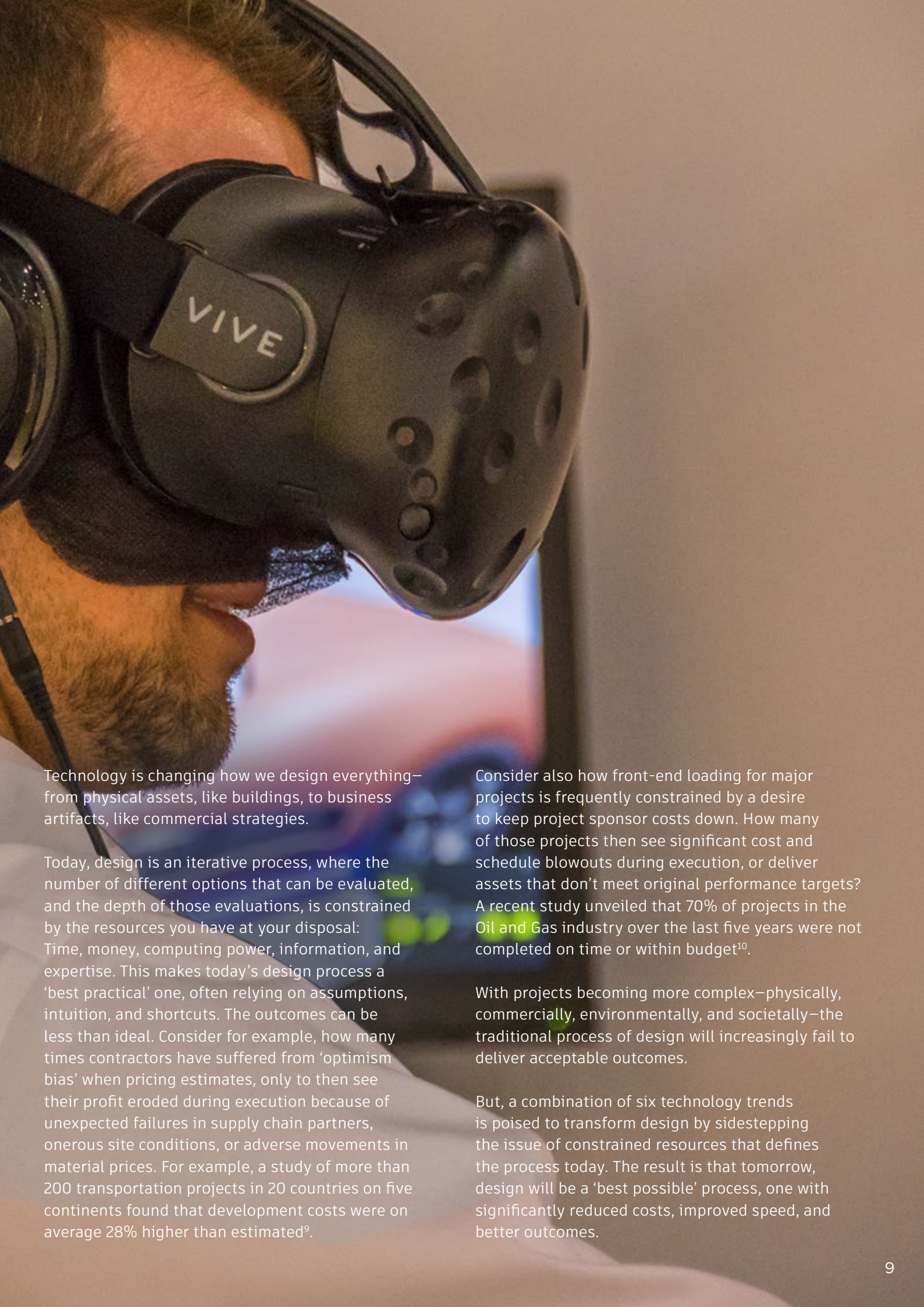
1997 First BIM tool established

2000s Cloud computing starts gaining momentum

2010s Emergence of drones, AI, virtual reality and augmented reality in construction

2013 First 2-meter building block was 3D printed

Changing how we design



Technology is changing how we design everything—from physical assets, like buildings, to business artifacts, like commercial strategies.

Today, design is an iterative process, where the number of different options that can be evaluated, and the depth of those evaluations, is constrained by the resources you have at your disposal: Time, money, computing power, information, and expertise. This makes today's design process a 'best practical' one, often relying on assumptions, intuition, and shortcuts. The outcomes can be less than ideal. Consider for example, how many times contractors have suffered from 'optimism bias' when pricing estimates, only to then see their profit eroded during execution because of unexpected failures in supply chain partners, onerous site conditions, or adverse movements in material prices. For example, a study of more than 200 transportation projects in 20 countries on five continents found that development costs were on average 28% higher than estimated[9].

Consider also how front-end loading for major projects is frequently constrained by a desire to keep project sponsor costs down. How many of those projects then see significant cost and schedule blowouts during execution, or deliver assets that don't meet original performance targets? A recent study unveiled that 70% of projects in the Oil and Gas industry over the last five years were not completed on time or within budget[10].

With projects becoming more complex—physically, commercially, environmentally, and societally—the traditional process of design will increasingly fail to deliver acceptable outcomes.

But, a combination of six technology trends is poised to transform design by sidestepping the issue of constrained resources that defines the process today. The result is that tomorrow, design will be a 'best possible' process, one with significantly reduced costs, improved speed, and better outcomes.

1. Infinite Computing in the Cloud

Cloud computing is something familiar to us all. We use it for e-mail, office automation and social networking. But there's another aspect to the cloud that has the potential to transform the future of design, the ability to access vast amounts of computer processing power, on-demand, to undertake complex analytical tasks quickly – "Infinite Computing".

In construction, this might enable project teams to reverse the design process and 'start with the end outcome.' For example, consider a contractor working with a commercial property developer who has identified an opportunity to provide 10,000 m² of new high-end office space in a particular city location. What is the right built asset answer to this business opportunity? Exploring the thousands of combinations of parameters—physical dimensions, material choices, financing options, and procurement paths, for instance—to land on a design and associated project with the maximum return and lowest total cost of ownership simply isn't possible under today's design process.

2. Generative Design

Humans are creative, able to process large amounts of disparate data, and capable of thinking in complex and abstract ways to solve problems. But we also bring our own biases to problem-solving. Computers do not.

Generative design—the use of smart algorithms that mimic nature's approach to design—is unconstrained by pre-conceptions of what 'good' design is. Imagine how the bidding process could be transformed. Consider for example, a contractor given six weeks to respond to an aggressively procured, single-stage design and build engagement. They could enter their client's specification, dial in the level of desired margin, contingency, and supply chain partner profiles, and watch as an algorithm identifies the best options for their response. The implications for the cost of bidding and the efficacy of bids could be huge.

3. Big Data and Predictive Analytics

Big data has been used by other sectors for some time, most commonly being associated with finance and retail where it's being used to predict default rates on loans and shopper behavior respectively. Today, in construction, large amounts of highly structured data is being generated through BIM and through other project technology tools. That's opening the door to a new discipline, *Construction Intelligence*—the ability to predict the future by mining that data.

Searching for patterns across a portfolio of projects, together with other data sources, might help a contractor identify everything from early signs of stress in the supply chain to the best way to optimize cash flow and the root cause for over-estimation in bids.

4. Symmetrical Collaboration in the Cloud

Construction teams are complex, frequently spanning multiple organizations and geographies. Collaboration between project teams and stakeholders continues to be a perennial problem—one that introduces cost, delay, rework, and risk to projects. Yet, a recent study revealed 82% of construction industry leaders expect there to be greater collaboration between project owners and contractors over the next five years[11].

At its heart, collaboration in construction is predominantly an asymmetric process—multiple parties in the supply chain each work on their own aspect of a project, then clash detection is performed by aggregating those individual models.

5. Social and Mobile Computing

No amount of computing power will negate the need for human input in the design process. But with overhead anathema for contractors, ensuring access to the best skills, at the right time, is something that the industry has long struggled with.

As the digital environment shortens the distance between us all, it's transforming notions of both 'work' and 'the workplace.' Work-exchange hubs—

digital marketplaces for fulfilling transactional pieces of work, such as Uber and TaskRabbit—are already taking hold in other sectors, creating the so-called 'gig economy.' While this hasn't translated into the construction industry yet, this type of development, together with crowdsourcing – where large numbers of people collaborate to solve complex problems via the internet – could allow contractors to access, on-demand, a far broader and deeper pool of expertise than today.

6. Collision of the Digital and Physical Worlds

All designs must ultimately translate into real-world assets, and those assets interact with the environment around them—physically, environmentally, socially, and economically. As technology continues to merge the digital and physical worlds, it's enabling project teams to design in the context of those real-world systems.

Augmented reality is enabling designs to be projected back into the real world to understand the physical impact that a proposed design will have on the environment. This is something that **Skanska** has started to adopt with its Innovation Grant Platform[12], which has supported pilot projects that integrate augmented reality and 3D gaming engines.

Of course, contractors can use these capabilities to drive down the number of mistakes made in the real world, in everything from asset design to operations and maintenance—it's far cheaper to get it wrong virtually than in reality. But perhaps more importantly, they can use these capabilities to deliver designs that perform better across multiple 'non-physical' dimensions. Using a gaming engine on a metro line expansion project could, for example, enable contractors to predict the impact on footfall for retail outlets near proposed station entrances.

Image courtesy of Skanska

The emergence of real-time collaboration environments should help shift the industry to symmetrical collaboration, as connectivity through the cloud will enable all project participants to effectively work in one 'virtual' project office. This is something that global construction firm, **Skanska**, has embraced, using the cloud to actively collaborate with its clients and design partners to solve problems virtually before they happen in the field[13].

Changing how we build

The means of physical production are also being fundamentally changed by technology with the way that all forms of capital projects are selected, funded, and delivered being directly affected.

Today, one of the industry's biggest challenges remains its level of labor productivity—if the workforce is 10% less efficient than expected, profits are reduced by a minimum of 5%[14]. As other sectors of the economy have seen significant gains in productivity over the last few decades, construction productivity has remained stubbornly low and flat15. This must now change, not just incrementally, but dramatically. With demand for construction output forecast to grow by 85% by 2030, the impact of scaling such poor productivity on our environment and economies, and the missed opportunities to add value to our built environments will be unacceptable. Collaborative procurement, integrated supply chains, and progressive legislation are certainly steps in the right direction, but will they be enough?

Image courtesy of MX3D

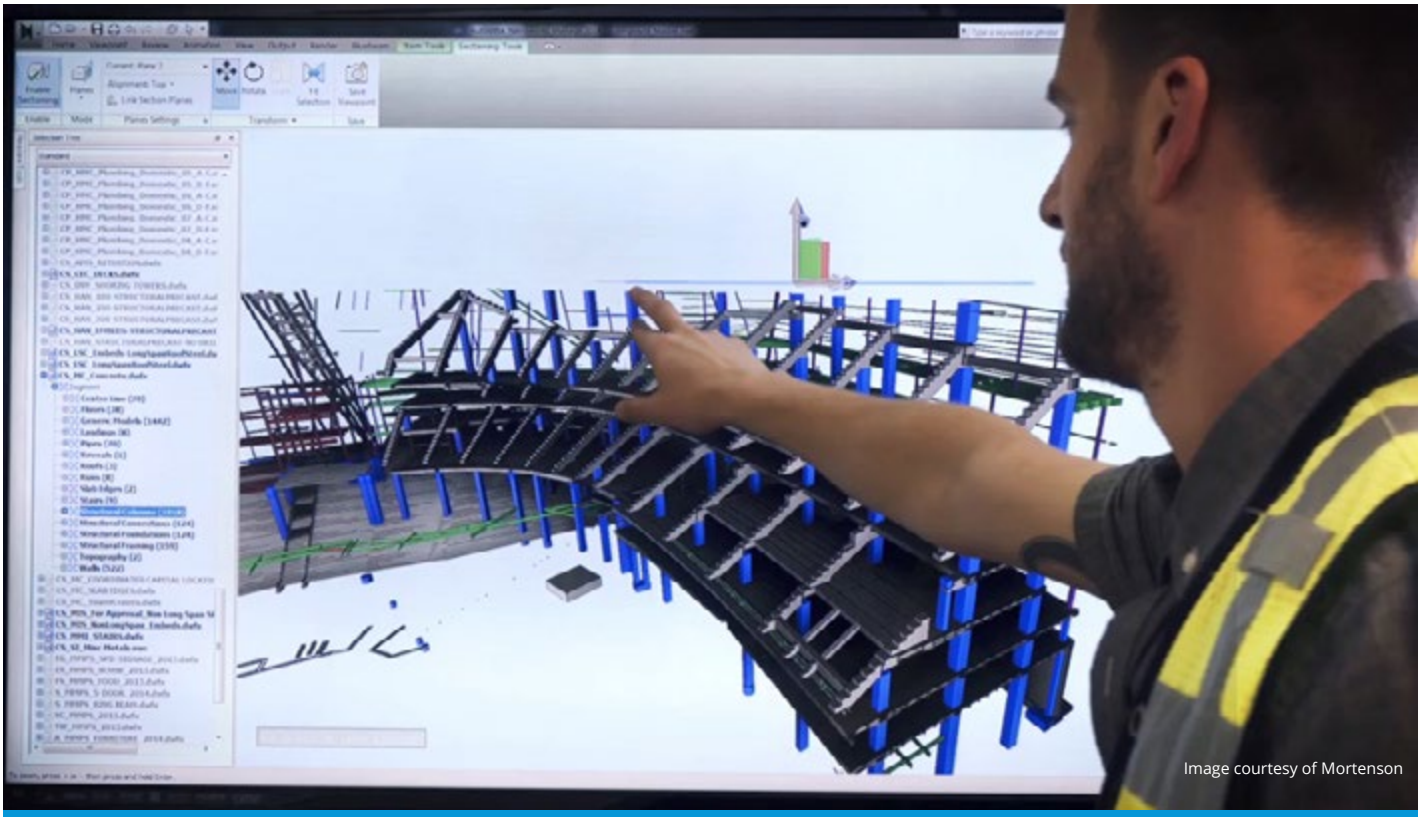


Image courtesy of Mortenson

Technology has the potential to offer a fast-track approach to transforming productivity. This is something that construction firm **Mortenson** has discovered thanks to its adoption of touchscreen interfaces and mobile hardware[16]. Productivity has dramatically improved, since feedback from the crews in the field can be shared in real time.

Contractors must also consider the productivity of the assets that they creating. For example, how frequently do they fully deliver the outcomes for which they were conceived? Does the toll road deliver the expected levels of revenue? Has the social housing development improved the quality of life of local residents? Did a new high-speed rail corridor deliver the anticipated GDP boost to a region? Technology can help them to make better decisions about what assets to build, and the mix and nature of those assets.

An 85% increase in the size of the this capital will come from. Indeed, global infrastructure faces an annual financing gap of $1 trillion[17]. But tomorrow's technology should help to improve the flow of money into tomorrow's buildings and infrastructure projects.

1. Big Data-Driven Decisions

In 2007, half of global GDP came from 380 cities in developed regions, but by 2025, 136 new cities, all from the developing world, are expected to enter the top 600 cities[18]. Construction is changing. It is increasingly being reshaped by the need to build in the context of complex urban environments, and by a shift in the center of gravity of output to emerging nations. Where and how should clients and contractors respond to this dynamic? Confirming which assets to build to achieve a desired outcome, and which projects to bid to ensure profitable growth, will increasingly rely on finding project pipeline needs to be matched by an equally sized increase in funding, but there are questions over where answers in data. Trends in population demographics, economic growth, disposable income, and more will be crunched by cloud computing to help answer those questions.

That need is driving the creation of new tools that

are capable of modeling building and infrastructure information at the macro scale, enabling contractors to help their clients to make decisions in multiple contexts. Perhaps most significantly, this will support a shift in the way we think about our built environment– for example, moving, infrastructure master-planning from a 'costs and assets' driven focus, where emphasis is on short-term point solutions, toward an 'outcomes and value'-driven focus, where contractors, and their clients, can think in terms of connected systems–a system-of-systems approach.

Global infrastructure construction group Balfour Beatty used BIM as part of its project to convert London's Olympic Stadium into the new home for West Ham United Football Club. BIM has enabled Balfour Beatty's teams to track performance in real time, identify and address workflow bottlenecks, and keep all project stakeholders up to date with the latest information and documentation[19].

2. Digitally-Driven Capital

Construction needs capital to build, but since the 2008 financial crisis, uncertainties have hindered the flow of funds into projects. Technology trends, however, are beginning to offer three new ways of unlocking capital with which to build:

- **Matchmaking on Risk:** Understanding the risk profile of projects is something that big data and predictive analytics can improve. 'Closing the loop' on how existing assets are utilized via the IoT should enable a better understanding of how future assets are likely to perform, enabling investors to understand the risk profile of a project before committing funding.
- **Determining Remaining Value:** The world's total built asset wealth is estimated to be $218 trillion[20]. Unlocking capital by selling assets then investing the proceeds in new projects is common. But it's a process dependent on accurately determining how much value remains in an asset. Predictive analytics, remote sensing, and IoT feedback should help to better quantify that value to maximize the level of capital released (and the liability being taken on). For example, interrogating maintenance patterns for a road system and future forecast vehicle movements might more accurately determine the likely cost of maintaining that road.
- **Crowdfunding:** Crowdfunding is already being used to raise capital in manufacturing, entertainment, and many other areas, but in the built environment, it could be used as a way to raise finance for private-sector real estate development and public-sector social infrastructure projects.

3. Prefabrication & Digital Fabrication

Prefabrication isn't new, but it is becoming easier. Advanced modeling technology is enabling contractors to work both from the bottom up to use standardized elements for buildings and infrastructure, and from the top down to split an inherited design into elements that might be prefabricated off-site, then assembled on-site.

Once the preserve of relatively modest assets, prefabrication is now scalable, and has the potential to help the industry to achieve a high degree of standardization–a cornerstone in unlocking manufacturing-style productivity levels. Buildings can be manufactured in low-cost execution centers, then shipped around the world for final assembly, providing significant implications for the competitive landscape in construction.

But standardization isn't appropriate for every project, or every component. The new industrial revolution in manufacturing is rewriting the process of going from a great design for an item to a finished real-world artifact. At the vanguard of this revolution is digital fabrication, and in particular, 3D printing. Today, it is possible to go directly from a 3D model of an item to a finished real-world object in a single touch, with a single machine, without having to retool, in over 80 different types of material– steel, glass, ceramic, polymer, concrete, and more.

This is transforming the modern manufacturing paradigm that has been with us for over a hundred years–to date, it's been cheaper to buy a standard off-the-shelf component then have a bespoke item made because 'complexity and uniqueness' have been expensive traits in manufacturing. With 3D printing, 'complexity and uniqueness' are essentially free. Freed from the constraints of standard components, contractors can focus on the ideal solutions for projects, and then deliver those solutions with minimal waste.

Dutch 3D printing firm MX3D (as seen on page 12) is equipping industrial multi-axis robots with 3D

tools to create a fully functional steel bridge that will span the Oudezijds Achterburgwal canal in Amsterdam. Once complete, the MX3D bridge will be the first 3D printed bridge in the world[21].

Will we see 3D printers on job sites undertaking direct construction activities? Possibly. But perhaps we'll see something else happening instead. Microfactories are starting to follow in the wake of the democratization of manufacturing technology—relatively small, neighborhood facilities equipped with digital fabrication machines that are able to produce items, regardless of complexity. Could these significantly disrupt the traditional construction supply chain, which for the last 30 years has taken advantage of reduced trade barriers and transportation costs to grow into complex, global networks to source all the building products and related components that go into projects? If so, we could see the rise of the citizen builder, where community factories become a key component in the supply chain, local to the project site—reducing transportation costs and upholding localism.

4. Site Automation

New technologies such as drones can be used to perform surveys, scans, and inspections on construction sites. Feeding imagery taken from drones into reality-capture software, which stitches photographs together to create 3D models, essentially brings the real world into a silicon environment on a large scale. We're already witnessing the use of camera-fitted drones for multiple applications—from remote surveying of tall buildings and structures, mitigating the risk and cost of having operatives work at height, to the larger scale inspection of linear assets, like pipelines or rail corridors.

Wearable technologies are being used to improve safety on construction sites. Human Condition Safety is one firm leading the charge here and is in the process of developing solutions such as smart vests to help construction workers to get their job done better, safer, and faster, and provide the site managers with a real-time dashboard showing how many workers are currently in areas with elevated risk[22].

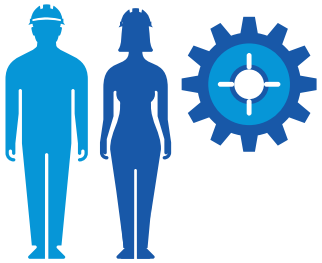
Robotics are also going from strength to strength in construction. Traditionally, robots have been used to do a limited range of repetitive tasks, mainly in handling materials and components. While this is well established on large-scale production lines, we're now at a point where robots are capable of so much more. In particular, robots can be connected to a broad range of sensors, which allows them to capture information about the parts they're working on. This data can then be fed back to the control system, which can then make adjustments to the robot's operation and drive greater efficiency and higher accuracy during the process.

The "I Make Rotterdam" project in the Netherlands is a prime example of a crowdfunded project. Why is crowdfunding so revolutionary? Because it opens the door to a new era of localism, one where contractor and community could be far more tightly coupled at all levels—finance, design, construction, and ongoing maintenance. One in which digital technology will increasingly be the common currency.

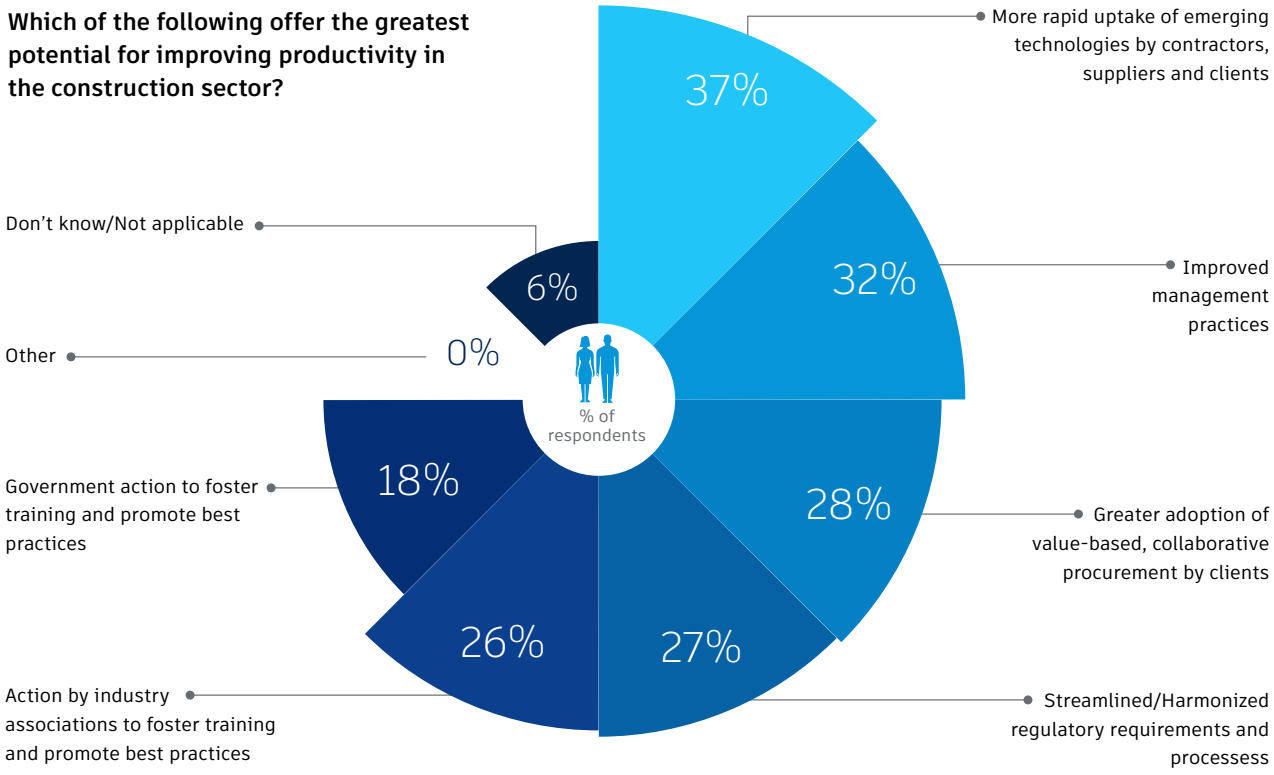
Image courtesy of Zones Urbaines Sensibles

Today, one of the industry's biggest challenges remains its level of labour productivity. If the workforce is 10% less efficient, profits are reduced by a minimum of -5%

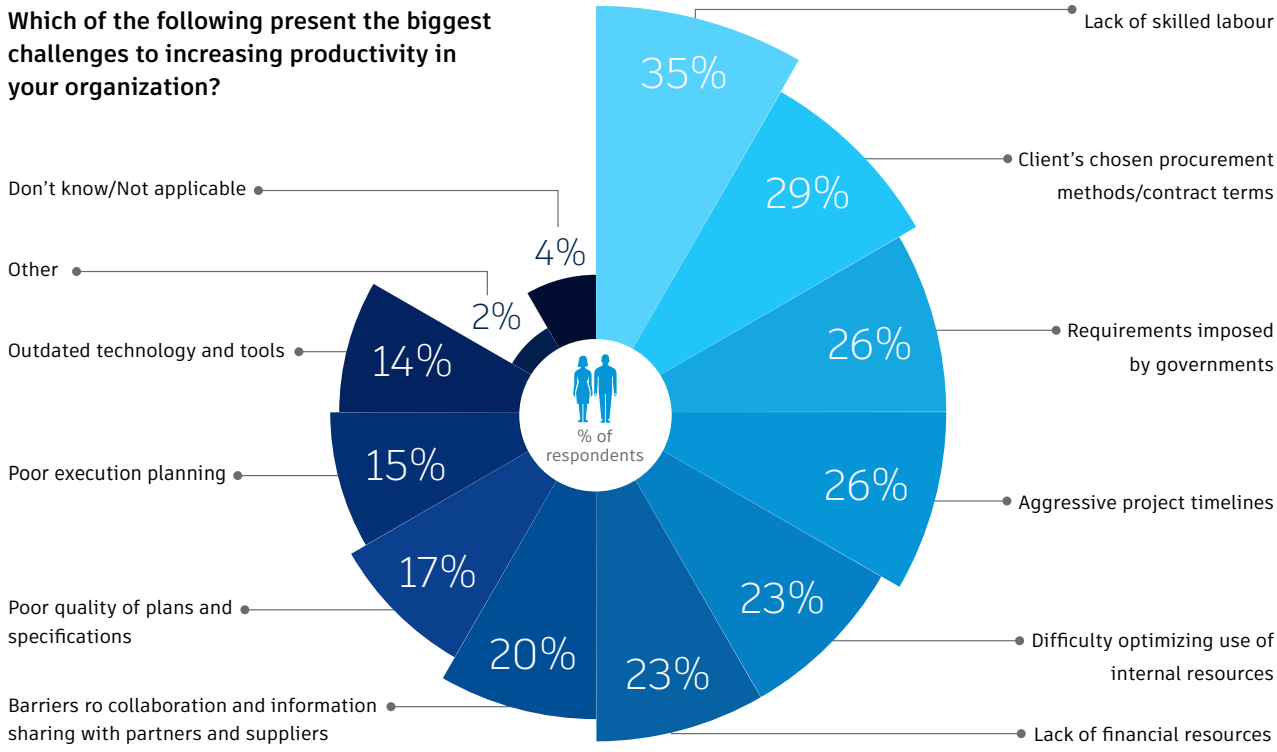
Source: Training4Contractors[14]



Which of the following offer the greatest potential for improving productivity in the construction sector?



Which of the following present the biggest challenges to increasing productivity in your organization?



Source: The Economist Intelligence Unit, Rethinking productivity across the construction industry, 2015

Changing how we operate

Technology is disrupting how we operate buildings and infrastructure, and the nature and quantity of those assets.

Things are getting smarter and more connected, from the proliferation of sensors in buildings that monitor everything from energy consumption to environmental conditions to smart utility networks that help to reduce energy consumption and improve resiliency. The digital and physical worlds are becoming deeply interconnected and interrelated.

At the same time, the rise of social and mobile computing is changing both living and working patterns, placing different demands on our built environment – from the nature and occupancy levels of office space to the volume and transit patterns of passenger journeys on our transportation systems, and to the type of telecommunications infrastructure needed. This pattern has already been witnessed in retail, as Internet shopping continues to displace bricks and mortar stores in shopping malls, with demand shifting toward warehouses and fulfillment centers.

Change is coming faster. Traditionally, a building might not need refitting or repurposing until a decade or more after construction. That cycle has not only been sped up, but we will increasingly see the need for concurrent “multi-purposing” of built assets.

And other, newer technology trends are already waiting in the wings. Drone-based delivery may reduce the number of vehicle movements on roads, changing future demand for highway infrastructure; and distributed manufacturing, a facet of the new industrial revolution in manufacturing, might similarly change freight transportation patterns.

1. Smart Assets Will Deliver Smart Value

As physical components, equipment, and systems become increasingly complex and interconnected with smart sensors, built assets have the potential to become more responsive to the needs of owners and end users. The traditional notion – that the value of buildings and infrastructure assets are static at the time of construction, predetermined and with a cap that is intrinsically linked to the asset's fabric and physical components – is changing.

The end-user experience is increasingly going to become personalized, for example, optimizing workspace environments for temperature, ventilation, and lighting. And as our cities become digitally 'lit up,' that experience will be personalized between assets too; for example, transport systems communicating the impact of delays in real-time on passenger journeys, and advising alternative routes.

Lighting accounts for up to 40% of a building's electrical use. In addition, it has been proven that the right level and quality of lighting in a space improves the alertness, accuracy, and wellbeing of its occupants. Tools like Panasonic's BIM aided and IoT enabled controller software can ensure optimal lighting conditions can be specified early in the design process, and accurately delivered downstream.

BIM-AM (asset management) is being used by **Hong Kong government department, EMSD**[23]. It links BIM with the building management system and CCTV, providing an accurate view of existing conditions (services and assets), which is linked to supporting information that can be viewed on desktops remotely or in the field via tablet devices.

When an incident is reported, users filter to specific equipment to view the necessary Operations & Maintenance information, alongside both historical and real-time performance data linked to the building management system (BMS). This enables facilities managers to more easily determine possible causes and potential resolutions. This can be achieved prior to visiting the facility in conjunction with CCTV to determine any access or safety issues.

The owner experience will change too. Access to unprecedented levels of data, such as occupancy levels, usage patterns, energy performance, water consumption, passenger journeys, and so on will offer increasing benefits. With access to these insights, owners and their project partners can make better, more informed decisions about a building and its surrounding infrastructure to lower costs, improve existing capacity without compromising end-user experience, or enhance it with new capabilities to maximize value.

When smart, connected products are combined with the cloud, they allow contractors to capture, analyze, control, and manage previously unseen data from remote products. For instance, energy management software provider **Panoramic Power** is combining its device-level energy analytics platform with Autodesk's cloud-based BIM portfolio to enable customers to identify inefficiencies in their sites and equipment, improve asset utilization, and reduce operational costs[24].

2. From Construction Services to Assets-as-a-Service

As an increasing proportion of our built environment is 'lit up' digitally via the IoT, the data produced could facilitate better forecasting of future demand patterns at a granular level. It could also enable future assets to be better designed to enhance performance, by feeding back usage data into new projects.

This 'closing of the loop' will offer contractors new business opportunities. By blending asset information with other large data sets, for example, population demographics, economic growth, and wealth levels, contractors will be able to achieve a deeper level of insight into future demand patterns for built assets. One of the industry's perennial problems, uncertainty in project pipelines, might, at least in part, be mitigated, enabling firms to focus on specific opportunities and to invest in those opportunities with a greater degree of confidence.

But moving beyond the individual asset, IoT data might support contractors in building new relationships with clients based on outcomes rather

than price or even value. As our built environments become more complex, and levels of risk increase, greater emphasis is going to be placed on how to achieve the end outcome without making a project unbankable, or otherwise unpalatable. No asset exists in isolation. Understanding how a proposed asset will connect with other systems, physical or otherwise, will be essential. Being able to ask existential questions like “What should we build?,” “Why should we build?,” or even “Should we build?” is something IoT data should help contractors to help their clients answer.

And as technology increasingly closes the gaps of understanding how assets are used, how they perform across their lifecycle, and the total cost associated with that lifecycle, it should open the door for contractors to venture further upstream into areas such as Real-Estate-as-a-Service.

Welcome to the Era of Connection

Construction must change. Today's procurement practices, commercial norms, business strategies, and productivity levels are simply unsustainable when placed against tomorrow's pipeline of demand for buildings and infrastructure. As our built environments become increasingly complex, ensuring they support the quality of life and economic vibrancy that the global population has come to expect is going to become increasingly difficult, and so too will attracting the much needed capital with which to build, if project and asset performance levels aren't addressed. Taking the risk out of construction and uncertainty out of work pipelines, improving both project delivery and contractor financial performance, making projects more bankable, closing the gap between targeted performance and actual performance of assets, and equipping the industry to think and act strategically, will be the entry requirements for tomorrow's market. Technology will deliver on those aspirations.

These three technology-driven disruptions—In how we design, build, and operate buildings and infrastructure—are giving rise to a new era for the industry. An era in which any contractor, regardless of size, location, sector, or capitalization will have democratic access to a new set of connected capabilities:

- ## Connected Teams

  the capability to connect people together dynamically, across geographies and commercial boundaries in real time. This will replace the industry's traditional, asymmetric approach to collaboration, and will reduce the overheads of having to access talent and expand the pool of available talent by the use of work-exchange hubs and crowdsourcing platforms.

- ## Connected Insights

  the capability to solve highly complex design problems, by connecting infinite computing power in the cloud, with big data and smart algorithms to make the best possible design decisions for everything from buildings to commercial strategies.

- ## Connected Outcomes

  the capability to 'start with the end in mind' by connecting the digital and physical worlds together seamlessly, through reality capture, gaming engines, and augmented/virtual reality. This will enable project teams to explore and refine options in the context of the real-world systems in which they are planned to reside—physical, environmental, economic and social.

- ## Connected Delivery

  the capability to go from a design for a building or infrastructure asset in a silicon environment into a finished real-world asset with the minimum number of physical 'touches,' waste, cost, and supply-chain overheads, through the use of digital fabrication, digitally driven pre-fabrication, and microfactories.

- ## Connected Assets

  the capability to connect real-world physical buildings and infrastructure assets digitally, to understand every aspect of how those assets perform, are utilized, and interact with the systems in which they reside. This collected data can then be used to inform future work pipelines and to improve our built environment.

- ## Connected Capital

  the capability to connect project proposals rapidly with committed funding by mitigating construction risks through highly digitally driven project delivery, and data-driven insights into the performance of proposed assets across their lifecycle; and connect project proposals with new sources of capital, through crowdfunding, and digital assessments of 'remaining value' in existing built assets.

What should contractors do to prepare for this impending Era of Connection? First, recognize the significance of what is coming—this isn't simply a case of incremental improvement to existing practices. Second, if not doing so already, adopt Building Information Modeling (BIM) since this will be the entry point to this new era. And finally, manage technology strategically, because the competitive landscape is about to be up-ended!

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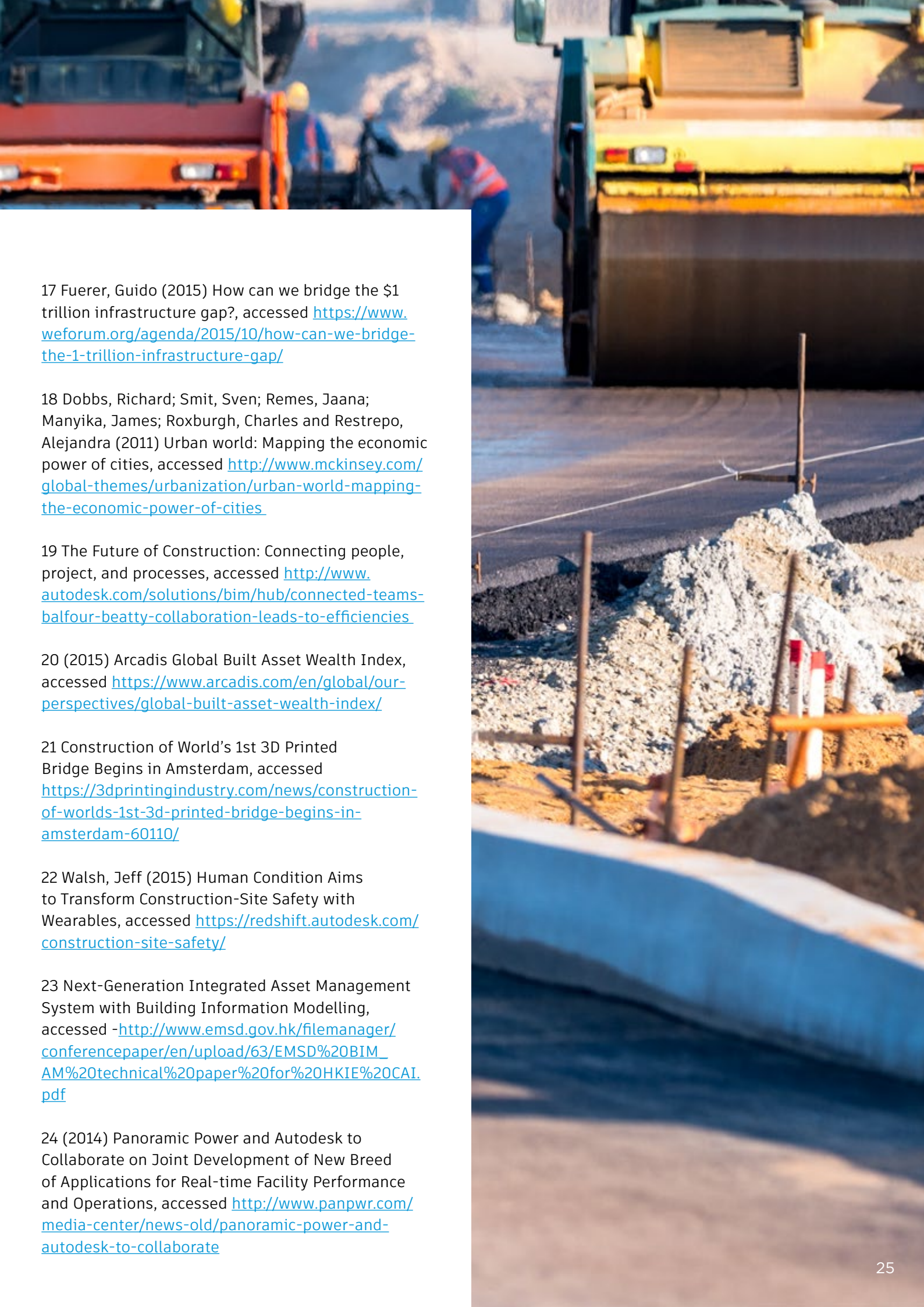

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