



GLOBAL
INFRASTRUCTURE
INITIATIVE

By McKinsey & Company

Voices on Infrastructure: Rethinking engineering and construction

October 2016



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Introduction: Rethinking engineering and construction

In this edition of *Voices on Infrastructure*, we focus on the engineering and construction (E&C) sector. Although the prospects for the industry are promising, given forecasts for future spending, there are also many challenges.



Jose Luis Blanco

Associate Partner, McKinsey



Maria Joao Ribeirinho


Partner, McKinsey

Among the issues: falling commodity prices, declining productivity, delays, cost overruns, a surge in competition, and a failure to adapt to new technologies. In addition, there is the uncertainty created by the “Brexit” vote, the US elections, and other geopolitical events, as well as the increased size and complexity of many projects. At the same time, the market is demanding that E&C firms master new delivery models, increase project accountability, and improve budget and on-time performance.

In this edition of *Voices*, we offer expert thinking on how E&C firms can do better. Operational transformation is a key theme. Two articles feature recent McKinsey research on how to improve productivity and profit margins. In one, three McKinsey colleagues examine five practical and relevant digital trends that will shape future capital projects. And in the other, together with Mauricio Janauskas, we suggest specific actions E&C companies can take to strengthen their operations.

Other contributions represent the views of leading external practitioners (these may not be consistent with those of McKinsey & Company). Jacqueline Hinman, the Chairman and CEO of CH2M Hill, describes how E&C firms can overcome short-term challenges while preparing themselves for the future. Jorge Quijano, CEO of the Panama Canal Authority, details the lessons learned from the recently completed expansion of the iconic waterway. Bechtel’s Craig Albert (President of Infrastructure) and Tam Nguyen (Head of Sustainability) share examples of how one of the world’s largest infrastructure companies is facing the challenge of sustainability.

E&C firms are big; they do not find it easy to change. Indeed, the transformations discussed in *Voices* are as much cultural as operational — and these are the most difficult of all to undertake. Companies that embrace change, however, will be best prepared for the years ahead.

We want *Voices* to be part of the conversation about the future of infrastructure — and invite you to join us. 

News from the Global Infrastructure Initiative

With the release of the third edition of *Voices on Infrastructure*, we can report that our reach is expanding. The second edition in June received comments and suggestions from people on six continents. Thanks for the feedback—and keep it coming.

We are pleased to announce our partners for the 2017 Global Infrastructure Initiative (GII) summit in Singapore in May 2017: Macquarie Group, Siemens, Spencer Stuart, and Surbana Jurong. In the buildup to this event, there have been a number of activities to enable participants to learn from global infrastructure leaders. In addition to the [roundtables](#) we have completed, [future ones](#) are scheduled for Mexico City, Perth, Singapore, Sydney, and Washington, DC. In June, we hosted a [site visit](#) to a modular-construction company in China; in September we visited GE Digital, and we're looking forward to a site visit at Crossrail and Tideway in October.

Based on the theme of this edition—rethinking engineering and construction—I wanted to highlight some of the tools that GII has developed for practitioners, in collaboration with McKinsey's Capital Projects and Infrastructure Practice. The [infrastructure-spending and stock database](#) delivers insights about existing infrastructure assets that can help governments, companies, and investors plan. The [road-and-bridge benchmarking tool](#) is a negotiation and risk-management approach to help owners understand what projects should cost and where schedules go adrift. Finally, the [infrastructure-projects analytics tool](#) tracks the key characteristics of more than 120,000 projects.

The next edition of *Voices* will be on the future of real estate. If you would like to let us know what you think of *Voices*, sign up for GII events, or receive more information, please contact us at info@giiconnect.com. 



Tony Hansen

Director of the Global Infrastructure Initiative



Engineering the future of maritime trade

Jorge L. Quijano

Lessons from the expansion of the Panama Canal.

When the Panama Canal opened for business in 1914, the 50-mile long waterway was hailed as one of the world's greatest engineering achievements. By linking the Atlantic and Pacific oceans, the canal immediately became a vital artery of international maritime trade.

As the demands of global commerce shifted, the canal had to evolve in response, for example by improving operational efficiencies. The most significant evolution, however, has been the recently completed \$5.25 billion expansion program, the largest construction project in the country's history.

The Canal connects more than 144 maritime routes. Its success has always been based on the quality and reliability of its service. But as the shipping industry began to rely more on vessels too large to enter the original Panama Canal's locks and channels, it was clear a major upgrade was needed. Following more than 100 studies on economic feasibility, market demand, environmental impact, and technical aspects, Panama voters approved the project in a national referendum in 2007.

The new and improved canal, which entered commercial service in June 2016, included the construction of wider, longer, and deeper locks, doubling the cargo capacity of the waterway. The new lane required the construction of three-step locks on both the Atlantic and Pacific sides, each 70 feet wider and 18 feet deeper than those of the original canal. The bigger locks allow the new generation of larger Neopanamax vessels to pass through, each carrying up to 14,000 twenty-foot equivalent units; these are responsible for the transit of 45 percent of the world's cargo.

It was no easy feat to complete a project hailed by many as a modern marvel. The work took nine years and included an intense and difficult gestation period. It meant bringing together a workforce of more than 40,000 people, including engineering professionals from numerous fields.

For infrastructure projects of this magnitude, it is not uncommon to run over time and for patience to wear thin. To ensure a successful outcome, it is important to maintain focus and to meet the problems that will inevitably arise, with ingenuity, creative thinking, and stamina.

During the canal expansion, for example, we faced the need to relocate up to 155 million cubic meters of material that was excavated and dredged to make way for the new lane. We devised a way to use this material to safely bury tons of unexploded munitions that the US military had left behind years ago, effectively using one problem to solve another.


Then there was a matter of water. The new wider and longer locks meant more water was needed to fill them. While the canal can draw the water it needs from surrounding lakes created for that purpose, these also serve as the main source of potable water for 55 percent of Panamanians. Maintaining these resources was critical. So we designed and installed 18 state-of-the-art water-savings basins, each with a surface area equivalent to 25 Olympic-size swimming pools. These allow the expanded canal to reuse 60 percent of the water used per transit and 7 percent less water in total than the original locks—a first for a lock complex handling ocean-going vessels.

Environmental stewardship is also imperative in undertaking major infrastructure projects. The canal expansion enables larger cargo volumes to transit with fewer vessels. That translates into fewer cargo movements, thus reducing the carbon footprint of shipping. By welcoming vessels that would otherwise have to use longer routes, fuel consumption is reduced. As a result, the new waterway is set to reduce carbon-dioxide

emissions across the shipping industry by an estimated 160 million tons in the first ten years of operation.

In the first three months of operation, the expanded canal received more than 360 reservations and transited more than 140 Neopanamax vessels. Comparing July 2015 to July 2016, we've already seen a 12 percent increase in tonnage, 7 percent in transits, and 6 percent in overall revenue. We expect annual cargo tonnage to nearly double in five years.

Already, we've seen global trade routes redrawn as major liners reroute service to capitalize on the expanded canal's considerable time and cost savings, as well as to reduce emissions. We've also begun to welcome liquefied natural gas (LNG), a new market segment that is expected to help reduce the cost of clean energy around the world. The canal can now accommodate more than 90 percent of the world's LNG tankers, which can reach more than 900 feet long and 150 feet wide.

For all these reasons, the Panama Canal's future looks bright. Plans are already in place for other enhancement projects, such as new container terminal, logistic parks, and a roll-on/roll-off cargo terminal. And the lessons we have learned we will apply to all future endeavors. 

Jorge L. Quijano is the CEO of the Panama Canal Authority, the autonomous agency that manages the Canal.

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A culture of improvement: Defining the role of scale and sustainability in building big projects

An interview with Jacqueline Hinman.

Jacqueline Hinman is chairman and CEO of CH2M HILL. Founded in 1946 and based in Colorado, the global engineering company (2015 revenues: \$5.36 billion) has been involved in major projects including restoration of Mississippi ports after Hurricane Katrina, Toronto's Metrolinx Rapid Transit program, the past six Olympic Games, plus major industrial developments in India and Saudi Arabia.

In this interview with McKinsey's Tony Hansen, Hinman discusses a wide range of issues, including dealing with environmental issues, the Olympics, attracting female talent, and the impact of Brexit.

McKinsey: *How would you describe CH2M's culture?*

Jacqueline Hinman: CH2M always has been a purpose-driven company, focused on delivering sustainable solutions for the clients and communities we serve. Since becoming CEO, I've focused on driving a client-centric strategy to deliver on that purpose all the way through our delivery model.

Aligning around our clients also helps us to execute across engineering, design, and scientific disciplines, enabling greater innovation and exposing our people to more rewarding opportunities. That's important if we are to retain remarkable people who are motivated to make a positive difference in the world.

We are never satisfied with making incremental improvements. Our approach combines broad, global engineering-and-construction (E&C) knowledge with local stakeholder intelligence to deliver the best outcomes.

McKinsey: *The United Kingdom recently voted to leave the European Union. How do you see this decision affecting CH2M's operations in Britain and Europe?*

Jacqueline Hinman: It's too early to tell. The terms of withdrawal are subject to a negotiation period, it could be a few years before it is implemented. But without a doubt, Brexit creates additional uncertainty in financial markets—on top of concerns like the postrecession “new normal,” the prolonged oil-and-gas slump, and the US election.

McKinsey: *CH2M has worked on a number of Olympics. Can you talk about that experience?*

Jacqueline Hinman: We played a small role in Rio, and we have been involved in such global-scale events for more than 20 years. We served as the first-ever environmental advisor to the Olympics, in 1996 in Atlanta. Over the years, working with others, we made some progress in establishing governance systems and standards for environmental sustainability for big events. But it took another 14 years—the London Olympics in 2012—for the world to realize there was a much greater opportunity: Olympic organizers could also advance social and economic sustainability by considering the needs of disadvantaged groups, workers, and cash-strapped communities in a meaningful way. In what may have been a once-in-a-lifetime combination of political courage, regulatory will, and unprecedented stakeholder engagement, London 2012 set a new gold standard for the Olympics. We had a leadership role in the development consortium that delivered a six-year, \$15 billion program to design and build 30 sustainable venues and scalable infrastructure, all finished a year ahead of schedule and 10 percent below budget.

This included perhaps the largest environmental cleanup ever accomplished in Europe, transforming a 600-plus acre brownfield site that paved the way for the Olympic Park.

We recycled 98 percent of the waste on site and delivered most of the materials via sustainable rail and water transport, while cutting carbon emissions in half and using 40 percent less water.

At the peak of construction, we had approximately 10,000 people on site, 70 percent of whom used public transportation to and from work. Another 26 percent either walked or rode bicycles. Who would have imagined some 9,600 construction workers doing this day in and day out?

Of the 40,000 people who worked on the project between 2006 and 2011, many were employed locally from some of the poorest boroughs nearby. A large number of these people had been unemployed. We established and paid for a health clinic on site, which provided health screenings for about 2,000 workers each month and more than 100,000 free health-assessment and treatment visits over a four-year period.

McKinsey: *Maintaining employment standards for workers is a challenge. What is CH2M doing?*

Jacqueline Hinman: Certainly there are very serious concerns about worker welfare. We've worked with clients Qatar 2022 [World Cup] and Expo 2020 Dubai to improve standards for employment, safety, and worker accommodations. Since third parties typically perform much of the work in the region, we strengthened supply-chain qualification requirements for procurement and contractor selection with an inspection regime for enforcement.

To advance these efforts, we have hosted industry roundtables with the Institute for Human Rights and Business this year, and now we are piloting a new mobile application that enables workers to anonymously share real-time feedback on working conditions. We see this as a valuable program-management tool to empower workers and ensure these welfare standards are being met.

McKinsey: *What do you think is the engineering-and-construction sector's responsibility with respect to the environment?*

Jacqueline Hinman: Delivering triple-bottom-line returns for clients—environmental, social, and economic—demands that we also demonstrate leadership in our own operations. We were among the first in our sector to sign on to the UN Global Compact, and we just marked the 11th year of publishing our performance via the Global Reporting Initiative.

Our tenacity for sustainable solutions stands as a point of competitive differentiation for CH2M. We serve clients who share our commitment to continuous improvements that involve incredibly complex infrastructure, conservation, mitigation, and development challenges.

For example, about 15 years ago, we started working with a major sports-and-apparel manufacturer to reduce operating costs by curtailing the use of toxic chemicals and increasing recycling. A breakthrough came when we examined the broader supply-chain implications. We worked with 300 textile suppliers in 25 countries to ensure that their manufacturing methods aligned with those efforts.

But the big idea was yet to come—a greater vision for a much bigger impact. Now, we’re serving as program manager for the Zero Discharge of Hazardous Chemicals program, helping 22 of the world’s leading fashion, sports, and outdoor apparel brands eliminate hazardous chemicals from their supply chains. By 2020, 11 classes of hazardous chemicals will have been eradicated from textile production; this is a huge step to elevate standards across the entire industry.

McKinsey: *Are there other examples?*

Jacqueline Hinman: Another idea whose time has come is the use of natural infrastructure. We are, at last, seeing a shift toward valuing natural capital—assets such as marine and plant life—as part of the solution to protect and improve ecosystems. The challenge has been developing the right regulatory, permitting, and technical frameworks to make it happen.

A classic example comes from the northeastern United States, where significant wet weather caused overflows of the community’s combined storm-water and sewer systems, polluting a nearby lake. The Environmental Protection Agency mandated a conventional treatment program, a provisional fix that would have cost more than \$100 million.

However, working with a very forward-thinking county executive, we convinced regulators to petition the federal courts to pursue an innovative, more sustainable hybrid approach incorporating both gray and natural green infrastructure. Outside the United States, these types of solutions had been proved effective to treat storm water at its source, harnessing nature to restore water quality. In November of 2009, a federal judge granted approval.


It was the first settlement of its kind in the nation to endorse green infrastructure as a storm-water-management solution. To date, the county has advanced more than 180 green and natural infrastructure projects, and the lake has made a comeback. Since then, we’ve partnered with industry and third-party experts, such as the Nature Conservancy, to pioneer hundreds of projects harnessing natural infrastructure.

McKinsey: *How is the E&C sector doing with respect to attracting and retaining women?*

Jacqueline Hinman: Both the E&C sector and the broader business community have plenty of room for improvement in reflecting real-world diversity, not only in terms of

gender but also in lifestyle, social status, age, economics, ethnicity, creed, ideology, and thought.

The solution is to foster truly inclusive corporate cultures. CH2M performs well above industry averages for workforce diversity, with women and minorities comprising 31 and 14 percent of management, respectively. In addition, women account for more than a quarter of the board of directors. But we still see opportunities to do more.

We have to play an active role to develop the next-generation workforce, starting at an early age and investing in STEM [science, technology, engineering, and math] education. Our CH2M Foundation supports partnerships with organizations targeting underrepresented populations at all career stages. We connect young students with college mentors and young professional role models—often some of the brightest female and minority engineers in the making. 

Tony Hansen is the director of McKinsey's Global Infrastructure Initiative;
Jacqueline Hinman is chairman and CEO of CH2M HILL.

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Transforming construction operations to improve productivity

Jose Luis Blanco, Mauricio Janauskas, and Maria Joao Ribeirinho

Engineering and construction firms suffer from low margins and relatively low productivity. Here is how to do better.

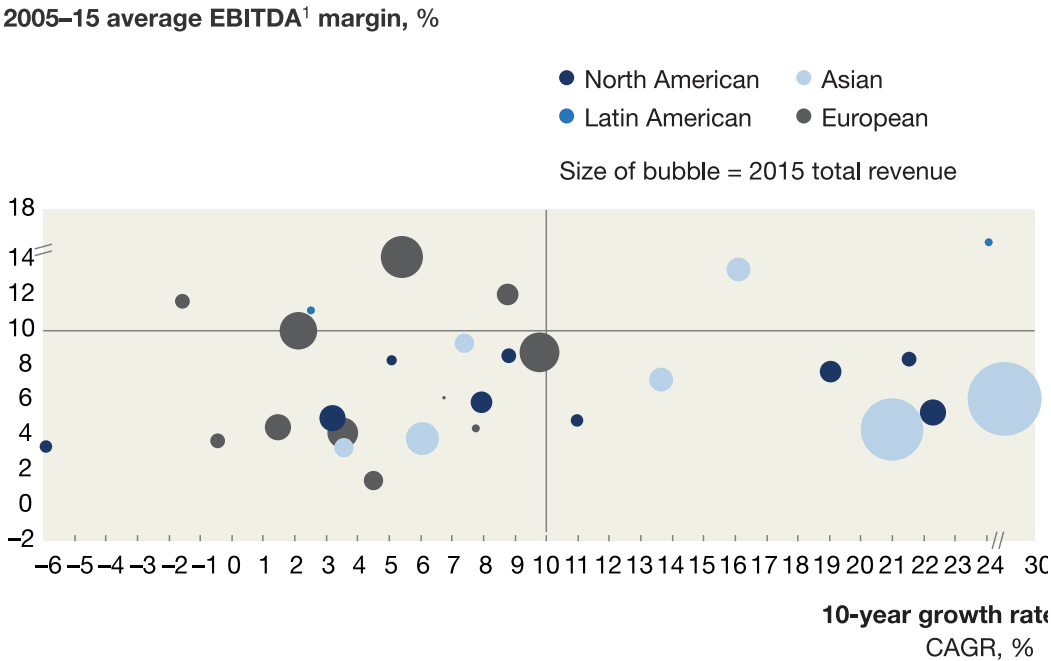
Infrastructure providers face a world of opportunity. The McKinsey Global Institute has estimated that \$57 trillion in infrastructure investment will be required by 2030 just to keep up with the global economy. For engineering and construction (E&C) firms, that translates into a steady 4 percent annual growth rate. At the same time, projects and contracts are getting more complex, and clients are also ever more demanding.

No wonder, then, that the E&C sector in many markets is struggling with low profit margins and poor productivity. And when McKinsey analyzed the financial performance of 30 major public E&C firms from 2005 to 2015, it found that fewer than 15 percent had achieved consistent double-digit growth and EBITDA margins (exhibit).

These results are not as good as they should be. In this article, we describe the challenges the sector faces, both internal and external. Then we suggest specific actions E&C companies can take to do better—and in the process help to build the infrastructure a growing world needs.

Exhibit

Few companies have experienced both aggressive growth and sustained double-digit EBITDA margins.



Key averages:

	North America	Europe	Asia	Latin America
10-year growth rate (CAGR ²):	10.4%	4.2%	13.9%	11.1%
10-year average EBITDA margin:	6.3%	7.4%	6.7%	11.1%

¹Earnings before interest, taxes, depreciation, and amortization.
²Compound annual growth rate.

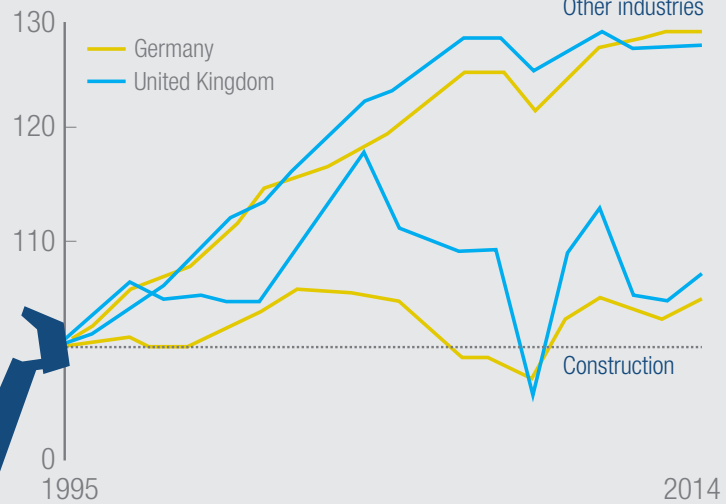
Beating the low-productivity trap: Transforming construction operations

**Engineering and
construction companies
suffer from low margins
and relatively low
productivity**



Labor productivity¹

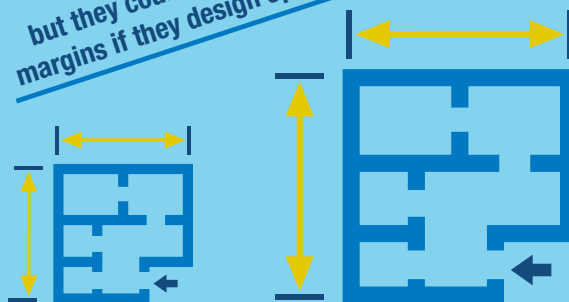
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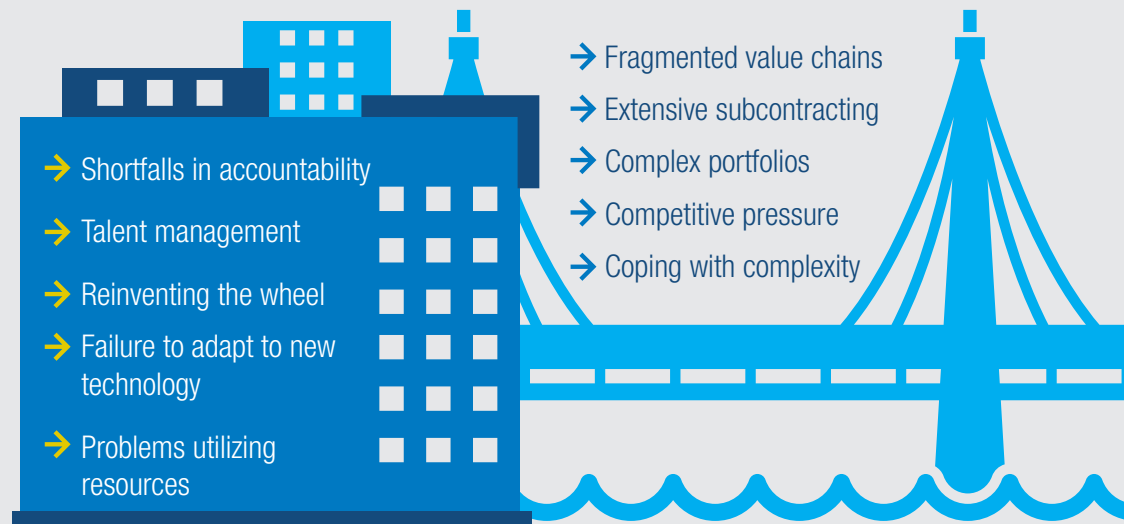
¹ Gross value added per hour worked, constant prices based on 2010 prices
Source: Organization for Economic Co-operation and Development

Fewer than 15% of E&C firms had double-digit growth and margins from 2005-2015,

**but they could achieve 20-30% operating
margins if they design operations differently.**



The industry faces internal and external challenges



But they can overcome the challenges and do better if they:

-  **1** Articulate a clear set of values and targets
-  **2** Build a development program for project managers
-  **3** Create an integrated data system
-  **4** Encourage speedy risk mitigation and decision making
-  **5** Make project delivery teams more accountable
-  **6** Standardize systems and practices
-  **7** Create an integrated and transparent performance management system
-  **8** Minimize the number of changes

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The internal challenges

A number of common flaws, outlined below, impair the performance of E&C firms; together, they create a culture in which innovation cannot flourish.

Shortfalls in accountability: Organizational structures are often unclear, so that no one takes responsibility for results. Moreover, financial incentives are often not aligned with the project goals. Staff will be more motivated to finish on time or early, for example, if there is a bonus associated with doing so.

Talent management: E&C firms everywhere complain of skills shortages; few are able to develop talent from within. In addition, many people do not want to work in difficult or risky regions. Finally, E&C firms have resisted hiring people from outside the industry, limiting the sector's ability to reinvent itself and to learn from others.

Reinventing the wheel: Too often, business units and megaprojects are run as if they were independent companies, without consistent performance management. By not standardizing operations and project reporting, companies do not manage their risks as well as they could and do not scale up best practices.

Failure to adapt to new technology: Some firms have tried to adopt innovative approaches to enhance productivity, such as advanced building-information modeling (BIM).¹

Most E&C firms, however, have legacy systems and unique client requirements when it comes to budgets, planning, and operations. That makes change difficult.

Challenges to resource utilization: As E&C companies have grown and diversified, they have had to deal increasingly with internal silos linked to geography and business units and/or asset classes. The result is that they struggle to use their resources effectively.

The external challenges

Outside factors can also make it difficult for E&C firms to improve their efficiency and profitability.

Fragmented value chains: Along the project life cycle, there are many different players, including owners, designers, contractors, and quality control and safety experts. The problem is that they do not always work together well. For example, typically, each entity gets its own contract, with no overall management. In effect, one participant can (and often does) create problems for the next one.

¹ 5-D building-information modeling (5-D BIM) refers to adding two more metrics (schedule constraints and cost) to traditional 3-D computer-aided-design models.

Extensive subcontracting: Many subcontractors are small and unsophisticated, lacking effective governance and talent management—and the firms that hire them have not seen it as their responsibility to improve matters. That affects productivity at every stage. Also, E&C firms typically want the subcontractor to accept most of the risks, an attitude that does not foster a spirit of collaboration.

Complex portfolios: International expansion means that companies are faced with different business conditions and partners. This can lead to an even more atomized way of working because they need to build up regional knowledge. The variety of local regulations makes it more difficult to standardize operations.

Outside pressure: Chinese, Korean, and European companies in particular are making great efforts to find work in high-growth markets. This heightened competition is forcing once-dominant local players to raise their game at a time when other kinds of pressures are also building, such as tougher environmental and safety standards.

How to do better

Successful E&C companies set appropriate goals, learn from their mistakes, and embed these lessons into the next project. To boost margins and productivity, then, here are the priorities:

Articulate values and targets: This may sound basic, but many E&C companies find it difficult to estimate baselines; that makes it all but impossible to make accurate plans. Creating a culture of measurement and precision on estimates is essential. Successful E&C firms promote this mind-set by tying performance bonuses to specific metrics in project execution. This ensures that the staff and the company have the same goals.

Build a development program for project managers: To promote excellence, encourage continuous improvement, and increase personal accountability, firms should design a career plan for project managers. Even smaller firms can do this through mentorships, well-designed performance evaluations, and feedback mechanisms.

Create an integrated data system: Firms need to have a single database that shows the most important metrics, such as construction progress and real unit costs. At the moment, the usual practice is that each stage—planning, design, procurement, construction—has a separate data base.

Encourage speedy risk mitigation and decision making: Working with the business-development and operations teams, E&C firms need to create effective programs that illuminate the riskiness of the portfolio as a whole. The current norm is to think of risk on a case-by-case basis; the better approach is to see how each project fits into the company's operations as a whole. For example, if a firm decides to bid on a project offering a 10 percent discount on its usual profit margins, then other projects will have to make up the difference.

Increase accountability of project-delivery teams: This effort has to begin at the beginning—establishing what the team is meant to do before it gets to work and choosing people who can accomplish those goals. It could be helpful to create a standard project charter that defines roles, responsibilities, and lines of reporting, and to establish a clear documentation system.

Standardize systems and practices: In the E&C sector, there is a tendency not to use standard solutions, even when they clearly work. E&C firms should seek to ensure that each project maximizes the use of the best features from other projects; doing so can significantly reduce procurement costs and execution times.

Implement a “stage gate” process to minimize project changes: This identifies the specific points where project objectives are approved and can help to keep changes to a minimum, through such mechanisms as change reviews and the allocation of responsibility for approving changes.

Conclusion

By setting a clear vision, strengthening talent management, and improving their processes, E&C companies can improve their performance and operating margins.

Getting started requires understanding a company’s potential and areas of strength, and then setting priorities. The commitment must come from the top. Even executives who accept that they need to do things differently, however, have tended to focus their efforts on improving specific functions, when an end-to-end approach is needed. For most firms, this will require a fundamental change in thinking, by emphasizing profitability rather than resource utilization and by being more selective on the work they target.

Those that make this shift, however, will put themselves in position to win. 🏆

Jose Luis Blanco is an associate partner in McKinsey’s Philadelphia office, **Mauricio Janauskas** is a partner in the Buenos Aires office, and **Maria Joao Ribeirinho** is a partner in the Lisbon office.

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Photo credit: Comscreen

The digital future of construction

Rajat Agarwal, Shankar Chandrasekaran, and Mukund Sridhar

The industry needs to change; here's how to manage it.

Although the construction industry suffers from sluggish productivity growth and relatively low financial returns, it has been slow to embrace the process and technology innovations that could help it to do better, with respect to both profitability and performance (Exhibit 1).

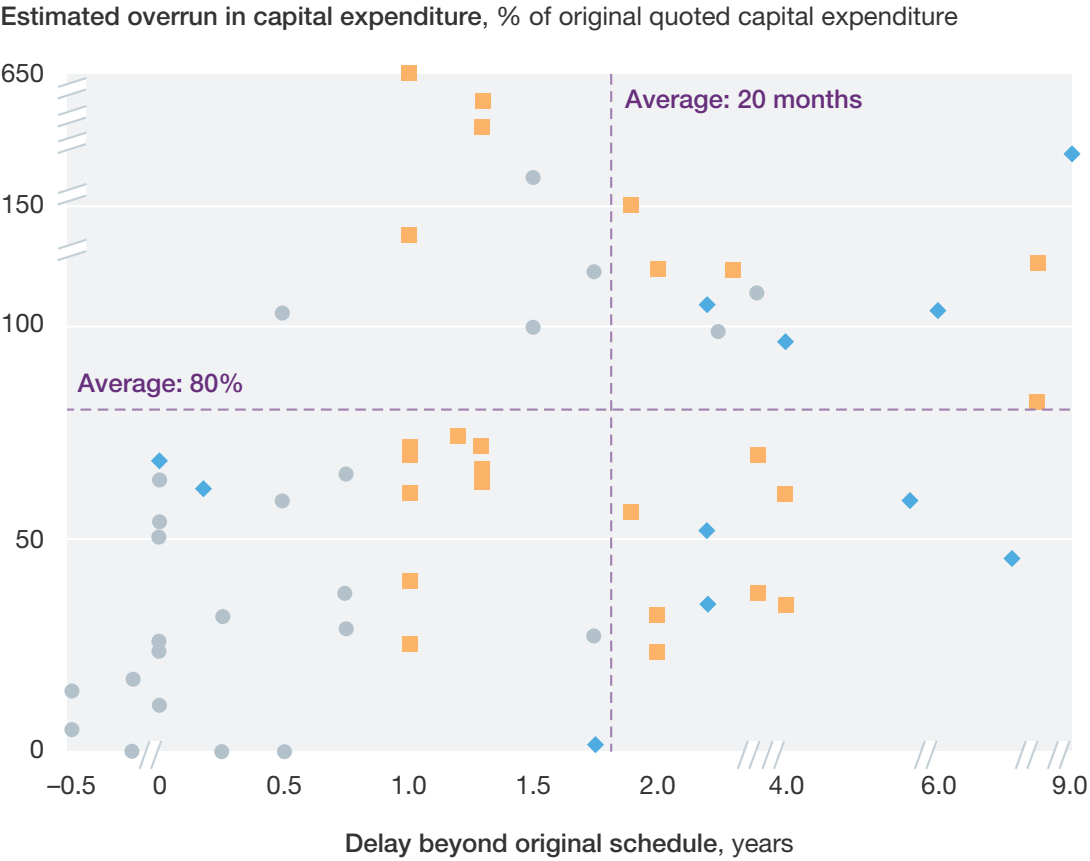
In general, R&D spending in construction runs well behind that of other industries: it accounts for less than 1.0 percent of revenues, versus 3.5 to 4.5 percent for the automotive and aerospace sectors. Ditto for spending on information technology.

Traditionally, the sector has tended to focus on making incremental improvements. But this will no longer do. Projects are ever larger and more complex. The growing demand

Exhibit 1

Cost and schedule overruns are the norm in the construction sector.

● Mining ◆ Infrastructure ■ Oil and gas



Source: Global Projects Database, IHS Herold, Nov 19, 2013, herold.com; McKinsey analysis

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for environmentally sensitive construction means traditional practices must change. And the shortage of skilled labor and supervisory staff will only get worse. These are deep issues that require new ways of thinking and working.

Here are five ways the industry could transform itself over the next few years.

Higher-definition surveying and geolocation

Geological surprises are a major reason that projects are delayed and go over budget. New techniques that integrate high-definition photography, 3-D laser scanning, and geographic information systems, enabled by drone and unmanned-aerial-vehicle technology, can dramatically improve accuracy and speed. And they are more accessible than ever because costs have come down substantially.



THE CONSTRUCTION INDUSTRY IS RIPE FOR DISRUPTION

Large capital projects typically take



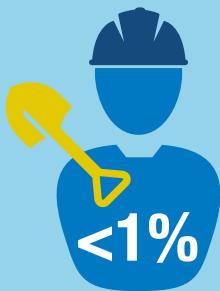
20% longer to finish...

...and are up to



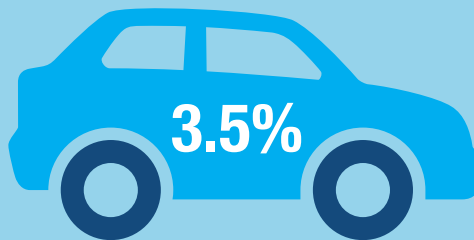
80% over budget,

and R&D spending in construction runs well behind other industries.



<1%

Construction



3.5%

Auto



4.5%

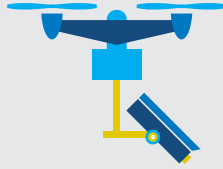
Aerospace

Note: Figure represents average percent of revenues

5 big ideas are poised to disrupt construction

1

Higher definition surveying and geolocation



2

5-D Building Information Modeling



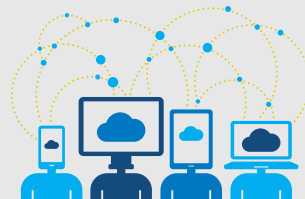
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Digital collaboration and mobility



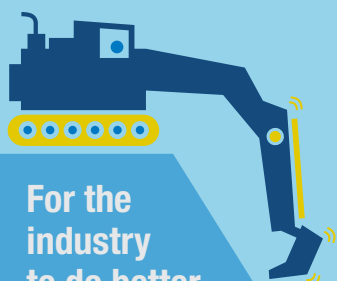
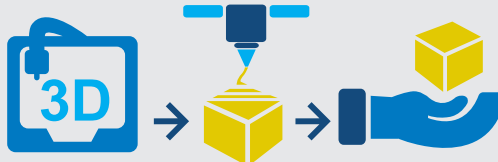
4

The internet of things and advanced analytics



5

Future-proof design and construction



For the industry to do better it needs to embrace 4 principles

1

Transparency and risk sharing in contracts

2

Return-on-investment orientation

3

Simplicity and intuitiveness in the design of new solutions

4



Change management

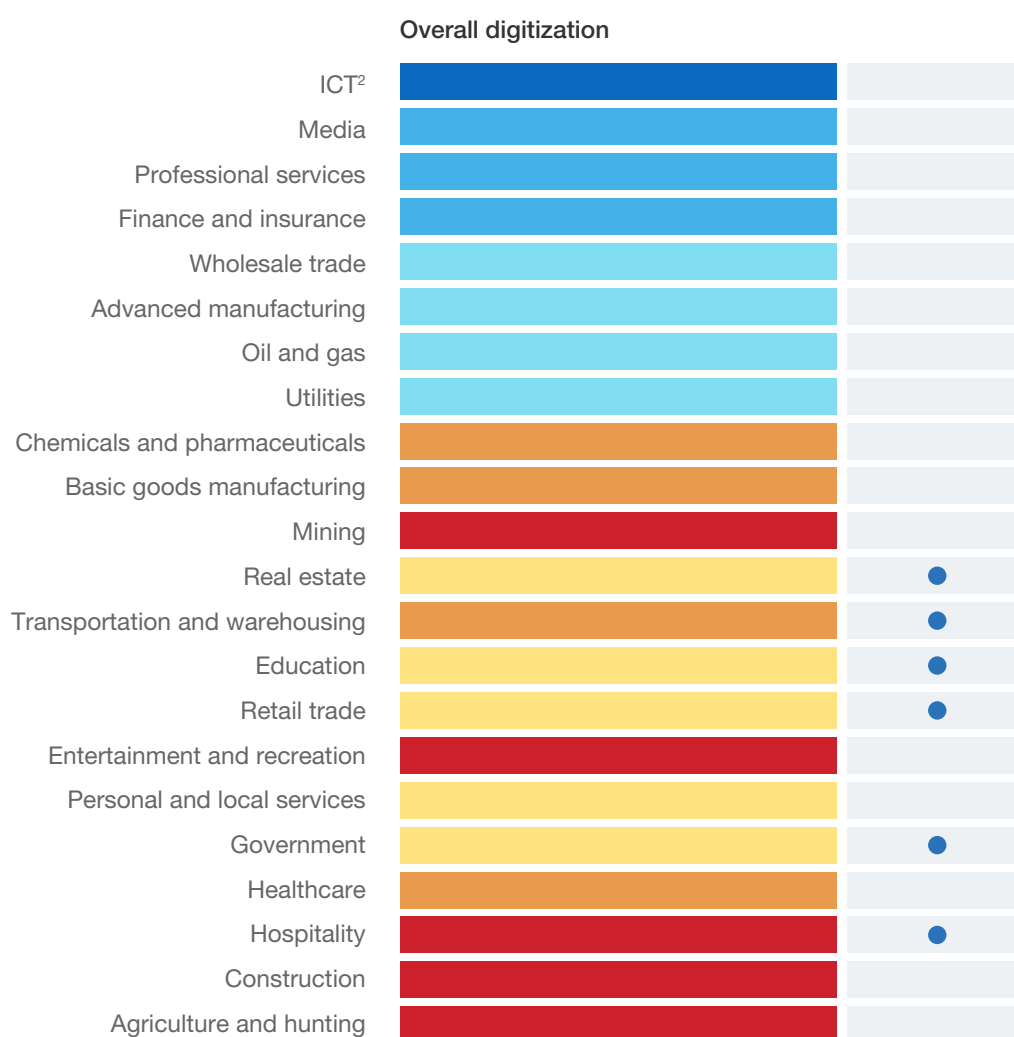
Photogrammetry, for example, provides high-quality, high-definition images of survey areas. Light-detection-and-ranging (lidar) technology is much faster than conventional technologies and provides high-quality 3-D images that can be integrated with project-planning tools, such as building information modeling (BIM), as Exhibit 2 shows.

Exhibit 2

The construction industry is among the least digitized.

McKinsey Global Institute industry digitization index; 2015 or latest available data

Relatively high digitization  Relatively low digitization  Digital leaders within relatively undigitized sectors



¹Based on a set of metrics to assess digitization of assets (8 metrics), usage (11 metrics), and labor (8 metrics).

²Information and communications technology.

Source: AppBrain; Bluewolf; Computer Economics; eMarketer; Gartner; IDC Research; LiveChat; US Bureau of Economic Analysis; US Bureau of Labor Statistics; US Census Bureau; McKinsey Global Institute analysis

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Used in conjunction with ground-penetrating radar, magnetometers, and other equipment, lidar can generate above-ground and underground 3-D images of project sites. This is particularly important in dense, environmentally sensitive, or historical project sites, where disturbance needs to be minimized.

These advanced survey techniques are complemented by geographic information systems that allow maps, images, distance measurements, and GPS positions to be overlaid. This information can then be uploaded to other analytical and visualization systems for use in project planning and construction.

Next-generation 5-D building information modeling

The construction industry lacks an integrated platform that spans project planning, design, construction, operations, and maintenance. Instead, it still relies on bespoke software tools. In addition, project owners and contractors often use different platforms that do not sync with one another.

Next-generation 5-D BIM is a five-dimensional representation of the physical and functional characteristics of any project. It considers a project's cost and schedule in addition to the standard spatial design parameters in 3-D. It also includes details such as geometry, specifications, aesthetics, thermal, and acoustic properties. A 5-D BIM platform allows owners and contractors to identify, analyze, and record the impact of changes on project costs and scheduling (Exhibit 3). The intuitive, visual nature of 5-D BIM gives contractors a chance to identify risks earlier and thus to make better decisions. For example, project planners can visualize and estimate the impact of a proposed change in design on project costs and schedule.

The use of 5-D BIM technology can be further enhanced through augmented-reality technology via tablets or wearable devices. A wearable, self-contained device with a see-through, holographic display and advanced sensors can map the physical environment, for instance. Companies are developing BIM-like design and construction solutions for these platforms. In this "mixed reality" environment, users can pin holograms to physical objects and interact with data using gesture, gaze, and voice commands.

Digital collaboration and mobility

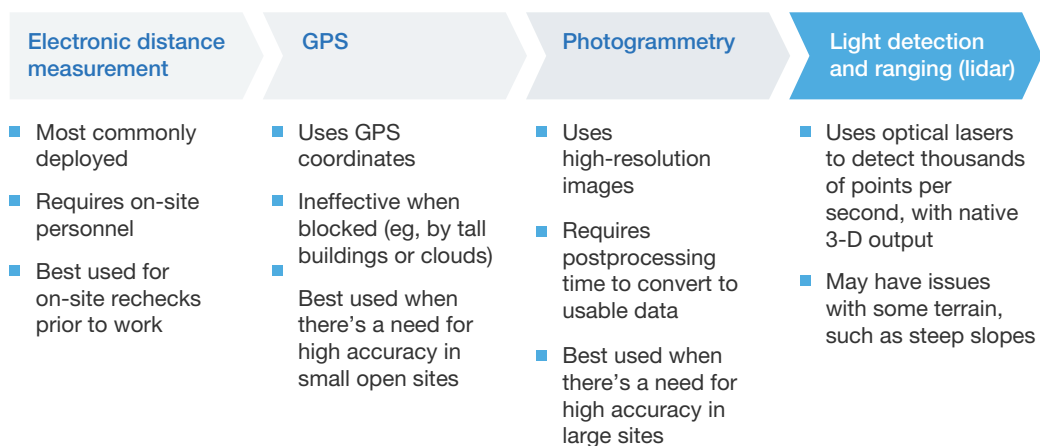
One reason for the industry's poor productivity record (Exhibit 4) is that it still relies on paper to manage its processes and deliverables such as blueprints, design drawings, procurement and supply-chain orders, equipment logs, daily progress reports, and punch lists.

Now owners and contractors are beginning to deploy digital-collaboration and field-mobility solutions. A large global construction firm recently announced it was working with a software provider to develop a cloud-based, mobile-enabled field-supervision platform that integrates project planning, engineering, physical control, budgeting, and document management for large projects. Several large-project developers have already successfully digitized their project-management work flows.

Exhibit 3

Lidar represents an evolution in surveying; added mobility from drones and handheld technology is a breakthrough.

Overview of technology commonly used in site surveys



While lidar has existed for some time, there has been a breakthrough in its use via drones/unmanned aerial vehicles (UAVs) and handheld platforms

- Handheld 3-D laser scanners
- Mounted on mobile platforms
- Some lidar systems are now under 10 kg and can be deployed with drones/UAVs

McKinsey&Company | Source: McKinsey analysis

In an American tunnel project that involved almost 600 vendors, the contractor developed a single platform solution for bidding, tendering, and contract management. This saved the team more than 20 hours of staff time per week, cut down the time to generate reports by 75 percent, and sped up document transmittals by 90 percent. In another case, a \$5 billion rail project saved more than \$110 million and boosted productivity by using automated work flows for reviews and approvals.

It's long been difficult for central planning teams and on-site construction teams to connect and share information about progress in real time. Now the availability of low-cost mobile connectivity, including via tablets and handheld devices, has ushered in a new generation of cloud-based crew-mobility apps. These can be deployed even on remote construction sites and could change the way the industry does everything from work- and change-order management to time and material tracking, dispatching, scheduling, productivity measurement, and incident reporting.

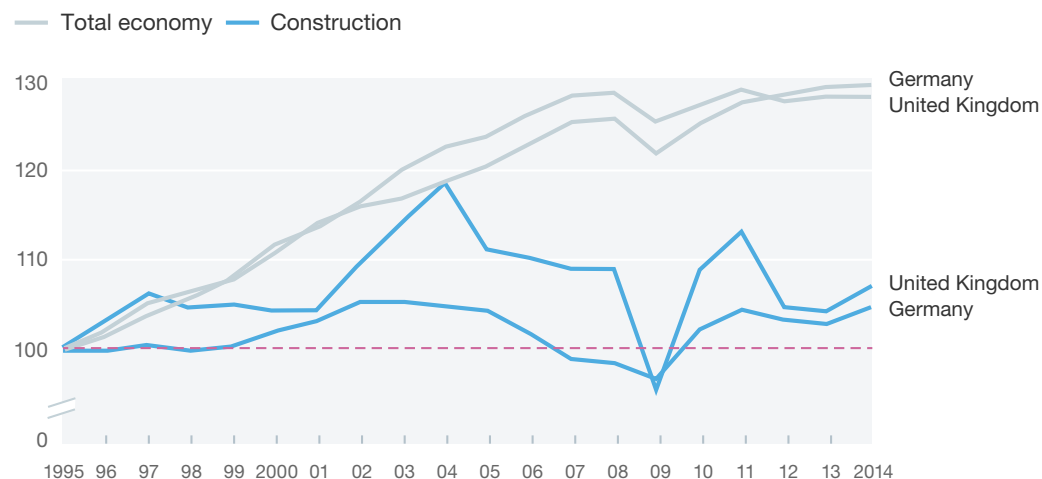
The Internet of Things and advanced analytics

Project sites generate vast amounts of data, but little of this is captured, let alone measured and processed. The Internet of Things—sensors and wireless technologies

Exhibit 4

Construction labor productivity has not kept pace with overall economic productivity.

Labor productivity, gross value added per hour worked, constant prices,¹ index: 100 = 1995



¹Based on 2010 prices.

Source: Organisation for Economic Co-operation and Development

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that enable equipment and assets to become “intelligent” by connecting them with one another—could change that. On a construction site, the Internet of Things would allow construction machinery, equipment, materials, structures, and even formwork to “talk” to a central IT platform to capture critical performance parameters. Sensors, near-field-communication devices, and other technologies can help monitor productivity and reliability. Potential uses include equipment monitoring and repair, inventory management, quality assessment, energy efficiency, and safety.

One popular form of near-field-communication technology is radio-frequency identification (RFID). This is used extensively in logistics, retail, and manufacturing environments to collect precise information about a product, place, time, and transaction. Since the 1990s, construction has used RFID to track materials and equipment and to develop automated time sheets. Costs of RFID equipment—including scanners, receivers, and tags—are falling, and new applications are emerging. Soon, tags will be able to include information on specifications, dates, defects, vendors and original-equipment manufacturers, maintenance records, operating parameters, and other applications.

In addition to the opportunities from the Internet of Things, digitization could enable construction firms to capture data. Then advanced analytics can help to improve efficiency, timelines, and risk management.

Insights from advanced analytics helped one oil and gas giant improve the productivity of its engineering function by 20 to 25 percent by pairing the right teams, appointing

appropriate team leads, and modifying their work flows to minimize waste and improve efficiency. In another case, a large Middle Eastern construction firm used a predictive-analytics engine to prevent equipment breakdowns on-site for its fleet of construction vehicles. This saved millions of dollars in downtime, fuel costs, and maintenance expenses.

Future-proof design and construction

New building materials and construction approaches can lower costs and speed up construction while improving quality and safety.

Building materials

These usually account for more than half the total cost of projects. Traditional materials such as concrete, cement, and asphalt make up most of this demand. But there has been a wave of innovation in construction materials over the past few decades; a number of products have been developed with specific uses in mind. Here are a few that are particularly interesting:

- *Self-healing concrete.* This uses bacteria as a healing agent to close cracks on concrete; it is currently at the proof-of-concept stage.
- *Concrete canvas.* Take a layer of “concrete cloth,” then add water and allow it to set. This innovation typically is used for drains, channels, and passages, and it is now available commercially.
- *Topmix permeable.* This is a cement alternative that can absorb 4,000 liters of water a minute. It is in the early-adoption stage.
- *Aerogel.* This supertransparent, superinsulator material is 99.98 percent air; it is available commercially.
- *Nanomaterials.* These superstrong, ultralightweight materials may eventually be a substitute for steel reinforcement in structures and foundations, though they are still in the research stage.

Adoption of these “materials of the future” has been slow due to a lack of awareness, a limited supply chain, a lack of availability at scale, and risk aversion. Despite being available for more than 30 years, for example, ethylene tetrafluoroethylene (ETFE) gained widespread adoption only after it was used to build part of the aquatic building for the Beijing Olympics in 2008. ETFE weighs less than 1 percent of an equivalent glass panel and costs 24 to 70 percent less.

Construction approaches

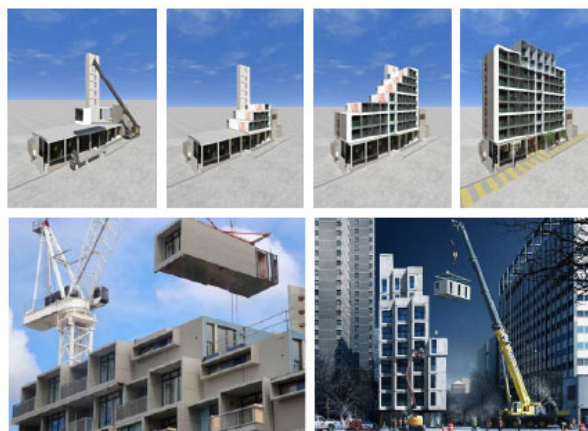
About 80 percent of all construction work is still done on-site, but project developers and contractors are deploying new approaches that show promise. Among them:

Exhibit 5

Singapore is pioneering a new model of construction.

Concept

- In prefabricated, prefinished volumetric construction (PPVC), complete flats or modules made of multiple units complete with internal finishes, fixtures, and fittings are manufactured in factories; they are then transported to site to be erected in a modular manner
- Typically relevant for hotels, hostels, budget condominiums, and other facilities with standard shapes and designs



Impact

- Productivity improvement of up to 50% with respect to staffing and time savings
- Minimal dust and noise pollution
- Improved site safety

Source: Building and Construction Authority of Singapore; McKinsey analysis

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- **Preassembly.** Relatively simple structures, such as factories and covered yards, can use in-factory or in-yard assembly for a complete building envelope. This technique can also be adapted for modular buildings, such as hotels and budget condominiums. Complete submodules of a larger building are put together in a factory or nearby yard before final assembly at the construction site.

Techniques such as prefabricated, prefinished volumetric construction integrate off-site capabilities to transform the construction site into a manufacturing system (Exhibit 5).

The result: greater efficiency, less waste, and improved safety. In addition, materials such as cross-laminated timber are emerging in response to the need for greener construction options. In the United Kingdom, an 80-story timber skyscraper recently received preliminary approval.

- **3-D printing.** Printing submodules or complete concrete structures before assembly and internal work could transform the industry with respect to design, cost, and time. However, 3-D printing is still in the early stages of its development and cannot yet be deployed at the scale and speed required for large projects.
- **Robot-assembled construction.** Construction projects are inherently unstructured and often unpredictable; they can also be sited in difficult terrains and environments.


For these reasons, the use of robots has been limited so far. However, robots are now being selectively used for repetitive and predictable activities, such as tiling, bricklaying, welding and spool fabrication, demolition, and concrete recycling.

Recommendations for action

It's time for a new mind-set. Owners often believe that their responsibility ends when they award contracts, forgetting that they pay the economic costs of delay. For their part, contractors often do only the minimum required to meet contractual terms, leaving substantial value on the table. For the industry to do better, it needs to embrace four principles:

- *Transparency and risk sharing in contracts.* Habits are tough to change, and one habit is to see contracts as adversarial opportunities to hand off risks. Instead, contracts need to be seen as tools that allow fair sharing of risks and rewards and that help both sides succeed. This will happen if contracts clearly outline responsibilities and allow owners and contractors to share the benefits that arise from the adoption of technological and process innovations.
- *A return-on-investment orientation.* Measuring and communicating how new technology will improve construction—for example, through the positive effects on cost, schedule, and risk optimization—is the surest way to build a compelling case for adoption. One oil and gas major measures, documents, and communicates productivity-related savings as a result of the deployment of an advanced-analytics and visualization solution for its deepwater platforms.
- *Simplicity and intuitiveness in the design of new solutions.* At the front end, user interfaces need to be “foreman friendly” to encourage usage. At the back end, building in compatibility with existing enterprise solutions mitigates the need to spend more on upgrading existing platforms.
- *Change management.* To move away from business as usual, organizations need a clear direction. Top management needs to communicate why these changes are important and what they mean for organizational structure, capabilities, and resourcing. Organizations that do not invest in change management will face pushback and are more likely to fail.



Other industries have shown that first movers can build a sustainable competitive advantage. In the construction sector, this is also likely to be the case. Over the next decade, these winners of tomorrow will take the lead in technology innovation and digitization. Resisting change is no longer an option. 

Rajat Agarwal is an associate partner in McKinsey's Singapore office, where **Mukund Sridhar** is a partner; **Shankar Chandrasekaran** is an associate partner in the Mumbai office.

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How infrastructure companies deliver real benefits

Craig Albert and Tam Nguyen

The best projects provide, connect, and produce sustainable outcomes.

Sustainable infrastructure is a confluence of ideas. It's physical, eco-friendly, and smart. It seeks to minimize costs and maximize the use of resources. It's also global. The United Nations specifically mentioned infrastructure in its 17 Sustainable Development Goals.

The role of infrastructure is to provide essential services to societies and industries, including transportation networks, energy grids, and wastewater-treatment plants. Such projects are critical to economic development and to connecting people and ideas.

Sustainable infrastructure does all this while also reducing, recycling, and reusing natural resources. The operating premise is both simple and expansive: infrastructure in the future will need to be smarter, greener, and more efficient than it has been in the past. That is far from impossible. In fact, there are already opportunities to optimize sustainability in specific parts of the system. To succeed requires thinking beyond what infrastructure does to considering how it is constructed and how one project, or part of it, can deliver other benefits.


This matters because several global megatrends are forcing governments and companies to change the way infrastructure is designed, constructed, and operated. By 2050, there will be about 9.7 billion people on the planet, with two-thirds living in urban areas. That will put tremendous stress on existing systems, particularly in developing countries. According to our estimates, \$48 trillion in investment is needed just to meet the world's energy needs by 2035. Half the world's population will be living in areas of high water stress by 2030; many will be vulnerable to actual crises, with critical shortages of clean water.

The challenge can seem overwhelming. By deconstructing the idea of an infrastructure system as the sum of its parts, however, it is possible to identify opportunities, and then to figure out how to broaden the possible benefits. For example, a Bechtel-led consortium is working on a rail project in the Middle East. While the primary task is to build two new rail lines, the system will also reduce pollution by giving nearly 3.6 million people an alternative to driving. In addition, more than 230,000 square feet of solar panels will power the depots, and all of the water needed for landscaping and other exterior uses will be treated municipal wastewater. This single project, then, promotes sustainability not only in transport but also in the use of energy and water.

Another example is Crossrail, which includes more than 26 miles of new tunnels under central London; 10 new stations will connect with subway and commuter-rail services. When completed, this could eliminate more than 300 million vehicle-miles each year, significantly easing congestion and reducing air pollution. Crossrail also has a comprehensive energy and carbon-management plan. Managers are working to reduce emissions by focusing on design features that improve energy efficiency, for instance, by reducing the weight of passenger cars, establishing targets to reduce energy consumption, and installing smart controls for lighting, heating, and air conditioning. By looking at individual elements, planners found many different ways to deliver sustainable improvements.

Another promising area is power generation. In the United States, Bechtel is working to help a number of power generators to incorporate more sustainable and diversified strategies, including utilizing nonfossil fuels in the form of large solar projects, as well as clean natural-gas plants, carbon capture, and nuclear power. Individually and together, they will help to decarbonize the supply of electricity while providing reliable power.

Developing nations are also beginning to realize the value of investing in sustainable infrastructure. Beginning in 2010, with the support of Bechtel, the government of Gabon and Bechtel started executing a \$25 billion national infrastructure master plan, which placed sustainability front and center. A new government agency, l'Agence Nationale des Grands Travaux (ANGT), is in charge of implementing the plan. The goal is ambitious: to build a truly sustainable economy. Part of the support provided includes working to modernize the construction sector and help it to perform to international standards. That raises local expertise, enabling future developments to become self-sustaining.

These examples demonstrate how investment in specific elements of infrastructure can offer a range of positive outcomes greater than the sum of their parts. The cumulative impact is a more livable urban environment and a more productive economy. 

Craig Albert is president of Bechtel Infrastructure, and **Tam Nguyen** is the global head of sustainability at Bechtel.

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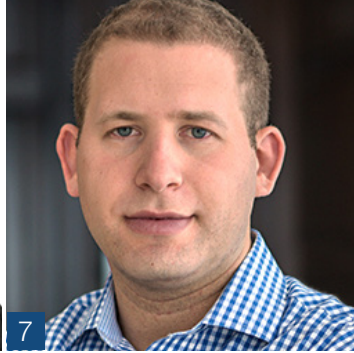
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Authors

1. **Rajat Agarwal** is an associate partner in McKinsey's Singapore office.
2. **Craig Albert** is president of Bechtel Infrastructure.
3. **Jose Luis Blanco** is an associate partner in McKinsey's Philadelphia office.
4. **Shankar Chandrasekaran** is an associate partner in McKinsey's Mumbai office.
5. **Tony Hansen** is the director of McKinsey's Global Infrastructure Initiative.
6. **Jacque Hinman** is chairman and CEO of CH2M HILL.
7. **Mauricio Janauskas** is a partner in the Buenos Aires office and leads McKinsey's Public Sector and Capital Projects & Infrastructure Practices in Argentina.
8. **Tam Nguyen** is the global head of sustainability at Bechtel Corporation.
9. **Jorge Quijano** is the CEO of the Panama Canal Authority, the autonomous agency that manages the Canal.
10. **Maria Joao Ribeirinho** is a partner in the Lisbon office and the global leader of McKinsey's work with the engineering and construction (E&C) industry.
11. **Mukund Sridhar** is a partner in the Singapore office and co-leads McKinsey's Capital Projects & Infrastructure Practice in Southeast Asia.



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McKinsey's Capital Projects & Infrastructure Practice is a leading adviser on the planning, financing, delivery, and operation of infrastructure, real estate, energy, and resource assets. The practice helps clients by combining McKinsey's proven business problem-solving skills with engineering, construction, and technical expertise to make informed decisions on how to deliver and operate these assets faster, better, and at a lower cost.

Our reach spans all geographies, project stages, and asset classes, including transport and logistics, city planning, oil and gas, chemicals, mining, and utilities. Our offering combines a global network of capital-project and infrastructure experts with an extensive understanding of local markets and global trends. Leveraging our collective experience, proprietary tools, and databases, we ensure world-class capital performance. Since 2010, we have served more than 600 clients on over 2,000 engagements, including work on 150 megaprojects, collectively valued at more than \$1 trillion.

Global Infrastructure Initiative (GII)

Our research suggests that up to 40 percent of global infrastructure investment is poorly spent because of bottlenecks, lack of innovation, and market failures. McKinsey established the Global Infrastructure Initiative to address these issues, promote economic growth, and contribute to more resilient and secure communities. GII is a separate entity and collaborates with infrastructure leaders from around the world.

While GII operates independently from the Capital Projects & Infrastructure Practice, McKinsey provides access to the firm's skills, resources, and convening power. McKinsey and GII are committed to improving infrastructure because we believe it is our responsibility to work on the world's biggest challenges. Developing and operating great infrastructure helps all of us—our clients, our people, and our societies.

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 info@giiconnect.com