Voices on Infrastructure

The project of the future

September 2020

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Welcome to the September issue of *Voices on Infrastructure*, a collection of insights on **the project of the future**.

The infrastructure ecosystem is ready for change: the typical project carries unwanted surprises, profits for the construction sector as a whole have been lower than its average cost of capital, and neither problem can be fully addressed so long as the industry's 0.5 percent annual productivity growth persists as it has for decades.

We all know the trends that would end the industry's inertia—digitization, ecosystem integration, collaborative contracts, agile-principled teams, sustainability-principled portfolios, and more. And in the wake of unprecedented global disruption, we see new urgency among leaders to turn these ideas from buzzwords into built reality.

Yet the landscape can certainly inspire skepticism about the industry's capacity to adopt and accelerate these changes: companies still run from project to project, incomplete packages are tendered based on the lowest price, risks are not well understood, margins are thin, and above-project improvement efforts usually seen as project "waste." At the same time, we are curious to see which ecosystems will find the virtuous upward spiral and create value for all participants.

Nevertheless, at the brink of this exciting transition, we believe the way projects are developed and executed could change profoundly. Our focus is therefore on how these changes will look on the ground: what will they mean for day-to-day work? How can companies break the cycle of mistrust among project partners? And how can players capture the benefits of a portfolio of projects?

In this issue, we polish up our crystal balls to explore these and anticipate other aspects of capital projects. Your insights are invaluable, so we encourage you to take our 5-minute "Projects of 2025" survey on capital-project delivery.

News from the Global Infrastructure Initiative

Tony Hansen

Director of the Global Infrastructure Initiative, McKinsey & Company

We are excited to publish this September 2020 edition of *Voices*, a collection of insights on the project of the future. In this issue, we explore how global industry trends are poised to dramatically change all stages of the project life cycle. The project of the future will forgo siloed project stages and operate as a single production system integrated by technology from design, procurement, and planning, to construction, commissioning, and operations. This edition emphasizes the essential qualities of future projects, discusses tangible actions taken on projects, and spotlights some of the emerging tools that will make long-term impacts—all while factoring in our new coronavirus reality.

Our seventh GII Summit will take place virtually on April 6–8, 2021. In addressing the project of the future theme, our program pillars will tackle fundamental industry challenges regarding digital and analytics transformations, collaborative project delivery, leadership and workforce development, and future-proofing the built environment. As this summit was originally intended to take place in Montréal, we will still feature the city, including virtual site visits to the most exciting infrastructure projects in Montréal. For more details, please visit our Summit page.

This issue was due to be published in April 2020, alongside the sixth GII Summit in Montréal. However, on account of the significant global impact of COVID-19, we postponed its publication and instead ran our June edition of *Voices* and our first GII Virtual Summit on the topic of **resetting amid COVID-19**. You can read our *Outcomes Report*, featuring the best ideas of 400 global leaders, here.

While addressing COVID-19 remains inextricably on our agenda, we are also moving forward with our pre-crisis content. Over the next six months, we will be running a dozen virtual roundtables in different regions around the world. Please visit our roundtables and innovation site visits pages for details on past and forthcoming events.

Looking ahead, our January 2021 edition of *Voices* will focus on the topical theme of **restarting economies with infrastructure finance and stimulus**. We hope you enjoy this issue, and we welcome your thoughts on any of our GII programs. If you have comments or would like to subscribe a colleague to *Voices*, please contact us at info@giiconnect.com.

Photo courtesy of CIB

CIB's Michael Sabia on the future of investment in Canada infrastructure

Attracting private capital to help finance infrastructure projects is more important than ever, according to Michael Sabia, chair of the Canada Infrastructure Bank.

Michael Sabia

Chair
Canada Infrastructure Bank

The COVID-19 crisis is straining the fiscal resources of governments worldwide, but they still have to find the money to finance essential current and future infrastructure projects. In this interview with McKinsey's Tony Hansen and Rob Palter, Michael Sabia of the Canada Infrastructure Bank (CIB) discusses the new investment models that the current environment will demand, especially balancing the tension between attracting private capital and safeguarding the interests of citizens.

McKinsey: You were recently appointed chair of the CIB. Could you describe the role of the CIB in the Canadian infrastructure market?

Michael Sabia: The CIB is essentially a development bank designed to bring private capital into the financing of infrastructure in Canada, either at the initiation of a project or, if necessary, to prove the financial viability of a market and to bring private capital in later on.

We also expect to get our capital back. We're not in the business of giving it away. But as one would expect, we are prepared to provide that capital at below-market rates in the interest of causing projects to occur. Today, we are especially interested in assets that contribute to increased digital connectivity and the transition to a lower carbon economy.

Finally, the bank is intended to be a center of expertise on infrastructure in Canada that can act as a source of new ideas and advise all levels of government.

McKinsey: How does the CIB fit in among grants or other financing methods offered by governments?

Michael Sabia: If we think along the lines of a continuum, projects that are purely commercial are at one end. At the other end are projects that require government expenditure—pure grants—to make them happen. Grants are the traditional financing model for infrastructure. Somewhere in the middle are projects that can be made commercially viable and can become attractive to institutional investors. The sweet spot for the bank is projects of that kind. All they need is a financial push to get them over that threshold.

McKinsey: Is there enough funding or commitment in the public sector to maintain infrastructure delivery and operations as we know it?

Michael Sabia: Let me address the second part of the question: should we actually be thinking about maintaining infrastructure delivery and operations "as we know it?" My perspective on it would be no. The traditional delivery models for infrastructure have revolved around government, a public authority essentially funding infrastructure projects, sometimes with a little private capital, sometimes not. That's led to slow delivery and escalating costs. In the world that we're moving toward, neither of those are going to work, or neither of them will be affordable.

So this is a time to challenge the notion of "as we know it." An example I've used is an urban light-rail transit project in Montréal—the Réseau express métropolitain (REM), designed, owned, and operated by an institutional investor. It is projected to be completed at about 60 percent of prior cost projections, CAD $6 billion to CAD $6.5 billion, and in about half the time required. It's time to think differently and innovatively about alternative models for delivering infrastructure.

McKinsey: What do you see as the role of infrastructure in stimulating economic recovery in the aftermath of COVID-19?

Michael Sabia: In many governments' recovery or economic-renewal plans, infrastructure is seen—as it should be—as important in terms of economic stimulus: the creation of jobs and creation of income, for example. That's true in Canada and, I believe, for a lot of other governments as well.

In many of these countries, the focus of this kind of stimulus will be around climate—first, because it is so high on the public agenda now and, second, because there's growing recognition among governments that infrastructure can shape what a national economy looks like down the road.

An interesting question is whether governments will be able to spend enough to fully seize the opportunity that is in front of them, specifically with respect to climate change. That's where different kinds of institutions like the Canada Infrastructure Bank play a particularly important role because they are all about finding ways to bring private capital into these infrastructure projects.

McKinsey: In such an uncertain world, how can stakeholders better understand and manage the risks involved in large capital projects that rely on long-term projections?

Michael Sabia: It's undeniable that uncertainty is a factor in the pricing and feasibility of infrastructure projects. That probably comes in two particular categories. The first is traditional exogenous uncertainty. We've always been aware of them but I don't know whether or not we've ever taken them seriously enough.

Take Eurostar, the European high-speed rail service. For years, passenger volumes at Eurostar continued to go up by 2 or 3 percent a year, almost without regard to the economic cycle. And then two completely unpredictable events occurred: one, terrorist attacks in Paris, and two, Brexit—both purely exogenous events. So that's one band of uncertainty, risks that are difficult to price.

The second category are risks like COVID-19 and how they will change the world—or rather, the role of cities in our economies and the degree of concentration within cities. This could influence thinking about infrastructure in cities, and it certainly raises questions about transit.

As we begin to exit this crisis and, as we learn more about managing pandemics, I'm not sure that I see a world in which cities become less important than they have been, which is to say, as motors of economic growth and development.

If cities continue to be magnets and motors, then—take the transit example—people may now prefer to take their cars in light of the pandemic. The limit to that is road capacity and congestion, and I don't see a lot of governments in the world building massive new highways. So what may happen is that public transit is going to continue to be important. What may change is the internal design of transit equipment—but public transit is a long way from becoming less necessary and valuable.

McKinsey: Factoring in economic, social, and environmental imperatives, what approach can stakeholders follow in thinking about stimulus spending on infrastructure?

Michael Sabia: In conversations that I have had with senior officials, both in Canada and outside, the word "stimulus" is taking on a different meaning. In the past, there have been lots of examples of governments spending money for short-term job creation, sometimes with dubious value in the infrastructure that was built. Now people are focused on the shaping capacity of infrastructure. How can you alter and cause to evolve the shape and composition of an economy? There's a much more strategic perspective on this, which I think is an extremely important development.

That being said, what does that mean? We should see several major priorities around that shaping role. The first I've already mentioned, which is a heavy emphasis on climate: electrification, renewable power, cleaning up emissions from cities.

Another, less obvious point is the role of infrastructure investment in reducing trade friction and costs. It's true that the global trading system is evolving, but that doesn't mean that trade itself becomes less important. It just means that the pattern of trade changes.[1] Therefore, continuing to focus on the efficiency of trading corridors will be key. If economic growth gets harder to come by, lowering those costs and becoming more trade-efficient will be increasingly important for virtually all countries.

Then, one thing that's come out of this pandemic crisis is the importance of broadband connectivity.

[1] See "Risk, resilience, and rebalancing in global value chains," McKinsey Global Institute, August 6, 2020, on McKinsey.com.

In a lot of countries, this issue will be addressed adequately by commercial suppliers of bandwidth. In other countries, that may require public-sector infrastructure investment. In a sparsely populated, large country like Canada, that's probably going to be important. It's less so in a dense, smaller country because it will be commercially viable for telecom carriers to do it themselves. And along with more connectivity comes data and the emerging importance of new platforms and infrastructure assets to realize the value of data.

McKinsey: Have you considered how to manage the tension between making decisions on projects happen faster—siting, permitting, and environment reviews, for example—with respect for the democratic process and the benefit that the approval process provides to the well-being of citizens?

Michael Sabia: That's an important question. I'll cite my experience with the REM project that we developed at Caisse de dépôt et placement du Québec. We fully respected those processes, but because we were the project planners, the project moved faster than it would otherwise have, and we were able to shrink the total elapsed time from project conception to the beginnings of construction.

I keep coming back to this point: standard operating procedures are the enemy. That's why models and who delivers these projects has to change—because it is possible to move faster than we've all gotten used to. And that doesn't involve compromising important democratic processes such as environmental assessments, where people, quite legitimately, have a right to express their views on whether something is good or bad or disruptive. It's the processes in the projects and inside of governments that are so slow, and they need to be accelerated.

McKinsey: In what ways do you think the project of the future will be different from the project of today?

Michael Sabia: Now is an enormously interesting time for creativity, innovation, and new ideas around models for delivery. Given the fiscal constraints that governments face and the importance of infrastructure in both stimulating and reshaping economies, the traditional way of thinking about this is no longer going to meet anybody's needs. So we must consider financial models that continue to use some government money to leverage other peoples' money.

Perhaps it's serendipity, but there are now gigantic pools of long-term-oriented institutional capital looking for a reasonably steady return. It's critical because any institutional investor thinking about the future is going to be reallocating capital away from fixed income and toward other reliable, cash-flow-generating kinds of investments.

So that creates a moment to be seized between the need and value of infrastructure, the fiscal constraints that governments are under, and the necessity therefore of finding models that leverage and bring these vast pools of capital into infrastructure projects. That's going to lead us to situations where public infrastructure ends up being designed, financed, owned, and operated by long-term institutional capital, probably working in conjunction with government so that the public interest is protected.

One of the issues is going to be how we deal with the issue of financial risk sharing between those sources of private capital and public authorities. The real question is going to be finding the right balance and distribution of risk between what public authorities and institutional investors are willing to assume. In sum, this is a fantastically interesting period of time because conditions are going to force us to innovate.

Preparing for the construction ecosystem of the future

Market changes, technological progress, and disruptive entrants will overhaul industry dynamics. All players must choose whether to defend the core or to reinvent themselves.

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The construction industry and its supporting ecosystem have shown unsatisfactory performance in recent years, and external market factors and complex industry dynamics have impeded attempts at change. Over the next decade, however, new technologies and increased product digitization are likely to disrupt parts of the construction ecosystem, transforming the industry as we know it.

Two-thirds of the industry executives we recently surveyed agree that the COVID-19 pandemic has accelerated this transformation; half report that they have already raised their level of digitization investment. Moreover, our research shows that a significant share of the $11 trillion global value added and $1.5 trillion of global profit pools could be redistributed along the value chain—a staggering 40 to 45 percent in the most affected segments. Executives must therefore consider not only the project of the future, but also the product of the future, developed along the value chain and the ecosystem of the future.

In other words, industry dynamics will shift from a fragmented construction process to one that is more standardized, consolidated, and integrated. Those players that move faster and smarter than their competitors can increase their own profitability many times over. As an example of how the industry's total value could be reshuffled, we will examine the materials distribution and logistics segment.

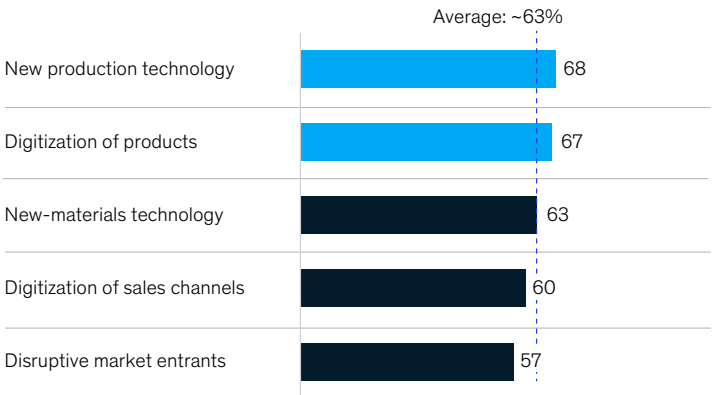
Industry disruption's effects on the value chain

In late 2019, we conducted a global survey of 400 industry decision makers—primarily executives, owners, and principals—and asked them which factors they believe will affect the industry. The results suggest unprecedented disruption, especially regarding new production technology and the digitization of products (exhibit).

Exhibit

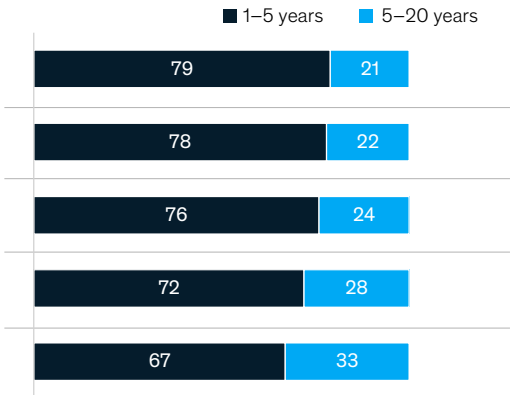
Industry leaders expect disruption to occur.

Which [of these emerging disruptions] do you think will have highest impact on the construction industry? Share of respondents rating that emerging disruptions will have "high impact,"[1] %



More than two-thirds of respondents think that industrialization and digitalization will have the highest impact of the emerging disruptions

When do you think the emerging disruptions will impact construction at scale? Share of respondents, %



More than two-thirds of respondents expect disruptions to impact construction in the near term

[1]High impact equals a 7 or higher, where 10 is highest impact.

Source: McKinsey survey of 400 construction-industry CxOs; expert interviews; McKinsey analysis

All players across the value chain will need to develop their strategies for dealing with disruption. This includes financing and development; the supply of materials, components, and machinery; off-site construction; and on-site construction and assembly. But it is especially true for materials distribution and logistics, engineering and planning, and general and specialized contracting—all of which survey respondents say will experience the largest disruption.

A closer look at materials distribution

Materials-distribution companies procure basic materials, components, and equipment and then resell them to consumers and businesses.

Today, the segment represents a high share of both value added (8 to 12 percent) and profits (13 to 17 percent) in the construction ecosystem. These figures come as no surprise, since distributors connect suppliers with project sites and subcontractors, keep stock of a complex array of components and materials, handle logistics, and even provide credit in some regions.

However, many survey respondents believe that distributors could see value erode if no action is taken to overhaul their current business models, particularly in the new-build segment:

— *Greater standardization and productization*, such as better planning with building-information modeling (BIM), could move decisions upstream to less-fragmented and more-sophisticated buyers, and reduce the scope of materials needed.

— *Digital twins and building-management systems (BMS)* could make it possible to plan for and predict repair and maintenance needs, thus reducing the need for local stock.

— *Better on-site efficiency* could increase the need for just-in-time logistics.

— *Expanded online marketplaces for materials and direct sales from suppliers* could increase price transparency versus performance, likely resulting in a reduction in the breadth of materials on the market and creating a new set of competitors—while also potentially increasing direct-to-site deliveries, undermining the economics of a store network.

— *Increased off-site construction* could shift procurement to factories with consolidated demand and relatively predictable planning horizons, reducing the need for store networks.

As a result, the value distributors add (and their profit pools) might materially decline in coming years, in a challenge that may not be as severe as the ones facing players such as contractors and designers, but which may still be notable. In fact, 20 percent of survey respondents believe that materials distributors will see the largest decline—or even stop existing in their current form—within ten years.

Yet another outcome is possible as well: distributors could reposition themselves as industrial-grade logistics hubs for the construction setup of the future. In this scenario, distributors become even more effective as catalysts for productivity at sites, generating substantial value for the entire industry by cutting time and effort now wasted in searching for, waiting for, and moving materials on-site.

What construction industry leaders can do now

All companies, regardless of where they are situated along the value chain, have a choice: either defend the core and transform to adjust to the changing environment, or actively reinvent themselves to attack and disrupt the markets they operate in. These disruptive plays require investing and risk taking, but successful moves could be rewarded with step changes in profitability and valuation.

The leaders will likely be those that gain scale and consolidate the market while excelling at demand forecasting and inventory planning, as well as

lean efficiencies and category reviews. These capabilities will be crucial to fulfilling increased demand for flexible, just-in-time, value-added logistics to construction sites and prefabrication plants, and to providing on-site logistics planning and operations. Digital interfaces are becoming increasingly essential as well, connecting with BIM and BMS for optimal planning and ordering, and offering advice through digitized expertise. Simpler preassembly, submodules, and kitting for the customer will save time on-site.

Companies will also be expected to meet customers' sustainability expectations on logistics emissions, design labeling that transparently communicates the sustainability impact of alternative building materials, and offer guidance in the selection of optimal materials.

Distributors could reinvent themselves by taking on a role as the future construction landscape's logistics hub. In doing so, they could create new value for customers, for instance, by helping with international sourcing or offering credit finance, packing in assembly order, in-room delivery, delivery before the working day, providing on-site logistics planning, and operations, or even offering simple preassembly.

As disruption creates a new "ecosystem of the future," all players in the value chain will need to reposition or reinvent themselves. While looming disruption may seem daunting, those companies who successfully take the lead stand to gain market share and raise profitability.

Download *The next normal in construction: How disruption is reshaping the world's largest ecosystem*, the full report on which this article is based, on McKinsey.com.

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[1] Materials distribution and logistics is just one of numerous segments along the construction value chain. Our recently published report offers an in-depth look into this and other segments; for more, see Maria João Ribeirinho, Jan Mischke, Gernot Strube, Erik Sjödin, Jose Luis Blanco, Rob Palter, Jonas Biörck, David Rockhill, and Timmy Andersson, *The next normal in construction: How disruption is reshaping the world's largest ecosystem*, June 4, 2020, McKinsey.com.

Alternative funding models for infrastructure projects of the future

COVID-19 has reinforced the need for new ways to fund projects. Approaches taken on urban transportation projects shed light on a potential path forward.

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The gap between what countries are spending on infrastructure and what is needed—both to facilitate growth in expanding economies and to replace existing aging infrastructure—was already substantial even before the COVID-19 pandemic: A 2017 McKinsey Global Institute report put this figure at $5.5 trillion between now and 2035.

And now, transport agencies around the world face a dramatic fall in the revenues they need to support current operations—let alone investments in future infrastructure needs. Consequently, once the crisis eases, we expect the fundamental question of how to fund these necessary infrastructure projects may become even more pressing.

Governments have traditionally funded major projects in two ways: allocating taxpayer money or procuring projects where the costs would be recouped by charging end users (for example, toll roads). However, the impact of COVID-19 may mean that these approaches will no longer be enough—indeed, they may no longer even be viable. On one hand, increasing government budgets to fund infrastructure projects may not be politically or economically feasible; on the other, end-user charges simply aren't sufficient to fund many proposals.

To deliver projects and help bridge the infrastructure gap, governments will need to find funding sources outside of this paradigm. Approaches already taken on urban-transportation projects around the world provide insights into the benefits and challenges of some alternative funding models.

Capture higher land values

Transportation infrastructure, especially railways, can transform a location's relationship with its wider geography and, in turn, its economic possibilities. Broadly speaking, the most promising alternative funding models rely on monetizing some of the positive externalities such major projects have been shown to generate—in particular, higher local property values.

While previous assumptions regarding the appetite for physical presence (and hence transportation) may be challenged in the fallout from the COVID-19 pandemic, the insights such funding models provide are likely to remain valuable. For example, if the location of the physical workplace became more fluid for the foreseeable future, residential areas located at greater distances from the traditional urban centers of work may become more appealing. This could, in turn, increase demand for—and value linked to—reliable, longer-distance transportation infrastructure to serve those locations.

Governments have successfully captured increases in land value as an alternative funding method using a few methods.

Developer contributions

Property developers may fund an infrastructure project because they expect the project to boost the commercial value of their own property. One approach to obtaining financing from private developers is to make their right to develop a property dependent on their financial contribution to local infrastructure projects. Local UK authorities often use this approach, as statutory planning powers allow them to set such conditions.

Given the critical importance of linking developments to transportation infrastructure, authorities may also be able to negotiate more wide-ranging commercial agreements between developers and procurement authorities. For example, London obtained part of the funding for its Crossrail project through commercial agreements with developers, through which financial contributions were obtained and two Crossrail stations constructed.

In cases, where authorities obtain funding from commercial developers, they may need to provide assurances that the project will integrate with the developer's commercial objectives. Ultimately, this additional layer of accountability can have wider benefits for the public. Similarly, contractual frameworks can mitigate risks to the private sector if, say, a major project were to be delayed or cancelled.

Tax increment financing (TIF)

TIF—which involves using public tax money to subsidize projects—presupposes that the growth associated with successful projects will boost local property values, which in turn can boost property-tax receipts. US authorities have used variants of TIF to fund infrastructure for decades; in recent years, other countries have also begun deploying this model. For example, London funded the Northern Line Extension to its underground metro system through a combination of TIF and developer contributions. Within a designated, adjacent enterprise zone, property tax receipts above a baseline amount are allocated to fund the project, thereby capturing part of the value arising as a result of the infrastructure.

While tax policy can be politically sensitive, the TIF model's use in diverse political contexts suggests that this funding model may be used more widely in the future.

Land development managed by the infrastructure provider

The Hong Kong Mass Transit Railway (MTR) system is a commonly cited example of successfully capturing land value. MTR functions as both a transportation provider and a developer—in partnership with other private developers—of the property it holds in and around the railway system.

MTR's approach is challenging to implement, however, as property-development expertise and a long period of time are required to realize returns, along with robust market demand. In addition, the authority or private entity responsible for the project needs to acquire enough property at prices that are low enough so that marginal profits are sufficient to fund the associated infrastructure. But in certain circumstances, this approach can lead to the development of infrastructure that is largely self-funding in the long term.

Development rights auction

While an MTR-style approach won't work in every situation, it may still be possible to unlock some of the advantages that large-scale development opportunities can provide through other means. For example, Transport for London (TfL), an arm of the Greater London governing body, has commissioned extensive research in recent years into the Development Rights Auction Model (DRAM).

When a host of private landowners hold parcels of property that would have development potential if combined, DRAM allows for some of the benefits of an MTR-like approach to be realized. The procuring authority arranges an auction of this aggregated property for third-party developers with a minimum reserve auction price, which should broadly reflect the value of the property in the absence of the infrastructure development. The proceeds of the sale above the reserve price are then distributed among the selling property owners and the project fund. An eminent-domain or compulsory-purchase process could then be used to acquire property whose owners did not participate in the auction, or alternatively impose levies on development which benefitted from the project but whose owners refused to participate in the auction.

Other ways to unlock and maximize value

Beyond capturing land value, other ways to commercialize aspects of infrastructure projects—such as using existing transport corridors (for example, road and rail infrastructure) to lay cabling for commercial broadband—can generate additional revenue. This approach is likely to become a greater focus as working patterns shift in response to COVID-19. Transport operators have also raised ancillary revenues through offering advertising space in stations and on trains; commercial property space, such as under railway arches; and alternative transportation services, such as bike-share programs.

Apart from economic viability, the utilization of alternative funding sources will often depend on the legal, regulatory, and contractual regimes applying to the project in question. Some restrictions will always be required: where

funding is raised through finding additional uses for critical infrastructure, such as transportation corridors, safety must always be paramount.

That said, to maximize the potential additional value, the regulations and contracts under which infrastructure projects are delivered and operated can and should be crafted with careful consideration of future needs. In keeping with the ethos of successful public–private partnerships, parties can establish how they will share additional revenue raised from new opportunities at the outset of projects. Setting such guidelines and agreeing ahead of time on ways to protect all parties' interests can encourage innovation and the exploration of creative approaches to raising additional revenue.

At the same time, unlocking the opportunities that alternative funding models present requires dialogue with—and sensitivity to the concerns of—a variety of local stakeholders, including residents, businesses, and investors. As such, alternative funding can underpin a wider political narrative, one that emphasizes the myriad benefits of investment in infrastructure projects.

The extent to which COVID-19 will affect the nature of the world's infrastructure needs is yet unknown. However, the fundamental need to deliver that infrastructure will remain, and with it the importance of exploring, adopting, and implementing creative ways for public- and private-sector participants to partner, collaborate, and collectively make the best use of their respective resources to bridge the infrastructure gap.

Voices *highlights a range of perspectives by infrastructure and capital project leaders from across geographies and value chains. McKinsey & Company does not endorse the organizations who contribute to* Voices *or their views.*

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Collaborative contracting: Moving from pilot to scale-up

Despite promising early successes, collaborative contracts remain a tough sell, especially in the context of a pandemic. Best practices can help project owners transition to greater collaboration.

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Over the past two decades, owners and contractors have experimented with elements of collaborative contracting to improve their relationships. However, collaboration has only been more generally accepted recently. The first adopters of true collaborative contracts—including companies in oil and gas, healthcare, water, and consumer-packaged goods—are already enjoying significant benefits.

In collaborative agreements and operating models—such as those found in integrated project delivery or project alliancing—key delivery partners work together during a defined preplanning period to develop the project scope, schedule, and budget; operate under a joint management structure; and form a single multiparty contract. The parties agree to waive their right to make claims against one another. And a governance board where all parties are represented makes every project-related decision, such as scope changes, and those decisions are binding—a stark contrast with traditional, adversarial contracting in which owners attempt to transfer as much risk as possible to the contracted parties.

This kind of collaboration and transparency presents many advantages, particularly in the context of the current COVID-19 pandemic. Indeed, collaborative contracting may actually help capital projects rebound from the crisis. For example, improved transparency on cost and schedule can help to determine the true impact of the pandemic, create opportunities to work together with key suppliers to address material shortages and delays in equipment delivery, and split the impact of lower productivity among parties. Seeing the benefits of more collaboration in solving the issues created by the pandemic will hopefully encourage industry stakeholders to take these lessons with them as they begin new projects in the post-COVID-19 era.

But project owners face challenges as they move toward more-collaborative contracts. Some public-sector owners are legally required to award their contracts to the lowest qualified bidder, while some projects that rely on financing require fixed-price agreements to increase outcome certainty. Other project stakeholders may be willing but stumble over unfamiliar elements of collaborative models—and some, rightly or wrongly, may anticipate difficulties in getting the best-suited partners onboard.

Our interview with one early adopter of collaborative agreements revealed that 30 percent of its contractors were unwilling to entertain the model when it was first suggested. Undeterred, the owner was able to find—and continues to work with—partners willing to work within the boundaries of collaborative structures.

Our analysis shows that to break old habits and increase adoption, project owners must first ensure that their organizations are ready for collaboration. Next, they must follow a set of best practices that includes selecting the right partners, investing early in building out a detailed project description, and aligning incentives for critical partners.

Implementing a collaborative contract

We studied eight collaborative contract pilots that collectively resulted in a 15 to 20 percent improvement in cost and schedule performance compared with traditional contracts (exhibit).

Select the right partners up front

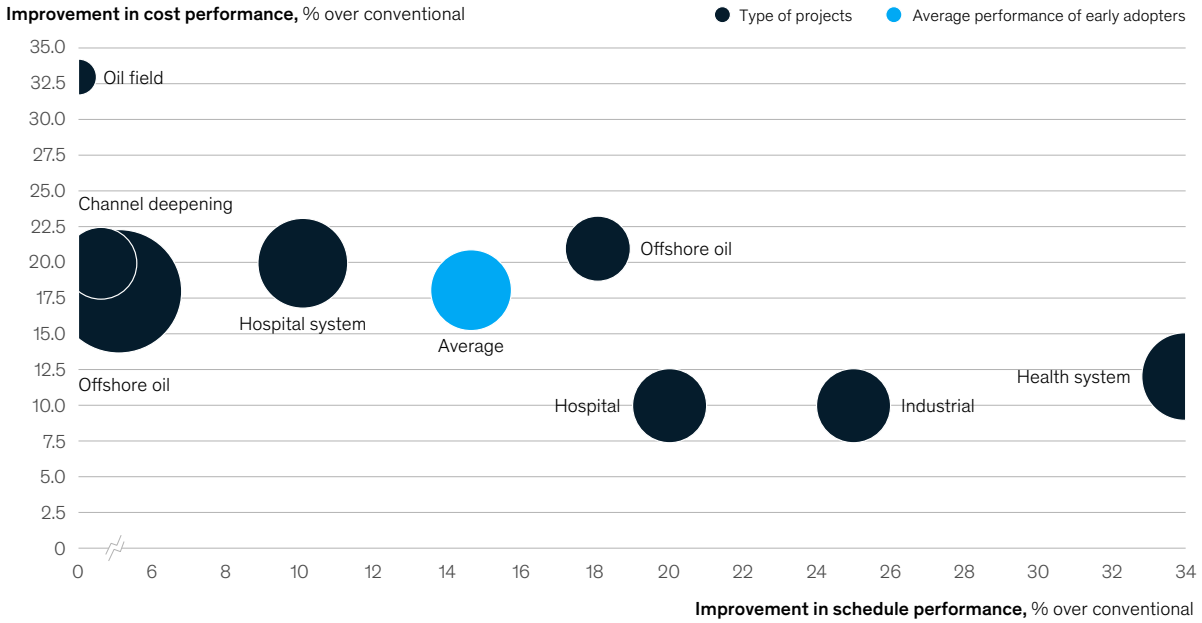
It is critical for owners to ensure that potential partners have the right qualifications and expertise. This includes relevant experience, such as having designed similar facilities or local knowledge and presence; distinct capabilities so that no two partners overlap; and general financial health. A potential partner's project team and senior management must also be open to and supportive of collaborative agreements. Ultimately, whether the people are a good fit is what guarantees trust and a healthy collective decision-making process.

Invest in detailed project definition

When a cross-functional team of core project stakeholders works closely together to create a detailed project scope, execution plan, and cost estimate, they drastically increase the likelihood of a sound final investment decision. One project for a North American transit agency, for example,

Exhibit

Early adopters of collaborative contracts are seeing improvements in performance.



involved a large and complex web of stakeholders. Initially, the agency used a traditional contract, intending to transfer risk to a developer. When potential developers evaluated this plan, however, none felt comfortable accepting this level of risk or even submitting an offer. The transit agency had no choice but to adopt a collaborative model in which each stakeholder—that is, the agency, developer, and designer—partnered to define the scope, craft design solutions, negotiate right-of-way approvals, and establish a target cost. The agency assumed the downside risk of delays that might extend past a certain point, but the developer, designer, and key subcontractors were given incentives to mitigate any potential overruns. Where a traditional risk-transfer model was unacceptable to the private sector, the agency made this project possible by adopting a collaborative model that more equitably distributed the risks.

Align incentives of all partners

Distractions and inefficiencies often occur when each project stakeholder works toward individual project goals. Setting up a common incentive pool that grows or shrinks based on overall project performance (along with all parties distributing pro rata compensation) is one approach to facilitate collaboration among project stakeholders.

Relentlessly invest in trust

Moving from an adversarial to a collaborative approach requires persistent investment in not only building and maintaining trust among delivery partners but also instilling collaborative behaviors, such as problem solving, knowledge sharing, curiosity, and creativity. To succeed, project owners should define their organizational aspirations and make those as important as

a project's financial or schedule goals and enforce reliability and openness. Then they must measure their progress against their goals using performance indicators, such as scores on project team surveys or the number of cross-stakeholder problem-solving sessions.

Some collaboration is better than none

Where procurement constraints, strict lending requirements, government restrictions, or generally opposed mindsets and behaviors exist, owners can make progress on initiatives that would facilitate better collaboration, including shared digital information, tailored incentives, and an integrated design environment. Adding even one or two opportunities for collaboration is not only frequently possible but also beneficial.

An oil and gas company, for example, recently undertook a self-funded, midsize project for which it signed a long-term reimbursable agreement with an engineering, procurement, and construction (EPC) contractor. In this agreement, the company and the contractor collaborated on digital transformation and project-data transparency. In return, the EPC contractor was guaranteed a minimum of three projects over the next four years and earned incentives based on overall project outcomes, including cost and schedule.

Transitioning from a transactional approach to a collaborative model is no easy task. To start, owners (the driving force of a project) must understand their own readiness to implement a realistic level of collaboration. For example, to succeed in more collaborative arrangements, owners generally need sophisticated contracting as well as a ecosystems of reliable engineering and construction partners. They also need to allocate sufficient resources to develop a detailed project definition and properly align incentives, as well as work hard to promote collaborative mindsets and behaviors.

The time is now

In addition to these essential steps, no collaborative agreement can succeed without contractual enforcement. Other key factors involve rigorous project planning and performance management, including a centralized reporting and project-management function or "war room," and agile teams that are accountable for delivering impact. For those project owners who are able to make the transition, the potential value at stake is enormous. Industry participants are increasingly frustrated with the status quo. Contractors with weaker balance sheets due to the pandemic are becoming more risk averse. As the economy recovers from the current crisis and focuses on delivering government stimulus packages, it is even more critical to boost engineering and field productivity through increased collaboration.

The time is now to make collaborative contracts the norm, thereby reinventing the owner–contractor relationship—and the construction industry along with it.

This article is adapted from "Collaborative contracting: Moving from pilot to scale-up," published in January 2020, on McKinsey.com.

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Image courtesy of CDPQ Infra

Remodeling infrastructure financing: A Q&A with CDPQ Infra's Macky Tall

Montréal's Réseau express métropolitain (REM), a new light-rail network currently under construction, serves as a model for how investors can help build crucial infrastructure quickly and sustainably.

Macky Tall

Head of Real Assets and
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President and CEO, CDPQ Infra

Mass public transit remains a crucial component of city planning and development, even in a post-COVID-19 era. Consistent city-wide traffic and the pursuit of carbon-neutral alternatives favor the development of public transit options. However, too many governments struggle to finance such projects, especially large ones. That's where institutional investors are increasingly stepping in. In Québec, CDPQ Infra is in the middle of delivering Réseau express métropolitain (REM)—the CAD $6.5 billion, all-electric, largest public-transportation network in half a century—which will interconnect multiple communities as well as the business center with the Montréal–Trudeau International Airport.

CDPQ Infra is a subsidiary of Caisse de dépôt et placement du Québec (CDPQ), an institutional investor that has been investing in infrastructure, including transit, around the world for more than 20 years. In this interview, Macky Tall, head of Real Assets and Private Equity at CDPQ and CEO of CDPQ Infra, discusses how the right business model can create win–win solutions for public and private partners as well as local citizens.

McKinsey: Why is CDPQ interested in infrastructure, and what challenge is CDPQ Infra trying to help solve?

Macky Tall: Investing in infrastructure means investing in tangible assets that generate stable and predictable returns—which is aligned with our clients' long-term needs. With CDPQ Infra, our model dedicated to the execution of major public infrastructure projects, our vision is to be a trusted partner for governments around the world as they try to solve their infrastructure challenges. Many governments today are heavily indebted. They either won't or can't invest in the major projects—like public transit, ports, roads and bridges—that hold the potential to improve a country's economic future and communities' quality of life. As a result, the global infrastructure gap continues to grow every year. Long-term investors such as CDPQ can play a meaningful role in reducing this gap by providing the capital and the know-how to ensure these important projects are executed. It is a win–win scenario. Local governments and countries provide the infrastructure people need to work and live better, and long-term investors can generate the reliable returns and predictable cash flow they need over time, all the while advancing public interest.

McKinsey: How does the business model work?

Macky Tall: Beyond providing capital, CDPQ Infra seeks to provide a one-stop shop for project delivery and development, with capabilities to support each project from A to Z. The REM illustrates how the model works. CDPQ Infra is working closely with every level of government: local, provincial, and federal. They outlined their needs, and we put forward the design for an integrated transit system to meet those needs. As one of the few organizations in the world with both the financial capacity and the technical expertise required to carry out major infrastructure projects from end to end, we manage design, permitting, procurement, construction, and, eventually, operations.

This unique kind of partnership is not devoid of challenges. We first needed to recruit a broad spectrum of talent that we did not have internally. But the project's scope and ambition appealed to professionals at the very top of their respective fields. Second, we had to convince governmental partners and the public of the benefits of our model, which is distinct from that of other public–private partnerships because of our involvement at the design and development phases. Third, we had to demonstrate that the model would allow us to plan, finance, and begin the construction of a major transit infrastructure project within an efficient time frame.

Finally, the REM is very much a coming together of old and new. We needed to use and upgrade the existing rail line that runs through downtown Montréal. Otherwise, the project wouldn't have been financially viable and socially acceptable. The promised result is a fast, frequent, and reliable light-rail service that serves a much wider area than we could have covered without reutilizing existing rights of way.McKinsey: How would you describe the REM as a "project of the future"?

Macky Tall: This model is a new way for governments to accelerate the development of much-needed infrastructure, so it's inherently a model for the future. The REM is a great illustration of how that model can work to serve people today—and well into the future. Like most big cities, Montreal struggles with congestion, which negatively affects productivity, quality of life, and the environment. Without action, these problems will only intensify over time. The REM project can deliver meaningful progress, improving how people travel for leisure, to work, to home, and to the airport, all in an efficient way. It will better connect the city in a sustainable way. What truly makes this a project of the future is our focus on the longer term. We are building the REM to last for many generations, to keep pace with changing habits, and to reduce greenhouse gas emissions to help fight climate change.

McKinsey: REM development has moved at a fast pace relative to other major infrastructure projects of this size. What strategies have enabled this momentum, and are they applicable globally?

Macky Tall: From the start, we established a clear system of governance involving our partners and stakeholders. Our goal was to create the conditions for decisions to be made in a timely and informed manner. The bottom line is that everyone is on the same page and committed to the successful delivery of the project. We made a point of avoiding the linear approach to planning and construction. Operating on a single track—with Decision A followed by Decision B followed by Decision C—can be a recipe for delay and inertia. Instead, we chose to function with a design-build model. We are moving along in parallel on several fronts, which means we are allowing for progress to begin immediately on certain aspects such as planning and land acquisitions while we are ironing out design elements and compliance.

The CDPQ Infra model could be easily exported because today so many cities need efficient, safe, and adaptable mobility solutions. We've had a great deal of preliminary expressions of interest from around the globe. Decision makers are intrigued by the model and its potential to create growth.

McKinsey: In September 2019, CDPQ committed to a carbon-neutral investment portfolio by 2050. How does CDPQ Infra fit into that goal?

Macky Tall: Infrastructure plays a crucial role in reducing emissions. And as an organization, we understand that our long-term returns are directly linked to the long-term stability of our economy and the communities we invest in. CDPQ formally committed to fighting climate change in 2017 by pledging to reduce the carbon intensity of our overall portfolio by 25 percent by 2025. And, by the end of 2020, our goal is to increase investments in low-carbon assets by more than $14 billion compared with 2017. We would like to be seen as a leader in sustainable infrastructure. The REM, for instance, is fully electric and will be carbon neutral from beginning to end. It will help reduce 115 million vehicle-km, which translates to a significant reduction in the distance being covered by cars. We want to show that the future of urban mobility can—and should—be efficient and carbon neutral.

Agile delivery of capital projects

Industry leaders are using the agile approach to reimagine how capital projects are delivered.

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The capital project-delivery process has changed very little over the past few decades.[1] Projects progress through a set of well-defined stages: concept engineering, detailed engineering, procurement, construction, and commissioning. Project managers and engineers may tout the rigorous approach taken to approve the passage of the project from one stage to the next, as well as project-management tools—such as cost and schedule baselines—used to control the project and keep it on time and on budget.

Pressed further, however, they may admit that certain organizational structures, while well meaning, have common flaws that lead to schedule and cost overruns. The root causes tend to be threefold:

— *Risk aversion* requires decision making by committee. Often this translates into needing a meeting for every decision, which slows the pace of progress.

— *Control mechanisms* such as stage gates or model reviews can lead to inventory building up between stages, which expands the schedule.

— *Silos* between disciplines create inefficiencies. As each silo controls for its own interest, negotiation about handoff criteria and acceptance slows down progress, and poor coordination among trades hampers productivity.

Over the past 20 years, industries that face similar challenges (such as manufacturing) have followed the lead of software engineering in adopting a new approach—agility—to overcome organizational inefficiencies.[2] In an agile approach to execution and development, self-organizing and cross-functional teams—sometimes extending to suppliers, customers, and end users—collaborate to create and continually refine requirements and solutions. While the use of agile methods in capital projects is still uncommon, some early adopters have been able to reduce capital expenditures by a minimum of 10 percent and increase productivity and reduce completion times by 10 percent each. These examples of the potential for agile to transform the capital-project process are beginning to pique the interest of industry leaders.

How agile works in capital projects

A typical capital project is designed as a rigid, linear, sequenced process, with each stage handled by its own team of specialists.[3] An agile project, on the other hand, is designed to be more nimble and dynamic: while a stable backbone defines clear deliverables and work packages at the standard project gates, dynamic capabilities are overlaid to react quickly to changes and allow projects to move more seamlessly through each stage.[4]

The key characteristic of an agile project is the empowered, cross-functional team, which works across silos to create end-to-end accountability. Work is carried out in shorter, more iterative "sprints" that enable the teams to quickly test and adjust ideas, minimizing risk of miscommunication or overdesign. Next-generation technology and a clear, shared purpose are crucial. These principles can be applied across the project life cycle—concept selection, engineering and procurement, and construction and commissioning—to compress schedules and improve productivity while maintaining safety and quality performance.

Concept selection

When projects are in the concept phase, teams usually generate multiple concepts and then select the most attractive through screening,

[1] Wouter Aghina, Karin Ahlback, Aaron De Smet, Gerald Lackey, Michael Lurie, Monica Murarka, and Christopher Handscomb, *The five trademarks of agile organizations*, January 22, 2018, McKinsey.com.
[2] Christopher Handscomb, Christiaan Heyning, and Jannik Woxholth, "Giants can dance: Agile organizations in asset-heavy industries," May 2, 2019, McKinsey.com.
[3] Aaron De Smet, "The agile manager," *McKinsey Quarterly*, July 12, 2018, McKinsey.com.
[4] Aaron De Smet, Michael Lurie, and Andrew St. George, "Leading agile transformation: The new capabilities leaders need to build 21st-century organizations," October 1, 2018, McKinsey.com.

further studies, and cost evaluation. In this phase, significant engineering capacity tends to be dedicated to the development of ideas that prove too difficult to integrate into a cohesive design, meaning more time and energy is expended than needed to get to the final answer.

In contrast, agile concept-engineering teams can switch to a new delivery model that prioritizes project features and the decisions required to get to the final answer. This would mean less time spent developing whole concepts and more time spent framing the right questions to help the team get the best answer that possesses the most possible desirable qualities. This approach can provide more time for value engineering, which reduces project costs, and significantly compresses the concept-engineering schedule.

One oil and gas company was working on a subsea tieback construction project to connect a new field to its production facility. But several open questions were outstanding, and waiting for functional silos to have capacity to answer them was stalling the project schedule. The company adopted an agile approach by challenging the team to focus on the most critical decisions and what features would determine which decision to make. The company was able to narrow down options enough to significantly reduce the amount of functional work, commercial-evaluation time, and subsurface studies, and to resequence several of the milestones. This certainty also gave the team enough confidence to place long-lead orders before the final investment decision without increasing the project's risk profile.

As a result, the company shortened the schedule for concept selection by 60 percent, reduced capital expenditure in the engineering and procurement phase through nonbespoke design, and cut the time to first oil by around 35 percent, which improved the overall net present value (NPV) of the project.

Engineering and procurement

Engineering teams, particularly for smaller projects, are often staffed with part-time discipline leads who work on multiple large projects at once, with dedicated oversight provided by a small number of project managers and project engineers. These fragmented workforces often lead to bottlenecks when hand-off timings don't line up and multiple commitments stall project progress.

Agile capital projects are characterized by smaller work packages that are more frequently integrated into the overall design, with multidisciplinary teams convened to tackle specific challenges in sprints lasting one to two weeks. Sprints will differ based on project maturity. Early sprints for projects that are just starting will focus on designing or setting and aligning on project requirements. More-mature projects will have sprints focused on core design aspects of the project, and sprints during construction will be broken into small work packages to enable detailed tracking and application of learnings from earlier packages. This approach requires a much more dynamic staffing model that assigns people for weeks, not months or years, and dedicates people at a much higher percentage to fewer projects at once. Doing this allows organizations to significantly reduce complexity, reduce spending, and compress schedules.

One national oil company had traditionally organized its engineers in asset-specific staffing pools. The company had been experiencing large schedule overruns and high levels of rework from functional silos. The company abandoned its top-down hierarchy and implemented an agile flow-to-work model, in which individuals are staffed to projects rather than specific tasks.[5] This approach enabled it to dynamically match project needs to the skill sets of engineers throughout the

[5] Wouter Aghina, Christopher Handscomb, Jesper Ludolph, Dave West, and Abby Yip, "How to select and develop individuals for successful agile teams: A practical guide," December 20, 2018, McKinsey.com.

organization and optimize project staffing. The model enabled the company to achieve higher productivity—freeing up about 25 percent of engineering capacity while accelerating schedules by 50 percent.

Construction, commissioning, and turnover
The traditional approach to capital projects is managing the front line reactively to achieve preset milestones, handing out tasks to crews in a stage-gated, sequenced process. This approach can optimize earned value and productivity within disciplines. But it fails to consider follow-on impacts to subsequent disciplines and inventory buildup between disciplines that expand the schedule.

Instead, agile capital projects approach construction as a network of interconnected and defined tasks and resources. To reduce inventory and shorten the schedule, they break down the silos between disciplines by setting up cross-functional production teams and managing the flow of finished packages through to system completion.

A basic-materials manufacturer was embarking on a $500 million capital project to build a new facility to produce a cutting-edge, high-strength product. At its peak, the construction workforce involved 650 craftsmen. At 50 percent complete, the project team realized that delays to critical engineered equipment would result in delays to the final completion date. To minimize the risk, the company created a cross-functional team including stakeholders from project controls, engineering firms, and contractors, who together optimized construction interfaces and sequences. The team took a project-level view, facilitated sprint-planning sessions to identify critical activities, and proactively removed constraints and variability. By analyzing the project at this granular level, the team was able to create workflows and processes that reduced the impact of delayed equipment and reprioritized resources to recover time where possible. This approach enabled the project team to deliver the project 17 percent faster, and with 124 percent higher productivity than was previously achieved on the project.

Getting started

Capital-project organizations have been slow in introducing agile into their project-delivery processes partly due to some common myths and misconceptions. Some believe, for example that agile methods do not allow for meetings and or planning. Others find agile methods a tough sell when the typical structure of a project's division reinforces both siloed communication and the rigid project stage-gates that drive traditional project development.

However, as pockets of case studies appear in capital projects, it becomes more clear that agile represents a transformative opportunity for the sector. To combat these common challenges to deploying agile, the next step for owners and engineering, procurement, and construction companies (EPCs) is to apply agile principles on a minimum-viable-product (MVP) basis—identifying a few specific areas to address, or "use cases," that agile could productively target. This way, their people can start to recognize what agile can achieve. Early successes can create an appetite for more—ideally leading to agile applied on an end-to-end basis for an entire project or stream of value. Among the most advanced organizations, an enterprise-wide agile transformation is the eventual result.

Apply the agile playbook in specific use cases. An MVP starts by identifying isolated opportunities in a part of a project where it's possible to deploy

and test agile ways of working. Examples might include proposal writing, concept selection, or strategy sourcing—processes that typically benefit from cross-functional teams, are time bound, and have clearly defined targets. Establishing an agile team, following the principles, and dedicating the required resources enables the iterative learning that's at agile's heart. Mindsets also matter: selecting team members who are excited about testing this new way of working and are keen to try new things and build capabilities helps build momentum and positive word-of-mouth.[6]

Find a candidate project within your portfolio for deploying agile end-to-end. Limited use cases will likely have limited impact until they build into something more comprehensive. Moreover, skeptics may wonder whether ideas that have been applied to narrow problems will work in their projects or functional area. To limit these risks, the next step after the MVP is to look for a project or moderately sized department that offers the potential for significant improvement in productivity, schedule reduction, or similar metrics—and then win support from the highest levels of leadership. Their commitment will be essential both for the agile changes to take hold, and for other parts of the organization to take notice.

It's important to note that agile might not work in every situation, and its use must be tailored to the project. A core understanding of the full agile way of working is critical. But agile could revolutionize how capital projects are delivered. If capital projects were to achieve half of what has been demonstrated in other industries, this could easily bring projects in budget and on schedule, and drive further improvements to NPV. It's worth the effort.

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[6] Stefan de Raedemaecker, Christopher Handscomb, Sören Jautelat, Miguel Rodriguez, and Lucas Wienk, "Lean management or agile? The right answer may be both," July 14, 2020, McKinsey.com.

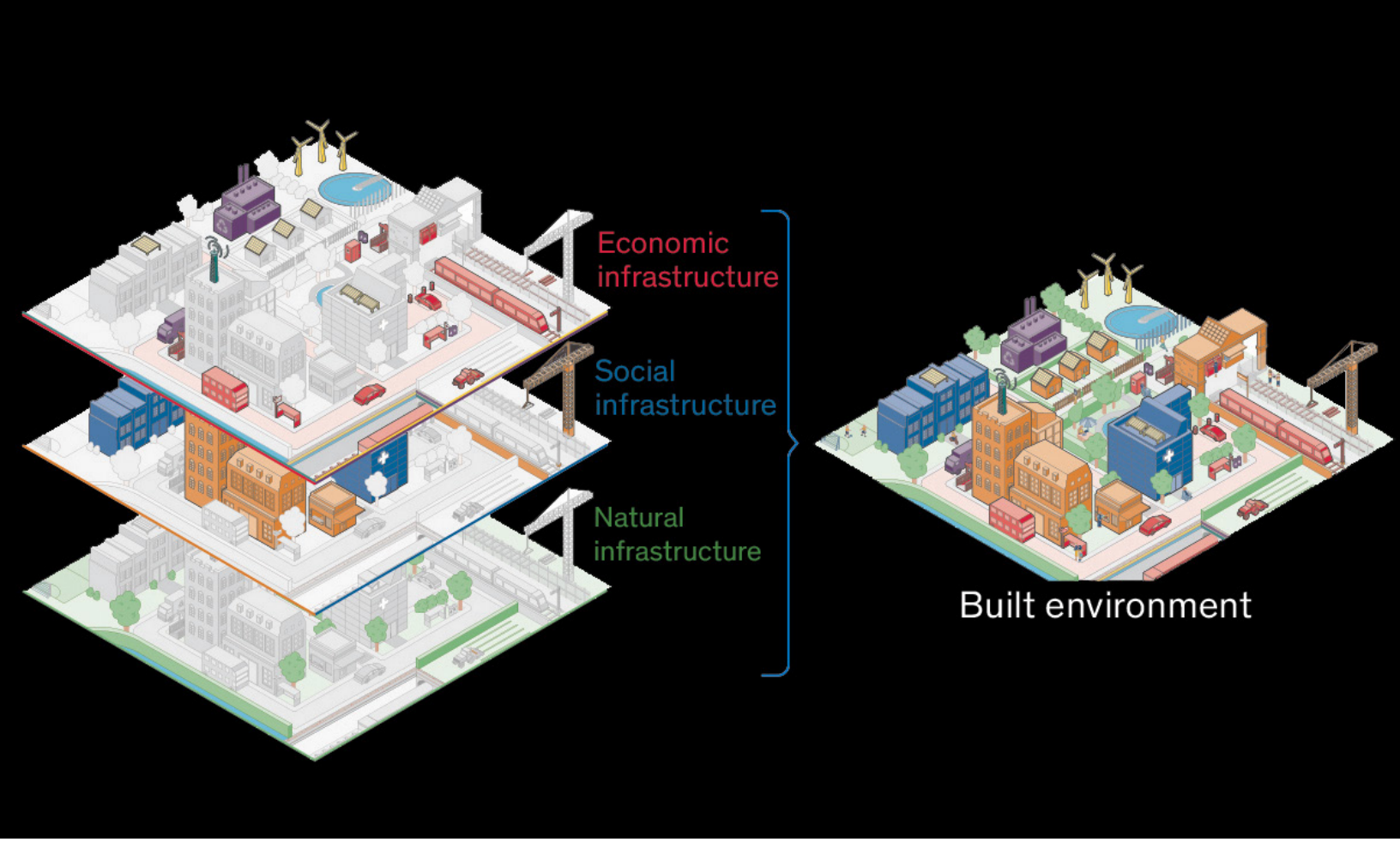

Image courtesy of CDBB

Establishing the National Digital Twin: A Q&A with CDBB's Mark Enzer

An ecosystem of connected digital twins is the start of a new approach to planning and managing assets.

Mark Enzer

Digital Director
Centre for Digital Built Britain, CTO of Mott MacDonald and Chairman of the Digital Framework Task Group

Today, in most of the world, information from across the built environment remains largely siloed and inaccessible. The United Kingdom's National Digital Twin Programme aims to change that. Infrastructure leaders will be able to conduct improved analysis of more comprehensive data—which leads to better decisions, interventions, and outcomes.

In this interview, Mark Enzer—digital director at the Centre for Digital Built Britain, CTO of Mott MacDonald, and chairman of the Digital Framework Task Group—describes the potential impact that connected digital twins could have on the country's infrastructure operations—as well as on its data-sharing practices.

McKinsey: What's your vision for how the National Digital Twin (NDT) will change construction and operations within infrastructure?

Mark Enzer: The National Digital Twin is envisaged to be an ecosystem of connected digital twins, enabled by secure and resilient data sharing across organizational boundaries. We at the Centre for Digital Built Britain (CDBB) expect the NDT to unleash value principally by facilitating better decisions—in use, operations, maintenance, resilience, planning, investment and more—across economic and social infrastructure. Quite simply, well-informed decisions based on better analysis of better data lead to better outcomes for people. This is the essential promise of the Information Age, and one we think is more important than ever after the challenges of this past year.

McKinsey: Where do you see construction and infrastructure heading in the United Kingdom?

Mark Enzer: For me, the really exciting thing is seeing Industry 4.0 applied to infrastructure for the benefit of the people it serves. Our Victorian forebears served us well by developing infrastructure that was fit for the First Industrial Revolution, and now we have the opportunity to bring the Fourth Industrial Revolution to our infrastructure systems. This means recognizing the genuine value of digital assets and melding them with more familiar physical assets to create cyber-physical systems. Such a development could potentially be as epoch-making as that first golden age of infrastructure.

McKinsey: Why is now the time we're really getting going with the NDT?

Mark Enzer: General technical advances in the industry are allowing us to imagine something that seemed like science fiction even ten years ago, and the unit cost of everything to do with data—collecting, processing, and transmitting it—has plummeted, creating the economic engine that drives digital transformation. In addition, the infrastructure industry has grown in digital maturity (though there is still a long way to go) and employed sufficient collaboration across the industry to make the NDT achievable. For example, the Infrastructure Client Group has established a Digital Transformation Task Group to accelerate digital transformation across the infrastructure industry.

In thinking about why now is the time to drive secure and resilient data sharing, and not in five years' time, we must also understand the cost of moving too slowly. If we don't come up with some common rules quickly, everybody will create their own siloed, incompatible rules—bespoke data models and inconsistent reference data libraries—that will make data sharing more difficult. They will build friction into the system.

McKinsey: Why are common data standards important, and how will they be used?

Mark Enzer: Common data standards are essential to enable the consistency and quality of data that is required for secure, resilient data sharing across organizational boundaries. It's all about interoperability and integration. Without such standards, it would always be possible to write bespoke application programming interfaces (APIs) to enable specific point-to-point data sharing, but that would create significant unnecessary additional cost if bespoke APIs had to be used for data sharing across the entire network

of potentially valuable connections. In effect, common standards would reduce the friction in data sharing. As an example, we currently find that data scientists working in artificial intelligence spend 80 to 90 percent of their time just making the data fit for use. We would change that. Interoperability will release the pent-up value of our infrastructure data.

To unlock this level of interoperability, we are developing the "Commons," a suite of national open-source information management standards to be shared across the entire built environment.

McKinsey: There are a lot of stakeholders involved. Who will own the NDT?

Mark Enzer: The question of ownership is quite tricky, so we will have to discover some of the answers as we go. At a basic level, it makes sense for owner-operators to own their assets' digital twins, processes, and systems as well as to curate the related data. However, the picture becomes more complicated when we start aggregating data across organizational and sector boundaries. Bringing such data together creates more value, and potentially more risk, so we'll need to be careful as we work through the questions of obligations and liability, risk and reward. No matter the ownership, we believe that data related to public assets must be used for the public good.

This key principle must underpin and inform all efforts and is enshrined in the *Gemini Principles*, which are effectively the conscience of the National Digital Twin.[1]

McKinsey: How do you drive consensus and standardization between those different stakeholders?

Mark Enzer: The infrastructure industry is really only the sum of many individual organizations and their assets, so the required change comes down to what incentives will convince them to get on board.

We can imagine a whole spectrum of incentives. In the early days, some organizations will be motivated to be seen as leaders. And a little further down the spectrum would be enlightened self-interest: if it makes their life easier, or if it's cheaper for them to follow the standards, then organizations will do so. We're already starting to see genuine value being associated with the data sets themselves. Board rooms that see that value (whether on their balance sheets or not) will pay a lot more attention to properly structuring their data in a way that will benefit their organization. So, we anticipate that the most effective incentivization will be the carrot of market forces rather than the stick of regulation or legislation.

[1]Alexandra Bolton et al., *The Gemini Principles: Guiding values for the national digital twin and information management framework*, Centre for Digital Built Britain, 2018, cdbb.cam.ac.uk.

Beyond taller walls: Meeting the resilience challenge of climate risk

Climate change poses serious threats to infrastructure systems and the human lives that depend on them. It's time for industry players to begin building resilience.

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Infrastructure faces an unprecedented threat from climate change over the next several decades. As described in a recent McKinsey Global Institute (MGI) report, the socioeconomic impacts from physical climate risk—that is, floods, fires, excessive heat, and storms—are occurring with greater frequency and severity, leading to prolonged disruptions far more often than many business leaders realize.[1] And infrastructure is not immune. Every asset is designed to withstand a climate threshold, such as a certain depth of flood water. As climate risk increases, those thresholds will be exceeded, and the effects will be nonlinear as damage rapidly flips from minimal to critical.

If climate hazards increase as projected, they could cause significant disruptions to entire physical and socioeconomic systems. For example, in a high-emissions scenario, the MGI expects that in Ho Chi Minh City, rising sea levels between now and 2050 would triple the economic cost of infrastructure damage from a 100-year flood—while the cost of other real-estate damage would increase sixfold. Likewise, flight groundings resulting from extreme heat would increase tenfold across the globe by 2030 and nearly a quarter by 2050,[2] affecting major international airports such as Dubai and Kuwait City. Grid outages resulting from excessive heat are also likely to be much more common and severe. Cities and countries that have not yet experienced extreme climate-related events may find themselves caught off guard. Take Bristol, England, where current defenses could fail to protect the city's most vital urban infrastructure by 2065 as extreme flood risk rises, increasing the economic impact of flooding from millions of pounds to billions of pounds.

Industry players will want to prepare for the growing vulnerability of today's infrastructure assets as well as the increasingly complex web of dependencies, whether intrasector (such as energy systems failing from the loss of critical substations) or intersector (such as data centers relying on grid electricity). Moreover, the industry plays a critical role in not only protecting existing assets but also helping societies adapt to inevitable changes and mitigate damage from physical climate risks, from reconceiving flood defenses to designing new water-treatment plants.

As physical risks become more widely recognized and climate-related hazards start affecting more assets, all major infrastructure players will need to understand what these changes mean for them. And because of inertia in the geophysical system, the impacts forecast to 2030 are likely locked in based on historic emissions. Business as usual is no longer an option. Infrastructure players will want to understand the risks in their assets and portfolios, focusing on durability as well as efficiency while capturing opportunities that arise from adaptation—and rethinking funding models.

If infrastructure systems fail, people will suffer. That means cultivating resilience now across the infrastructure industry.

Understand the risks in assets and portfolios

Infrastructure assets and portfolios of various kinds—and in a wide range of geographies—are exposed to underappreciated climate risks. Even portfolios that appear to be diversified by geography and asset class may in fact be exposed to systemic risks. And as with the city of Bristol, assets that have not historically been susceptible to weather-related hazards may soon be at risk—including public transport in Boston from flooding, airports in the southern United States from excessive heat, and electrical distribution in Portugal from wildfires.

Infrastructure investors are facing the reality that, in time, climate risks could depress returns from infrastructure assets. Thus, as physical climate risks become more broadly understood and accurately projected, capital allocators will increasingly demand visibility into climate risks in

[1] For the full McKinsey Global Institute report, see "Climate risk and response: Physical hazards and socioeconomic impacts," January 16, 2020, on McKinsey.com.
[2] For more, see "Will infrastructure bend or break under climate stress?," McKinsey Global Institute, August 19, 2020, on McKinsey.com.

portfolios—as Larry Fink, founder, chairman, and CEO of BlackRock, suggests in his 2020 annual letter[3]—and investors will start pricing climate risks into asset valuations.

We can no longer assume that the climate of the future will look like the climate of the past. Instead of using historical standards with safety margins, industry players will want to assess against a range of future climate scenarios. Fortunately, extensive data and sophisticated tools allow organizations to simulate these risks and understand risk exposure at a high level of specificity. For example, climate projections and flood modeling can help in understanding how many centimeters of water might flood a substation or an airport—or which parts of an electrical-transmission system might be vulnerable to wind damage. With a better understanding of the technical limitations and economic impact of downtimes, organizations can create fact-based estimates of how much climate change–related disruptions could cost.

Design to last

Industry mindsets are likely to change to incorporate this new risk. For instance, infrastructure players will want to evaluate large capital projects to reflect the probability distribution of climate hazards in a specific location, and how that distribution may change over time. They will also need to evaluate scenarios that could change the cost of capital for exposed assets, contractual responsibilities for major climatic disruptions, or even the underlying citizen demand for the service an infrastructure asset provides.

Increasingly, infrastructure planners and builders will be expected to incorporate climate change–related durability and hardening measures into the design and construction process. Underwriting assumptions, investment-committee memos, design choices, and acquisition or exit decisions will benefit from a practical and fact-based understanding of climate risk. Projects may need to be redesigned to strengthen climate-change resilience; for example, there are parks that serve as drainage in Shanghai and road tunnels that double as flood tunnels in Kuala Lumpur. If perspectives on the resilience imperative of infrastructure shift, so too will asset mixes, such as by moving toward more distributed energy assets.

Capture opportunities from rising demand for adaptation

Infrastructure is on the front lines of challenges associated with physical climate risks—and it is also on the front lines of creating solutions. Many have viewed sustainable, low-carbon, resilient infrastructure as too costly, but when faced with the realities of climate change, it is clear that the investment is not only justified, but necessary.

The need for adaptation over the coming years is enormous—cities will need flood walls, energy utilities will need to make resilience investments, water infrastructure will need to be upgraded, and real estate will need to be hardened. And all of this must happen in an ever more hostile climate. Thus, the ability to meet the shifting demands and overcome the challenges created by climate change will become a competitive advantage as much as a socioeconomic imperative. The infrastructure players that lead the way now can mobilize investors and provide the stream of capital necessary to achieve that imperative.

Innovate to secure funding and financing

The front-runners in the next normal will be those who can innovate on partnership models, financing mechanisms, and delivery approaches. Those who can build better but also cheaper in hotter or wetter climates will be better positioned to capture share. Those who can shift to innovative models linking remuneration to better uptimes on more resilient assets will be more likely to profit. Regulators may start to adopt a

[3] Larry Fink, "A fundamental reshaping of finance," BlackRock, January 14, 2020, blackrock.com.

longer-term view on total lifetime expenditure for these assets to thrive. In particular, in the current COVID-19–driven economic environment, the challenges of finding financing may be exacerbated. However, in some jurisdictions, governments are funding climate adaptation projects as part of their COVID-19 recovery planning.

As the investment pool expands, infrastructure players are likely to find that value arises not only from financial gains but also from deeper social capital, higher trust, and stronger networks that together create meaningful, lasting impact.

Several efforts are underway to support the sector in making informed decisions. For example, the Coalition for Climate-Resilient Investment has convened a range of organizations across the infrastructure-investment value chain to develop tools and standards for incorporating climate risk into decision making. The coalition is developing a framework and methodology for physical risk pricing to help channel investment toward more resilient infrastructure—which is necessary for developing and advanced economies alike.

Infrastructure players are already battling increased risks related to climate change, and these risks are set to balloon over the next few decades. Responses will need to be fundamentally different than historical approaches to developing and financing infrastructure. The answer is not simply to build taller walls. Players must act now, and in new ways, to meet the need and prevent irreversible damage and loss—both to infrastructure assets and people across the globe.

The extent to which COVID-19 will affect the nature of the world's infrastructure needs is yet unknown. However, the fundamental need to deliver that infrastructure will remain, and with it the importance of exploring, adopting, and implementing creative ways for public- and private-sector participants to partner, collaborate, and collectively make the best use of their respective resources to bridge the infrastructure gap.

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Photo courtesy of Autodesk

Data to the rescue: Embodied carbon in buildings and the urgency of now

Building companies seeking to make informed materials-procurement choices may confront data that are either lacking or too complex. A precompetitive consortium has responded with a free, open-source tool that anyone can use to help fill in the gaps.

Lynelle Cameron

Vice President of Sustainability at Autodesk and CEO of the Autodesk Foundation

The 2020s are a make-it-or-break-it decade for addressing climate change: humanity must halve its carbon emissions by 2030 to meet the goals of the Paris Agreement. Given that buildings contribute around 40 percent of greenhouse gas (GHG) emissions worldwide, it is critical that architecture, engineering, and construction (AEC) professionals understand their role in reducing the sector's carbon footprint—and how to use the tools available to assist them.

For years now, the industry has focused its climate efforts on operational-energy consumption from lighting, heating, cooling, hot water, and other plug loads. And it has made great strides in increasing efficiencies and renewable-energy supplies. However, there is another, less obvious source of GHG emissions associated with buildings: embodied carbon. It's already in the atmosphere, quietly warming our planet, by the time materials reach the project site. And for new buildings, its climate impacts are nearly even with those of operational energy.

Embodied carbon consists of all the GHG emissions associated with building construction, including those that arise from extracting, transporting, manufacturing, and installing building materials on site, as well as the operational and end-of-life emissions associated with those materials. "Cradle to gate" embodied carbon refers to the emissions associated with only the production of building materials, from raw material extraction to the manufacturing of finished products; it can be thought of as supply-chain carbon, and it accounts for the vast majority of a building's total embodied carbon.

Unfortunately, embodied carbon is more difficult to measure and track than operational carbon, which is relatively simple to extrapolate from occupants' energy bills. Determining the embodied carbon of any building material is impossible to ascertain from the finished product alone and requires self-assessment and process transparency on the part of the manufacturer. Two materials may look identical, cost the same amount, perform to the same standard—but have totally different embodied carbon characteristics. For example, a 100 percent recycled-steel beam produced using renewable energy may appear identical to a virgin-steel beam produced using a coal-fired furnace—but have significantly different levels of embodied carbon. Where each steel beam came from and how far it was transported add further complexity.

Accordingly, a nonprofit consortium of construction-industry players came together to develop what is now known as the Embodied Carbon in Construction Calculator (EC3): a free, cloud-based, open-source tool that utilizes data to power better materials choices and tackle cradle-to-gate embodied carbon.

Calculating embodied carbon

What gets measured gets managed.

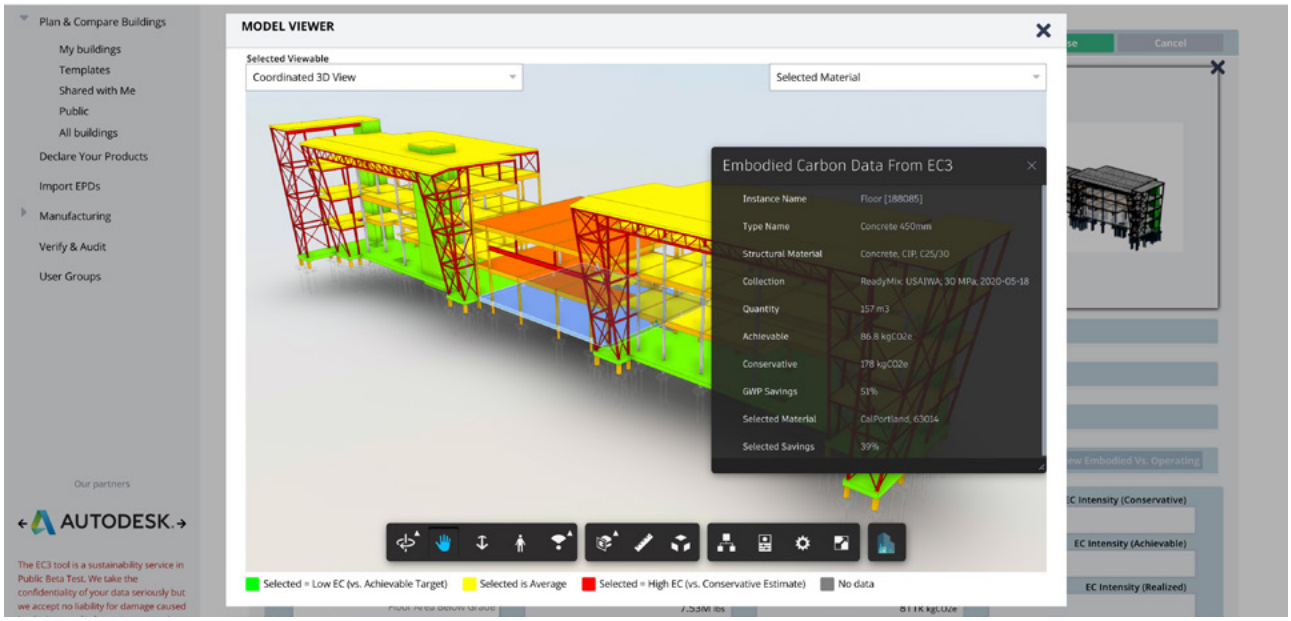
The primary function of EC3 is to accelerate and scale the reduction of embodied carbon in the built environment. Building-industry users can easily access and view material carbon-emissions data for products manufactured within a defined geography, thus enabling carbon-smart choices during design and procurement. What would have taken experts days can now be accomplished in minutes by general practitioners.

Integrating EC3 with standard building-information modeling (BIM) tools can further extend its utility. The resulting industry-wide connectivity allows AEC professionals to transfer quantitative project-material data directly from the building's digital model to EC3, and then visualize the embodied carbon impacts of their materials choices (exhibit).

Perhaps the most powerful factor in EC3's fast carbon benchmarking is its underpinning materials-data strategy, which allows users to rank locally produced materials by embodied carbon performance. The data is drawn from publicly available materials datasheets called "environmental product declarations" (EPDs)—which are easily consulted one at a time, but not in large numbers. Having collated more than 23,000 EPDs, EC3 scrapes the embodied carbon

Exhibit

EC3 turns the 3D building model into an interactive carbon heat map.



metric from each one, along with the material's performance specifications and location of manufacture.

As a result, building professionals can quickly see how materials stack up against one another within their supply region, making it simple to distinguish between, say, two identical-looking steel beams.

EC3 is the product of industry collaboration by general contractors, structural engineers, architecture firms, materials manufacturers, technology companies, and academics.[1] The project quickly attracted a broad consortium of AEC firms—including a number of competitors—that banded together for mutual benefit. This coopetition allowed EC3's developers to build their methodology and validate ideas with input from a large cross-section of industry, ensuring the tool's quality and relevance.

The community of partners and sponsor companies continues to expand. Microsoft was the first to pilot the tool on a large project during the campus remodel of its corporate headquarters in Redmond, Washington.[2] And in a recent blog post, Bill Gates recognized EC3 as the type of technology that will aid us in getting to zero emissions.[3] Further, the Port of Seattle is using EC3 in pilot projects,[4] Skanska US has reduced embodied carbon in its projects by as much as 30 percent without increasing procurement costs, and California-based Webcor is rolling out EC3 on all future projects.

[1] For more on this collaboration, see "Initiative: EC3 Tool," Member-led initiatives, Carbon Leadership Forum, carbonleadershipforum.org.
[2] "Building a modern campus," Microsoft, news.microsoft.com.
[3] See "Buildings are bad for the climate.," *Gates Notes,* October 28, 2019, gatesnotes.com.
[4] Leslie Stanton, "Building to reduce embodied carbon emissions," Port of Seattle, September 24, 2019, portseattle.org.

Solving construction's sustainability challenges through collaboration

At a high level, the challenges around climate change that the AEC industry faces today require true collective effort, outside-the-box thinking, and openness. AEC firms across disciplines can move the needle on global greenhouse gas emissions much faster when they rally around a shared solution. The coopetition behind EC3 can therefore serve as an important catalyst for change. In this age of heightened concern over data privacy, the precompetitive openness and willingness to share data and best practices to reduce embodied carbon is truly striking.

EC3 also signals what the connected platforms of a sustainable future will look like. Open data and collaboration across silos are going to be key, and the technology the industry uses to measure and reduce the environmental footprints of buildings is starting to reflect that. EC3's underlying data set brings together standardized material-manufacturer information, making it open and geolocated. And BIM connects the whole AEC value chain across project phases. Together, these technologies deliver data-driven insights on a unified platform, empowering better decision making throughout the project life cycle.

Inspiration can spur the creators of tomorrow's sustainability solutions—perhaps to address embodied carbon in other parts of the built environment, such as roadways. As BIM adoption grows, Autodesk has recognized the tremendous opportunity to create an open platform and partner with the creators of these tools to deliver ever-better insights to customers through seamless experiences.

With new models of collaborative solution development powered by connected data, it may become possible to cut GHG emissions dramatically in less than a generation. We all have a part to play in making the sustainability solutions of the future easy for, accessible to, and trusted by the industries we serve. Banding together to beat back the tide will benefit us all.

Voices *highlights a range of perspectives by infrastructure and capital project leaders from across geographies and value chains. McKinsey & Company does not endorse the organizations who contribute to* Voices *or their views.*

Lynelle Cameron is the vice president of Sustainability at Autodesk and CEO of the Autodesk Foundation.

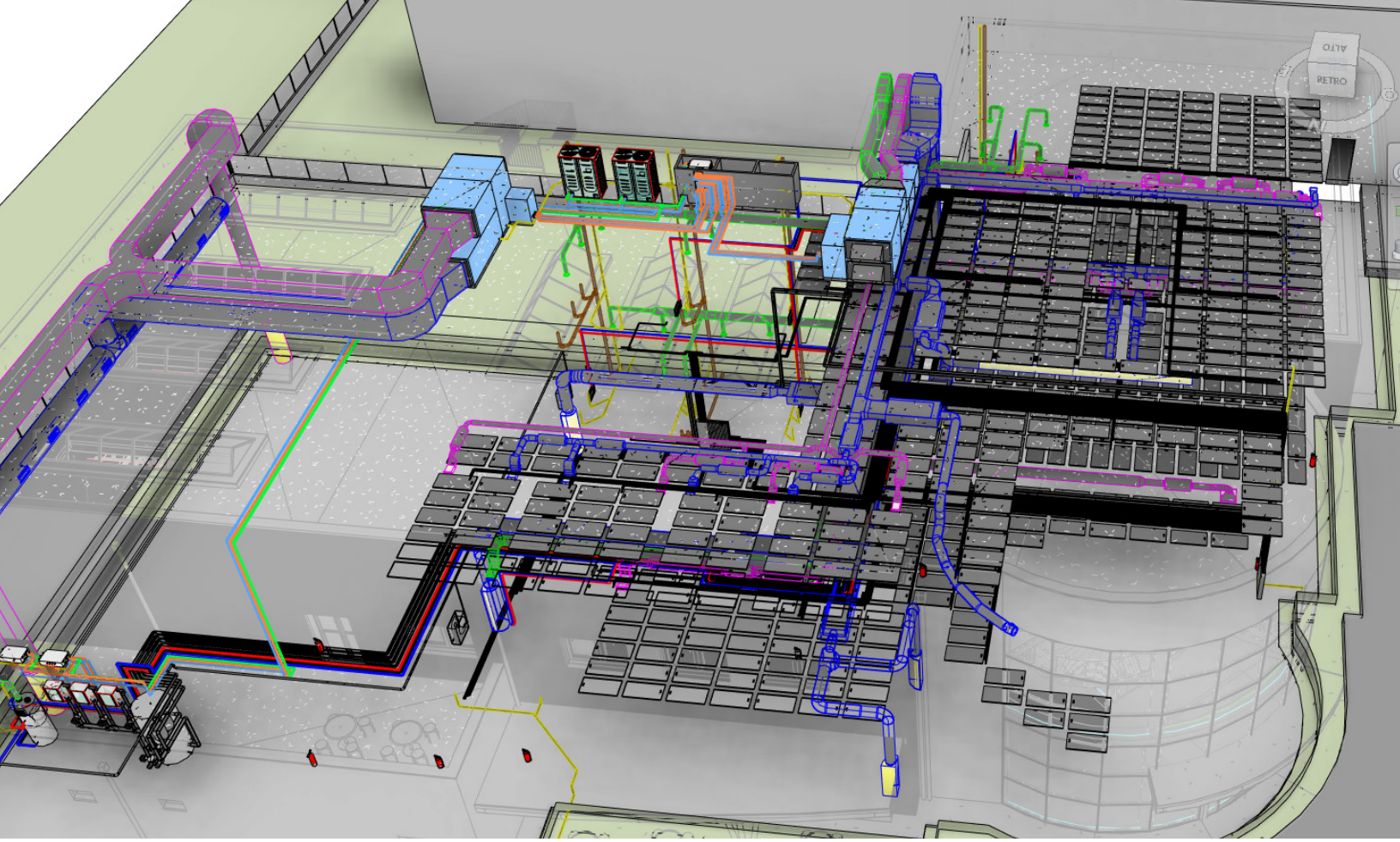


Image courtesy of Consorzio Ponte Rosso

Walking the talk: Best practices for digital construction

We are taking the advice we typically give our clients and applying it to our own construction project—and we'll be sharing the challenges and lessons as we go.

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It's no secret that digital innovations can improve productivity and help the construction industry navigate disruptions and mitigate risks. And in the wake of the COVID-19 pandemic, many project owners have been forced to step up their use of technology to enable their teams to work and collaborate remotely.

But beyond the context of the current crisis, adoption of digital innovations has been slow. This delay is at least partly due to a lack of digital standards and experience within the industry. In addition, many players likely anticipate high up-front costs and a long wait before their investment pays off. Project owners are understandably wary of testing new digital tools on multibillion-dollar projects. And given that project success typically hinges on collaboration, introducing new digital workflows—which may be unfamiliar to some of the parties involved—can seem daunting.

But the benefits can be greater—and the barriers lower—than many industry players expect. In the design phase, a fully digital construction project can reduce drawing revisions, redundant conversations, and version errors while lowering project risk and facilitating clash detection.[1] Going digital also supports procurement across work packages and over time, increasing safety standards and allowing better workforce planning and machinery use. Of course, achieving these benefits requires parties to be willing to explore new solutions and fundamentally shift the way projects operate.

So when it came time to add a building to the McKinsey Digital Capability Center in Venice—an almost unique opportunity for us to build a project from the ground up—we chose to take our own medicine. Together with our partners on the project, we decided to roll out core digital tools, build the required capabilities, and push the boundaries of what is possible: exploring new ground to see for ourselves (and for the industry) what these tools and a new way of working can do.

Although we are still in the early stages of construction, a number of unforeseen challenges have already shown us how quickly digital tools can improve collaboration among stakeholders. These challenges, and the ones that will surely follow, will allow us to better understand the benefits of digital tools in construction and to empathize with companies facing these hurdles. We plan to share everything about our process—good and bad—so that construction leaders who are starting their digital-transformation journeys can take our lessons to heart and capture all of the value on offer.

Three pillars of digital construction

The entirety of our new building was designed using a building-information-modeling (BIM) process. Our goal was to bring digital tools into the construction phase to influence the following:

— *Collaboration.* A digital control tower brings together owner representatives, the lead contractor, and subcontractors to discuss plans and track progress around one common source of truth, with an integrated master schedule.

— *Tracking and forecasting.* Using drones as well as fixed and hand-held scanners, frequent 3D site scans linked to the BIM model can automatically detect deviations, forecast potential clashes in constructability or work-package execution, and ultimately feed into the reporting dashboards of the digital control tower.

— *Worker safety and material workflows.* Sensor-based safety technology fosters a safer and more focused on-site work environment, helping workers follow safety protocols more closely and remain aware of their surroundings.

[1] Clash detection is a feature of BIM that identifies areas where parts of a building may conflict with one another before construction begins.

First steps toward fully digital construction

Pushing technology frontiers is less important to success in digital construction than a shared commitment to changing the approach. Most architects and engineers today work in BIM, but finding other critical partners with experience in—or who are open to other new solutions as part of a fully digital construction model—can be complicated.

In our initial discussions, contractors expressed great curiosity about the applications of digital tools. In particular, executing contractors worried that a rollout of digital tools might actually create more work, especially at the beginning of the effort. This initial hesitance was not unwarranted—the 3D site scans, digital tracking tools, and sensor equipment for workers all had to be budgeted for, and some foundational work, such as creating a more meticulous schedule, had yet to be completed.

Indeed, before putting these digital tools to work, we needed not only to champion tangible, granular data but also to reset the general understanding of collaboration. The digital control tower is intended to facilitate this new way of working among parties—shifting from reporting only on specific milestones to routine, almost real-time reporting that allows for ad hoc problem solving.

More important, we have learned that walking toward rollout together is essential for building trust in the tools. Digital tools create value not by reinforcing old mechanisms, where the project owner exerts control and contractors struggle to deliver, but by serving as catalysts to a joint understanding, joint truths, and joint success.

For example, by collaborating on schedule granularity and quality, our owners and contractors established physical key performance indicators (KPIs) to guide the project—such as the volume of concrete that had been poured or the area of semi-precast slabs that had been installed, both of which could be found in the scans. Monitoring this activity in almost real time enabled daily tracking. The significant effort paid off in multiple ways. For example, it increased the owner's understanding of what needed to be done, where to expect bottlenecks, and the challenges facing contractors (which were sometimes as simple as making sure ensuring an adequate workforce was available on a holiday). The effort also yielded immediate performance improvements—for instance, better visibility allowed us to resequence activities and reclaim several weeks of delay due to COVID-19 shutdowns.

Keeping ambition high—what's next

We are still at the beginning of our digital-construction journey, but the benefits of using digital tools have already outweighed the added up-front cost.

Thinking ahead, we want to better link our tools and enhance our analytics. We are striving, for instance, for fully automated progress reporting that links the performance KPIs embedded in the digital control tower with the evaluation of the 3D scans against the BIM model. We also want to optimize our integrated master schedule so that all parties benefit from improved activity sequencing, earlier alerts on required worker mobilization, real-time knowledge of timing and logistics (for both off- and on-site materials), and safer working conditions.

And we are keen to train additional subcontractors as they come on site to ensure they have a consistent level of capabilities and continuously foster a shared understanding of this new way of working.

We have high hopes for the outcomes this approach will deliver. We are wading through uncharted waters, and we are bound to make some mistakes. But once we learn from those mistakes, we expect that these improved methods—enabled by digital tools—will unlock new value. If players across the construction ecosystem capture all the value at stake, total profit pools for general contractors could nearly double, to an average of 10 percent.[2] For those that succeed, a $265 billion annual profit pool awaits.

And, as further disruptions confront the construction industry, all players will need to prepare for the next normal, work through the uncertainty, and determine how to capture that value.[3]

Learn more about our Venice Capability Center here. We will be adding new content as the project progresses and hope you will check back regularly.

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[2] For more on the disruptive trends facing the industry, see Maria João Ribeirinho, Jan Mischke, Gernot Strube, Erik Sjödin, Jose Luis Blanco, Rob Palter, Jonas Biörck, David Rockhill, and Timmy Andersson, "The next normal in construction: How disruption is reshaping the world's largest ecosystem," June 4, 2020, McKinsey.com.

[3] Ribeirinho, Mischke, Strube, Sjödin, Blanco, Palter, Biörck, Rockhill, and Andersson, "The next normal in construction."

Photo courtesy of Trimble

Connected construction: Reviving the United States' central nervous system

US infrastructure could again act as the country's central nervous system—if the industry joins together to pursue connected construction.

Bryn Fosburgh

Senior Vice President
Trimble

Eisenhower-era infrastructure has been the backbone of the United States since the 1950s. Today, the convergence of physical and digital assets is creating next-era infrastructure that has the potential to serve as the nation's central nervous system—and dramatically redefine the ways infrastructure serves society. In this vision, the central nervous system will not only enable the movement of people and goods but it will enable digital activity such as commerce and online content to be consumed, visualized, edited, and made actionable throughout the transportation network.

Building the new central nervous system requires industry-level change. The construction industry has demonstrated an institutional resistance to technologies that can lead to meaningful productivity improvements. As decades-old workflows and siloed teams continue to characterize the industry, scale remains the primary lever to even the score. Yet, despite the hopeful optics of bigger machines and teams, these strategies have not resulted in meaningful improvements in the quality or cost of our infrastructure.

Some players are already there. Around the world we see projects and project owners proving that technology-based transformation can, in fact, improve project delivery. Improvements in task-level productivity are enabling predictable, on-time delivery of discrete tasks. At the same time, integration and sharing of information between stakeholder groups throughout the production continuum result in on-time, on-budget delivery of the final project. Digital transformation of construction is underway today and at an accelerated pace; however, the only organizations positioned to benefit are those owners, agencies, and municipalities demanding and adopting new thinking. These are the change agents that will drive the nation's progress toward the new central nervous system and gain real value today.

Connected construction is the foundation

Creating the new central nervous system begins with connected construction. The word "connected" has become ubiquitous in the marketing jargon of a broad range of industries. Wireless connectivity is one aspect of being connected—but other impactful forms, such as sensor-based asset management and offsite construction, deserve attention. The prevailing benefits of connectivity are improved task productivity, process integration, and the ability to connect the digital and physical worlds simultaneously and transform project delivery.

Through connectivity, stakeholders can speed up delivery, achieve cost efficiencies, and reduce environmental impact. Connected construction provides all participants with confidence through improvements along five key dimensions: productivity, quality, safety, transparency, and sustainability (see sidebar, "The connected construction site").

Productivity

Hardware and software technology alone or in combination increase the chance of on-time delivery and improve quality. Productivity is subdivided as task and process integration, and implementing these technologies can result in a significant improvement in the development of infrastructure.

Task. Productivity tools such as global navigation satellite systems (GNSS), laser scanning, 3-D modeling software, imaging, machine control, and inertial navigation can drastically improve productivity. In our experience, engineers, machine operators, and surveyors using these technologies have doubled productivity when compared with conventional techniques.

Process. Process improvements along the life cycle of the project enable the infrastructure owner to deliver the project 30 percent faster than when conventional design, build, and maintain processes are used. The constructible

The connected construction site

The connected construction site combines task productivity with process integration along the construction continuum. The transformation of infrastructure projects is akin to 3-D printing: design, validation, and iteration are exclusively digital processes, but the "printers" are technology-equipped machines such as pavers and trenchers.

The process consists of creating a geometrical representation of the infrastructure digitally and then coupling attributes, such as soil types, utilities, or right of way, to determine potential overlaps, gaps, and design flaws that might exist prior to the physical build. The output results in a constructible model that can be used by all stakeholders on the project and becomes the single source of truth that all engineers, surveyors, estimators, and machine operators utilize throughout each phase in the continuum.

The constructible model is continually updated as the work progresses, and heavy equipment automatically reports on work performed (when, where, and how much). The updated model is then used to track schedule and cost to provide the owner and all stakeholders with a real-time view as the asset is being built, maintained, or operated.

model becomes the single source of truth throughout the design, build, operate, and maintain phases. Users can view cost in real time and address potential issues that cause delays and cost overruns. Because all stakeholders contribute and collaborate in the same ecosystem, all teams share reliable information.

Quality

Studies have shown that the costs of rework in construction can be up to 25 percent of the contract value and 10 percent of the total cost of the project,[1] often due to management, planning, and communication issues. Coupling task productivity and process integration makes it possible to better understand design intent while on-site and collaborate more easily, which in turn can reduce errors. This is accomplished by using accurate sensors on machines and instrumentation during the build phase. Rework is also reduced by using the constructible model across the continuum. The single source of truth is seamlessly transported between phases and stakeholders to reduce transcribing errors, undetected overlaps, or gaps in the design.

Safety

Task productivity tools enable workers to perform out of harm's way. For instance, they can take measurements virtually instead of in the middle of roadways or runways. In addition, by creating the constructible model in advance of physical work, stakeholders are able to run safety scenarios to determine potential hazards related to the project plan, weather challenges, and completed design features antagonistic to everyday use. These scenarios enable organizations to reduce injuries and lessen the likelihood of needing to modify the design after construction.

Transparency

Task productivity and process integration enable all stakeholders to determine the schedule, cost, and critical path of their piece of the project. This integrated approach to project management makes it possible to recognize and prioritize problems and visualize them on-screen—and solve them at any stage of the project (including after completion) before they affect schedule, cost, or quality. Since all project data is recorded in a protected cloud environment, this data can be

[1] Mahsa Khaksefidi and Mohammad Miri, "Cost management in construction projects: Rework and its effects," *Mediterranean Journal of Social Sciences*, December 2015, Volume 6, Number 6 S6, p. 212, mcser.org.

used to audit, track progress, and reduce the likelihood of fraud or malicious behavior.

Sustainability

Task productivity tools, such as machine control, reduce rework, which in turn reduces wasted resources. In grading and excavating, failing to reach the specified grade the first time wastes fuel, time, and money due to trips back to the work site. Overcuts require the same, as well as requiring replacing materials and potential new compaction cycles. Reducing rework also results in using fewer materials and generating less waste; when we know exactly what we are building, we can maximize the potential of all raw materials.

The path forward

Connecting the digital and physical worlds can also apply to the funding process. Today, the United States still has one of the premier highway systems in the world. If we do nothing, it is likely to degrade significantly within 20 years. As a society, we must think ahead to a multimodal infrastructure that enables and facilitates electric vehicles, autonomy, platooning (of both commercial and consumer vehicles), high-speed rail, and autonomous bus services.

The ideal transportation network of the future will also be multiuse. It will become a framework to socialize, network, and work. Roadways may become Wi-Fi hotspots, facilitating commerce and improving business efficiencies. Road networks could even be active electrical charging systems for the vehicles using them and the surrounding communities. Multimodal, multiuse infrastructure will draw new users and new industries to create a sustainable funding base for the next 70 years. Conventional funding methods and use-based taxes will not adequately fund the central nervous system network, but innovative partnerships and approaches built from the joint benefits of connectivity can help the United States achieve this vision successfully and sustainably.

The construction industry and its workflows have been largely unchanged for decades. But to build a smart, connected, sustainable central nervous system, all stakeholders must work more efficiently and collaboratively and rethink the role of technology in improving productivity, quality, transparency, safety, and sustainability. Connected construction is an attainable goal that will form the foundation for a vision that aims to better connect and serve communities across the country.

Voices *highlights a range of perspectives by infrastructure and capital project leaders from across geographies and value chains. McKinsey & Company does not endorse the organizations who contribute to* Voices *or their views.*

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Global Infrastructure Initiative

Since 2012, McKinsey & Company's Global Infrastructure Initiative (GII) has convened many of the world's most senior leaders in infrastructure and capital projects to identify ways to improve the delivery of new infrastructure and to get more out of existing assets. Our approach has been to stimulate change by building a community of global leaders who can exchange ideas and find practical solutions to improve how we plan, finance, build, and operate infrastructure and large capital projects.

GII consists of a global summit, regional roundtables, innovation site visits, and the Voices on Infrastructure digital publication. The sixth GII Summit took place virtually on June 10 and 11, 2020.

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