GLOBAL INFRASTRUCTURE INITIATIVE
By McKinsey & Company

Voices on Infrastructure

Future-proofing infrastructure in a fast-changing world

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Welcome to the October 2018 issue of *Voices on Infrastructure*, a collection of insights from McKinsey and industry experts on **future-proofing infrastructure in a fast-changing world**.

Infrastructure is a critical foundation for much of our economic activity and social life. Demand is rising not only for more infrastructure, but also for infrastructure that is produced effectively and efficiently. But we must put a high priority on making our infrastructure systems as resilient as possible to emerging trends, disruptions, and risks. Tragic accidents, like bridge and dam collapses, and natural disasters serve as stark reminders of a broad array of risks facing our infrastructure.

This issue looks at resilience through four lenses:

- **Physical resilience.** How can we address the need for maintenance, as our assets slowly crumble? How can we account for climate risks and use our resources more effectively—from natural disasters to long-term water management? How can we defend infrastructure and built assets against cyber and conventional attacks?

- **Economic resilience.** Technology affects both the use and the cost of infrastructure, and it can make assets obsolete or noncompetitive. Contractual terms can make or break a project financially.

- **Protecting cities from stress.** Many large cities face continued rapid growth, including sudden inflows of migrants, as well as frequent shocks and emergencies. Smart-city technologies can help alleviate these stressors, and affordable housing strategies can accommodate planned and unplanned growth.

- **Cultural resilience.** Amid these sweeping, and often abrupt, changes, organizations must prepare to operate with more adaptability, pragmatism, and innovation. Leaders must prioritize culture change to withstand long-term demands and threats.

We hope these insights inspire new thinking about the long-term future of the built world and help you scale best practices in your organizations and geographies.

News from the Global Infrastructure Initiative

Tony Hansen

Director of the Global Infrastructure Initiative, McKinsey & Company

Welcome to our 13th edition of *Voices*, sharing perspectives on future-proofing infrastructure in a fast-changing world. Migration, urbanization, climate change, and burgeoning maintenance backlogs are cumulatively placing massive pressure on the world's existing infrastructure. Factoring in an estimated $5.5 trillion spending gap between now and 2035, it is critical for leaders to deliver infrastructure that is resilient and climate-smart for an uncertain future.

In this edition, we explore some of the innovative strategies and global best practices, including the leadership imperative, managing scarce resources, dealing with maintenance backlogs, meeting cybersecurity and affordable housing requirements, and creating citizen-centric cities. We hope that these perspectives will engage and inspire readers to act in future-proofing the world's infrastructure.

Since June, GII hosted our second roundtable on the implications of disruptive technologies on infrastructure investors in New York City and a fascinating site visit to the city's supertall towers. The site visit was attended by more than 30 global leaders in high-rise development and delivery and valuable insights emerged regarding the drivers and enablers of a worldwide boom in supertall buildings. A recap of all past GII events can be found at globalinfrastructureinitiative.com.

A central part of GII's mission is to stimulate change by providing a safe forum for global leaders to exchange ideas, build relationships, and make the commitments required to bridge global infrastructure gaps. In this spirit, GII convened a cross-sector industry working group to accelerate the adoption of digital technologies across the construction value chain. This volunteer effort has already made significant progress, and we will share more information in the coming months.

The last quarter of 2018 kicks off with an October roundtable in Paris focused on reinventing the construction sector in France. Also, our fifth GII Summit will take place in London from October 29 to 31. We are fully subscribed with an impressive list of participants and a robust agenda that includes site visits to London's leading projects, interactive plenary and breakout sessions, sector-specific roundtables, and a selection of the best new ideas from around the world.

We hope you enjoy this edition of *Voices* as we collectively determine what it will take to future-proof our existing and new infrastructure. Our December issue will consist of a recap of the best ideas from the 2018 GII Summit and our March 2019 edition will focus on real estate. We welcome your thoughts on Voices at any time. Please contact us at info@giiconnect.com if you would like to attend any forthcoming events or subscribe a colleague to *Voices*.

Climate resilience: Asset owners need to get involved now

Climate-related risks are on the rise, and our critical infrastructure is underprepared. Both public and private infrastructure owners should pursue three actions immediately to shore up our assets.

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Infrastructure represents an enormous collective investment by our society and a tremendous resource for our economy and communities. However, these essential assets are increasingly vulnerable to climate-related forces: rising sea levels, drought, earthquakes, and violent storms are having far-reaching humanitarian and economic impact. The Global Facility for Disaster Risk Reduction estimated in 2016 that extreme weather events due to climate change in the preceding two decades affected more than four billion people and caused more than $1.9 trillion in economic losses across sectors.[1]

In addition, we are starting to see economic impact beyond the direct costs. In the United States, for example, average home prices in areas prone to flooding, hurricanes, and wildfires have stalled in comparison with those in lower-risk areas—in fact, homes in exposed areas are worth less today, on average, than they were a decade ago.[2]

Despite this threat, governments and infrastructure owners around the globe continue to underinvest in infrastructure adaptations that would mitigate the predictable effects of climate change.[3] One reason for this shortfall is the unpredictability of disasters in both timing and extent. Another is that many cities, regions, and nations are struggling to keep up with basic infrastructure needs; building for resilience is costly, making it a frequent target for cuts in infrastructure budgets.

But as with most modifications, in the long run it is nearly always easier and cheaper to build resilience considerations into asset development from the start rather than as a response to a major event.

Owners of major infrastructure projects, notably those developed in coastal and heavily urbanized areas, can make real strides toward building resilience by taking the following three actions:

- Incorporate risk assessments and adaptation strategies into capital budgets at the start of a project
- Take a layered approach in applying adaptation strategies (single solutions seldom address all threats)
- Adopt a resilience scorecard and rating system

Making a concerted effort in each of these areas will help infrastructure asset owners develop more climate-resilient infrastructure to strengthen the communities they invest in.

Make resilience part of asset development and design

Building adaptation strategies into design typically costs much less than incorporating them after construction or in response to a major event. The Institute for Building Sciences estimates that every dollar invested in building resilient infrastructure saves $6 in future costs including economic disruptions, property damage, public health crises, and deaths caused by extreme weather disasters.[4]

Asset owners must start by answering fundamental questions about the particular risks of their unique geography, calculate costs of asset loss or damage as well as business disruption, decide how to protect critical components, and prioritize strategies with the greatest return on investment.

Pay attention to local risks and hazards. Local hazards are often a function of climate, topography, and the extent of the local built environment. A host of government agencies and nonprofits have attempted to predict sea-level rise and flooding, but owners should recognize that current policies and guidelines are typically based on broad assessments and should be taken as just that—guidelines.

Because many risks are localized, asset owners may need to modify the published code requirements to meet their specific needs. For example, the US National Flood Insurance Program uses the 100-year floodplain (that is, areas with a 1 percent change of flooding in a given year) to define zones likely to experience a flood in each century—but the frequency of these floods has increased in recent years, particularly in low-elevation coastal locations such as New Orleans, Louisiana. Owners may be better served by more cautious standards that recommend a greater elevation for critical infrastructure assets, such as the 500-year floodplain, or they may consider adding freeboard—essentially a buffer that assumes higher flood levels—to their standards and planning.

To help determine these needs and predict hazards more accurately, owners should consider consulting with experts who are familiar with local conditions. Specialized firms, often associated with environmental or engineering firms, are meeting this need at a local level.

Calculate potential costs. Typically, owners only consider damages to the asset itself. However, the true costs and externalities of damage go much deeper, including both direct and indirect costs such as loss of use, business disruption, lower property values, and continued unreliability. Owners also need to consider potential damage to services that they depend on but do not control, such as the power grid and other utilities.

Identify and protect critical elements. Finally, asset owners must quantify and assess the risks to critical components of their infrastructure assets and make these a priority for mitigation strategies. For example, the owners of a wastewater-treatment facility at sea level may decide to protect the entire asset with a perimeter wall. Or they may find it more economical and practical to protect critical components by elevating the switch gear and controls, and accept risk in other parts of the facility.

As technology becomes more accessible, advanced analytics can help guide decisions on whether to maintain or replace an asset. A data-driven approach can yield more accurate insights on asset longevity and the trade-offs between maintaining an asset or investing in a new one.[5]

Use a layered approach

Infrastructure asset owners need to use a range of adaptation strategies to mitigate climate-related asset risks. In general, owners and government agencies can either accept these risks (and their resulting costs to society) as inevitable and opt not to act, or mitigate them through adaptation strategies.[6]

Clearly, adaptation is the preferred response. To begin with, asset owners should not exclusively consider local regulations and guidelines in siting a project; in addition to that baseline, they should develop their resilience strategies using forward-looking analyses based on recent impacts and trends.

Early consideration of resilience will also lead to greater flexibility in selecting adaptation strategies. Owners should consider a layered approach including a range of solutions, starting with no-regrets and robust designs that have minimal cost (which is almost always easier to implement if done early). For example, backup generators can be elevated, or storm-resistant windows can be added to existing structures to provide a first line of fundamental protection or basic power redundancy. Asset owners should also explore strategies that allow them to be isolated from the disruption caused by the loss of service of critical utilities. This includes backup power supply and alternative water sources, for example, as well as the road networks that support them.

In addition to physical adaptations, owners should think critically about how they include hazards in their insurance coverage. Insurance growth may

What governments can do

Governments at all levels can support owners in three major areas: establishing building codes and guidelines that promote climate-resilient infrastructure, supporting owners with funding and resources, and establishing resilient, focused land-use policies.

Building codes and policies. The long-term survival of infrastructure demands a more prescribed approach to characterizing threats and ensuring compliance. Governments, particularly at the local level, can promote greater infrastructure resilience across all assets through mandatory building codes and policies. This sort of effort is not without precedent. As early as the 1920s, the Uniform Building Codes in California mandated consideration of seismic forces to protect infrastructure from earthquake damage.

Funding and resources. Governments could provide incentives to help encourage compliance with building codes and guidelines for resilient structures, much as they have done with energy-friendly solutions. For example, they might offer funding and grant programs via special-purpose zones or tax credits for improvements.

Land-use policies. Thoughtful planning can restrict building in exposed areas. For example, building is becoming significantly more restricted in many coastal areas to prevent structures from being built in high-risk areas.

Governments can also adopt land-use policies to account for stormwater drainage and catchment systems that naturally canalize floodwaters and runoff. Often, poorly placed infrastructure blocks these flows or redirects them into inappropriate spaces. The city of Jeddah, Saudi Arabia, for example, failed to properly account for surface runoff in its urban planning. The city experienced an increasing number of climate change–related storms off the Red Sea, contributing to significant municipal flooding with substantial damage and fatal results. The problem was eventually resolved through a drainage program that cost more than $10 billion—costs that could have been avoided with better planning.[10]

be an important driving force for more resilient infrastructure, and the role of insurance in encouraging best resiliency practices is a topic that warrants exploration.

Adopt a resilience scorecard and rating system

As owners and investors become more cognizant of the need to consider climate change, and as the need for resilient infrastructure becomes more pronounced, they would benefit from a formal resilience-risk assessment and an acceptable resilience rating system. These measures will help owners and investors determine the true risk exposure that a particular asset faces and indicate whether an asset owner has incorporated the necessary adaptation strategies to mitigate the effects of climate change. The scorecard can provide an objective rating system by building on the efforts of organizations working toward greater transparency. For example, the Task Force for Climate-related Financial Disclosures (TFCD) aims to "develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders."[7]

In the best-case scenario, the scorecard would include industry-accepted standards akin to the Envision sustainability scorecard adopted by the American Society of Civil Engineers (ASCE). It would also include a program like ASCE's Sustainable Infrastructure Certificate Program to ensure a shared understanding and sustained communication on resilience.[8]

Currently, there is no generally accepted assessment tool focused on evaluating the resilience of an infrastructure asset in the face of climate-based risks. Still, existing work in this area can serve as a foundation. For example, the United Nations International Strategy for Disaster Reduction has developed a well-known disaster resilience scorecard that helps cities assess their disaster readiness; it includes infrastructure considerations but is not specifically focused on asset-level infrastructure assessments.[9]

As the need for resilient infrastructure grows, industry, academia, and professional organizations should work as a community to develop a scorecard and certification program. Governments, meanwhile, can support infrastructure owners in several ways (see sidebar, "What governments can do").

Conclusion

The economic impact of climatic events on infrastructure around the globe has continued to grow each year, in part because of insufficient consideration of resilience when such assets were planned and built. Asset owners should approach the problem with a bias for action and invest in understanding the problem and the associated risks.

Though government policies and guidelines can help, infrastructure asset owners need to take positive action to make their infrastructure more resilient. ■

[1] *Introducing infrastructure resilience*, United Kingdom Department for International Development, July 2016, gov.uk.

[2] Christopher Flavelle and Allison McCartney, "Climate change may already be hitting the housing market," *Bloomberg*, June 18, 2018, bloomberg.com.

[3] Laura Lightbody, "Washington must modernize policy to make America flood-ready," Pew Charitable Trusts, June 8, 2018, pewtrusts.org.

[4] "National Institute of Building Sciences issues new report on the value of mitigation," National Institute of Building Sciences, January 11, 2018, nibs.org.

[5] For more on this topic, see John Levene, Sacha Litman, Ian Schillinger, and Chris Toomey, "How advanced analytics can benefit infrastructure capital planning," April 2018, on McKinsey.com.

[6] The other two classic responses to risk—avoid and transfer—generally do not apply; as demonstrated by this and other work on the subject of climate-related disaster, infrastructure owners cannot reduce the probability and thus *avoid* climate-related disasters. Similarly, they are generally unable to reduce the impact of such disasters by *transferring* the risk to a third party, as the owner will remain the ultimate steward of the asset.

[7] For more information, visit the website of the Task Force on Climate-related Financial Disclosures at fsb-tcfd.org/about.

[8] For more information about the Sustainable Infrastructure Certificate Program, visit ASCE's website at asce.org/sustainable-infrastructure-certificate-program/.

[9] For more information, see *Disaster resilience scorecard for cities*, United Nations Office for Disaster Risk Reduction, May 2017, unisdr.org.

[10] MD Al-Sulami, "'Long-term Jeddah flood projects will be ready by September 2013,'" July 19, 2012, *Arab News*, arabnews.com.

Future-proofing infrastructure often means going back to basics

In the effort to tackle the backlog of infrastructure maintenance in the United States, five steps can help prioritize projects to not only meet the greatest needs but also build resilience.

Kristina Swallow

President
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It is a reality many of us know all too well—balancing competing infrastructure needs and immense maintenance backlogs while the world changes beneath our feet.

The American Society of Civil Engineers (ASCE) gave US infrastructure an overall grade of D+ in the *2017 Infrastructure Report Card* for good reason.[1] Our infrastructure is aging, deteriorating, and holding our communities back; we are relying on infrastructure built more than a century ago to meet the needs of a completely changed world. In older regions in the Northeast, wooden water pipes still run beneath city streets. The backlog of infrastructure projects related to drinking water manifests itself in broken water mains—an average of one every two minutes.[2] We depend on a network of roads and bridges that were designed in the Eisenhower era or before. Our roads claim the lives of an estimated 40,000 people a year, in part because of outdated designs that fail to meet our current mobility needs.[3] Large river barges sit for hours, even days, on the Mississippi River while aging locks are patched and fixed.

While these problems seem insurmountable, areas of thoughtful progress offer models for improvement. In our experience, five steps in particular can have an outsize impact: building a foundation of data, evaluating the full life cycle of a project, considering a variety of disaster scenarios, looking to land use and context-sensitive solutions, and supporting research and development that can be applied to the infrastructure sector.

The current state of US infrastructure

The United States has coasted along on the investments of our grandparents and deferred major maintenance, spending a meager 2.5 percent of GDP annually to maintain and modernize our infrastructure assets.[4] Despite rising needs, the federal government's contribution to water projects has fallen over the past 30 years, from 63 percent of the sector's total capital spending in 1977 to 9 percent in 2014.[5] This deferred maintenance is costly to the economy and hits us all in the pocketbook. If the problem is not addressed, the average American household will lose $3,400 in disposable income every year from 2016 to 2025 because of inadequate, unreliable infrastructure.[6]

With earthquakes, wildfires, volcanic eruptions, rising sea levels, and hurricanes dominating the headlines, it is crystal clear that our system of aging infrastructure needs to be made resilient. As engineers, we are working to rebuild and upgrade infrastructure to better withstand these challenges, operating under the assumption that hazard events will continue with increasing regularity and severity. But that's only one element of what it means to future-proof our infrastructure.

In addition to anticipating what hazards and conditions our roads, bridges, drinking-water pipes, wastewater-treatment plants, airports, and power lines must withstand, engineers are also thinking about the impact of new technologies, population shifts, and other trends on communities' needs.

Infrastructure that is designed to meet future needs and withstand future hazards often incurs a higher initial cost. However, it is a worthwhile investment that pays for itself in the long run; the National Institute of Building Sciences estimates that every dollar spent on making infrastructure more resilient saves $6—an improvement over 2005, when the ratio was 1 to 4.[7]

Five steps to reduce the backlog and build community resilience

The backlog of projects on our collective plates is daunting, but it also presents an opportunity.

As we make plans to repair and upgrade our infrastructure with an eye to the future, the following steps will have an outsize impact:

1. **Build a foundation of data on assets and use it effectively.** In this era of big data, infrastructure owners can monitor a wide variety of asset metrics and address problems in real time.

   When the city of Syracuse, New York, analyzed data on water-main breaks, administrators realized that breaks occurred most frequently downtown, particularly in the central business district—a great inconvenience for restaurants in the neighborhood. With the support of a grant from the Rockefeller Foundation, the city partnered with graduate students to use data to predict at-risk water mains, increasing accuracy sixfold over random choices and preventing more breaks.

   Infrastructure ownership in the United States is highly fragmented, making it difficult to get a big-picture view of community resilience. To this end, the state of Michigan has embarked on an ambitious statewide infrastructure plan; in their initial scan, officials found that more than 3,300 agencies deal with some sort of infrastructure in the state. Enabling these agencies to share data and tackle cross-jurisdictional projects is a Herculean task—but a critical one if we are to sufficiently evaluate community resilience.

   While the Michigan effort is the first undertaking of its scale in the United States, engineers and infrastructure owners across the country are embracing comprehensive asset-management strategies on a smaller scale. Agencies of all sizes are routinely using data and electronic records to keep a more accurate inventory of infrastructure conditions and to better prioritize capital projects. This improved record-keeping process has enabled many infrastructure owners to shift their focus from fixing the worst problems first to preventing catastrophic failures down the line, considering the highest risk and cost to the community in the event of failure.

2. **Evaluate the full cost of a project, not just the initial capital costs.** A renewed focus on life-cycle cost analysis (LCCA) is allowing engineers and planners to assess not just the up-front cost of a project but also the operation and maintenance cost, as well as the cost of retiring an asset. We tend to plan extensively for a ribbon cutting but give less thought to the condition of our assets 20 years from now. Evaluating the total cost of project ownership in the early stages of planning has an impact on design decisions and increases resilience. For example, the Port Authority of New York and New Jersey uses a standardized form of LCCA across all of its major projects to determine project selection and design, saving an estimated $37 million in 2014, the program's pilot year.

   Research commissioned by ASCE found that while nearly all government entities agree that LCCA should be part of the decision-making process, fewer than 60 percent of public-sector transportation projects include this step, and fewer than 50 percent include an operations plan as part of the planning process.[8] Those percentages must increase if we are going to future-proof our infrastructure assets, resulting in more strategic use of limited funds and projects that are designed with an eye toward anticipating and meeting future needs.

3. **Consider a variety of disaster scenarios.** As we face increasing risks and a changing climate, we need to reevaluate our assumptions and use comprehensive scenario planning to drive better-informed decisions.

   Of course, the scenarios vary by location; projects in Miami, Florida, need to anticipate a higher sea level, while the city of Tucson, Arizona, must manage water now with an eye toward dwindling supply in the future. Indeed, Tucson city leaders recently decided they could no longer rely on historical water trends and availability; instead, they had to envision a future in which they may not be able to depend on underground aquifers. They developed a robust set of solutions that includes both water storage and reclaimed water to ensure a reliable water supply for the region under a number of different scenarios.

4. **Look to land use and context-sensitive solutions.** Preparing for the future often means improving land-use planning and considering how the natural environment can serve an individual location's unique infrastructure goals. Sometimes, a resilient design is remarkably low tech, such as placing control rooms for utilities above ground so they don't flood during a major storm event.

   Following the disastrous Hurricane Katrina in 2005, New Orleans, Louisiana, has reinvented itself and is embracing green infrastructure as a way to manage frequent flood cycles and reduce stormwater flows. For example, the city is integrating new methods of storing and filtering stormwater with the system that has been pumping stormwater out into Lake Pontchartrain and other bodies of water for more than a century. Similarly, Hurricane Harvey—the most expensive natural disaster in the history of Texas—affected more than 40 of the state's 254 counties in 2017. In Harvey's wake, communities in the Lone Star State are evaluating a watershed approach to flood-risk management, investing in green infrastructure such as permeable pavements, and considering new development standards to reduce risks and strengthen community resilience.

5. **Support research and development, including on-the-ground assessments.** Scientific research in a variety of fields is sparking development of technologies and processes that can be used to extend the life of infrastructure, expedite repairs and replacements, and increase cost savings. Public R&D budgets are often the first to be reduced in a budget cutback, because research lacks guaranteed outcomes, but explorations often yield great results if researchers have the funding and time to innovate. For example, researchers looking for methods to strengthen concrete are currently developing self-healing concrete. The use of such concrete in roadway infrastructure would reduce the need for repaving and make roads less susceptible to the potholes that form when a crack takes in water and then expands during a freeze.[9]

   Furthermore, one of the best ways to learn how to future-proof infrastructure is to assess the site of a major disaster to gather evidence on to see what worked and what didn't. Both ASCE and the National Institute of Standards and Technology routinely send teams to global disaster sites to study building and infrastructure performance. These findings are critical for reducing future loss of life and property, as well as enhancing the resilience of our infrastructure assets.

The backlog of infrastructure maintenance in the United States presents an opportunity to go beyond the status quo. Optimizing our infrastructure investments will require civil engineers and community leaders to rethink and reinvent every stage of project delivery and embrace the challenge to innovate and to transform our practice. We can learn from past successes and failures and design our infrastructure to be resilient—built for today and ready for tomorrow.

Voices highlights a range of perspectives by infrastructure and capital project leaders from across geographies and value chains.

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.*

[1] "America's grades," *2017 Infrastructure report card*, American Society of Civil Engineers, 2017, infrastructurereportcard.org.

[2] Dan Bobkoff, "In the US, a water main breaks every two minutes," *Marketplace*, May 12, 2014, marketplace.org.

[3] Ranjitha Shivaram and Adie Tomer, "Do our infrastructure systems put people at risk?" Brookings Institution, May 10, 2018, brookings.edu.

[4] Drew Greenblatt, "Five keys to infrastructure investment & why it's critical for US manufacturing," *Inc.*, March 9, 2017, inc.com.

[5] *The economic benefits of investing in water infrastructure*, Value of Water Campaign, 2017, thevalueofwater.org.

[6] *Failure to act*, American Society of Civil Engineers and the Economic Development Research Group, 2016, infrastructurereportcard.org.

[7] *Natural hazard mitigation saves: 2017 interim report*, National Institute of Building Sciences, December 2017, wbdg.org.

[8] *Maximizing the value of investments using life cycle cost analysis*, American Society of Civil Engineers and Eno Center for Transportation, 2014, p. 6, enotrans.org.

[9] Congrui Jin, "Fungi can help concrete heal its own cracks," *The Conversation*, January 19, 2018, theconversation.com.

From resource to asset: Building a water-resilient Singapore

The country's long-term vision, use of innovative technologies, and stakeholder engagement efforts have been critical to its success.

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For decades, Singapore has struggled to secure an adequate supply of drinking water. Rainfall isn't the problem: its tropical climate produces an average annual amount of 240 centimeters (95 inches). Instead, the challenges lie in a shortage of freshwater sources (such as ground water and aquifers) and the lack of sufficient space to capture and store rainwater. Despite these obstacles, Singapore has managed to meet the full demand for fresh water since 1979, though with significant effort.

Singapore's journey from scarcity to sufficiency highlights the importance of an integrated urban systems approach, with public–private partnerships and stakeholder engagement. These factors have enabled the water-stressed city to manage its challenges in an integrated and holistic manner. One key shift is that the city has begun to approach water as an environmental asset to enhance the livability of the urban environment. Structural challenges remain: a 2015 report from the World Resources Institute estimated that Singapore would be one of the most water-stressed countries by 2040. However, the country's planning and development approach alongside dynamic urban governance has ensured that Singapore is able to adapt and thrive. Its experience offers lessons to other global cities facing water scarcity in the coming years.

A brief history of water management

Since Singapore's independence in 1965, the country has faced two primary water management challenges—an exploding population and flood risk. First, from 1990 to 2018 the population nearly doubled, reaching 5.8 million. Without natural sources to draw on, Singapore's primary option was to contract with Malaysia to provide drinking water. Second, as a low-lying country, Singapore faced the threat of inland flooding, an issue that was exacerbated as development geared up in the post-independence years. Recurring droughts and floods further heightened the risk to property and residents and complicated the management of scarce water resources.

Singapore's initial solution—building reservoirs and drainage networks—was necessary to provide a domestic source of water and mitigate flood risk. As the country grew, officials recognized they must develop and implement a strategy to increase Singapore's water resilience. Under the country's 1972 Water Master Plan, officials designed a policy that called for the construction of catchment areas and reservoirs to collect rainwater to boost local water supply.[1] However, the implementation of an island-wide drainage network, a critical feature, would inevitably compete with rapid urbanization and economic development for scarce land. Balancing these priorities required close coordination between government officials and land use planning agencies.

In the 1990s, Singapore's National Water Agency, PUB, was able to apply breakthroughs in water recycling and desalination technologies to close the water loop. This effort included integrating the water catchment networks, drainage and sewerage systems, water treatment and distribution, and the production of NEWater into one ecosystem.

Integrating multiple objectives

Singapore's current water infrastructure has enabled the country to manage its resources more effectively. Yet elected officials recognized that waterways also needed to be multifunctional assets integrated with residential, commercial, and recreational spaces to make the best use of land. To do so, the public needed to be part of the dialogue on the management of water resources. Such shifts in thinking enabled the government to further unlock the potential of waterways as environmental assets that contribute to urban areas and enhance livability.

The Active, Beautiful, Clean (ABC) Waters program, for example, demonstrates how Singapore has incorporated sustainable city planning with stormwater management. The program was launched in 2006 with the goal of creating community spaces around reservoirs and canals, giving these assets a recreational function by combining "green space" with "blue space." Collaboration played a key role. PUB coordinated with housing, transportation, and other agencies; the private sector; and the public to facilitate the implementation of ABC Waters projects and integrate water-sensitive principles into new development. For example, the Waterway Ridges housing project features ABC Waters design and green waterways to promote the use of natural systems to manage stormwater flows.

The ABC Waters Program also provided an opportunity to develop an integrated urban landscape. Since the nature of the program blurred the boundaries between planning and administration, cooperation between agencies was of utmost importance. One means of encouraging this integration was to maintain open lines of communication to facilitate knowledge sharing.

Case study: The Marina Barrage

The Marina Barrage showcases various ways Singapore has reaped the benefits of integrated development. The project was conceived in the late 1980s, shortly after the cleanup of the Singapore River. Then–Prime Minister Lee Kuan Yew envisioned a barrage at the mouth of the Marina, creating a lake that would serve as a freshwater reserve and support flood control. The idea was put on the backburner until advancements in membrane technology, a vital component of water treatment facilities, made the project viable. The decreased cost of operation and maintenance meant that raw water from urbanized catchments could be treated cost effectively to produce potable water.

Construction on the Marina Barrage began in 2005 at a cost of $165 million.[2] Upon its completion in 2008, it provided three benefits. First, it boosted the country's water supply by creating the island's largest catchment at 10,000 hectares (the barrage now provides enough water to meet 10 percent of Singapore's needs). Second, it alleviated flooding in low-lying areas. Third, it was available to the public. In the past, reservoirs were restricted areas. Opening the Marina Barrage gave people access to the waterfront. Over the past decade, close to 15 million people have visited the barrage for tourism, picnics, water sports, and other activities.[3]

Other cities or countries getting ready to embark on similarly ambitious infrastructure projects should note three factors that enabled Singapore to achieve its goals.

1. **Clear vision and dedicated leadership.** The country's progress was the product of far-sighted plans. In the 1980s, the Singapore river was polluted, so officials set a long-term goal of creating a reservoir and remediating the river so it could serve as a space for the public. The cabinet and ministry reviewed its plans every five years and committed the time and resources necessary to make projects a reality. Some elements of the plan had to be put on hold until technology made projects feasible, but the overarching plan remained consistent.

2. **An imperative to act.** Government leaders prioritized water because it was critical to Singapore's survival and they lacked alternatives. Recent history and long-term trends indicated that Singapore needed to devise effective water management solutions for the country to support economic development and ensure national security.

3. **Flexibility and innovation.** Singapore's leaders were open to new ideas. The ABC Waters program, for example, initially struggled to secure the buy-in of engineers, who were baffled that the government wanted to redesign canals that were already effective and integrate them into the urban surroundings. Government leaders educated stakeholders to persuade them to embrace new approaches such as water-sensitive design that could alleviate flooding.

Much remains to be done

Amid climate change, Singapore will experience increasingly extreme and unpredictable weather, resulting in more frequent and intense storms. To build resilience to the current flood protection scheme, PUB has adopted a "Source-Pathway-Receptor" strategy, which seeks to develop catchment-wide solutions. This holistic approach introduces flexibility and adaptability to the entire system, addressing not just the stormwater drains and canals (the pathways for water) but also areas that generate stormwater runoff (source) and where floods may occur (receptor).

Singapore has continued to adapt its approach to manage scarce water resources. Its leaders intend to strike a balance between urban development and other national needs. By making the management of water infrastructure part of the conversation, its leaders have managed inland flooding while providing sufficient space to capture rainwater to augment the drinking supply.

Singapore reinforces the necessity of continuous innovation. The country is still far from unlocking the full potential of water as an environmental asset. It needs to scale, further develop, and institutionalize the ABC Waters Program to spur the adoption of water-sensitive design into urban-planning efforts. But its efforts to date have built a solid foundation and offer a valuable example to other countries. ■

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[1] Tan, Y. S., Jean, L. T. and Tan, K. (2009). *Clean, Green and Blue: Singapore's Journey Towards Environmental and Water Sustainability*. ISEAS Publishing, Singapore

[2] Silvia Schmid, "Catching rainfall in Marina Bay: Water necessity, policy, and innovation in Singapore," Wharton School of the University of Pennsylvania, IGEL, September 2012, igel.wharton.edu.

[3] Siau Ming En, "The big read: A decade on, Marina Barrage is now key to S'pore's water management," *Today*, September 18, 2018, todayonline.com.

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Smarter cities are resilient cities

Technology and data can help cities absorb future growth and weather any shocks that come their way.

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Cities are complex systems with millions of moving parts and many concentrated risks. Their complexity and scale makes them vulnerable to disruptions—and when bottlenecks or bigger disasters strike, the ripple effects and economic losses can quickly spiral.

Smart technologies give local agencies new tools for taking preventive measures, responding to emergencies, and planning for longer-term sustainability and growth. A recent McKinsey Global Institute report outlines how dozens of currently available digital solutions for cities can make infrastructure systems more nimble and robust.

Cities seize up when transit, traffic flows, electrical grids, and other fundamental services are hit with bottlenecks and outages. But smart technologies can keep these systems running smoothly. Adding Internet of Things (IoT) sensors to existing infrastructure, for example, can help crews perform predictive maintenance on equipment, fixing problems before they turn into commuter delays, water main breaks, and blackouts.

By reducing the cost of gathering data about usage patterns, smart technologies give agencies and the public alike the real-time information they need to optimize existing systems. Some encourage people to use transit during off-hours, to change routes, to use less energy and water and to do so at different times of day, and to reduce strains on the formal healthcare system by encouraging preventive self-care.

To give just one example, dynamic electricity pricing relies on sophisticated meters to monitor usage precisely and charge consumers higher prices during periods of peak demand. Various pricing schemes and personalized feedback to the consumer can encourage conservation and shift the load to off-peak periods—and smoothing the peak reduces the need to add capacity and the potential for brownouts during periods of high usage. The combination of digital monitoring and consumer notifications can similarly help cities improve waste management, recycling, and water conservation.

But local agencies are not just tasked with day-to-day operations. On those occasions when a true emergency strikes, the speed and coordination of first responders can be a matter of life and death. While the setup of emergency operations varies from city to city, technology has become essential to all the critical phases, from call centers to the field to the hospital admissions process.

MGI's research finds that cities can improve emergency response times by 20–35 percent by optimizing emergency call dispatching and synchronizing traffic lights for emergency vehicles. Newer emergency call systems have enhanced GPS capabilities to pinpoint the location of callers using mobile phones; they are also designed to be more secure from hackers and more resilient when call volume spikes. Some enable callers to submit video, images, and text to dispatchers so that first responders can have a clear picture of what to expect at the scene of an emergency.

When it comes to natural disasters, providing as much advance warning as possible enables the public to take precautionary measures or evacuate if necessary. Storm-tracking satellites and weather-prediction modeling have made dramatic advances. Some new early-warning systems for earthquakes will cause elevators to stop and open at the nearest floor so people are not trapped, send alerts to hospital operating rooms, and shut down the flow of natural gas in pipelines to reduce the risk of fires. Similar efforts are under way to develop systems that will give residents more warning of impending tornadoes.

In emergencies, people now stay glued to their smartphones. Where cities once relied on the news media to inform communities in peril, they now supplement those efforts by using social media channels. The flow of information runs two ways, with the public providing real-time digital updates that can help authorities assess damage and deploy resources. Cities can crowdsource data gleaned from Twitter, Waze, or specially designed websites and mobile apps to piece together a picture of which evacuation routes are passable, where power is out, and whether specific shelters are full.

Thousands of calls for help can strain a city's resources and first responders to the limit in an emergency, and a lack of information sharing across agencies and neighboring jurisdictions can hamper efforts. Command centers with big data dashboards and data visualization tools can help authorities monitor rapidly evolving situations, allocate help where it is needed, and coordinate multiple agencies. Drones are increasingly being used to survey damage over large areas, while robots are beginning to assist with search-and-rescue efforts.

The ability to manage things in the moment is one aspect of keeping cities resilient. Another is planning ahead to meet long-term challenges. Analyzing data sets at scale and using tools such as geospatial mapping can give city planners better insights and ultimately support smarter decisions about where to expand infrastructure systems to accommodate growth. Unlike traditional capital projects, smart solutions are often much faster and cheaper to introduce, enabling cities to become more responsive and adaptable.

The biggest long-term challenge of all is, of course, climate change. Urban areas consume over two-thirds of the world's energy and generate roughly 70 percent of its greenhouse gas emissions. A host of smart technologies can help to reduce emissions. These include smart mobility options that discourage the use of private vehicles and cut down on idling traffic and delivery trucks. Intelligent building management systems and smart meters can reduce energy consumption. MGI's research finds that cities deploying a range of smart solutions could, on average, cut greenhouse gas emissions by 10–15 percent. Officials can also use big data, climate models, and predictive analytics to understand their vulnerabilities and plan accordingly—by, for example, mapping flooding risks and changing their zoning codes, or building levees and seawalls.

As cities face the dual challenges of managing everyday stresses and preparing for worst-case scenarios, they need to improve their operational capabilities and future-proof their infrastructure. Smart technologies can help on both fronts, although digitizing the urban environment means that cybersecurity is another critical priority. Forward-looking investment in building robust, flexible infrastructure systems can position cities to absorb future growth and weather the shocks that come their way. ■

Changing culture: How to break infrastructure's vicious circle

To thrive in changing industries, capital projects and infrastructure owners, contractors, and operators must acknowledge the importance of culture, build forward-looking leadership teams, and embrace diversity and inclusion.

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At the heart of many pressing challenges in capital projects and infrastructure—improving productivity, attracting and retaining talent, building more diverse and agile leadership teams—are problems with culture.

The forces affecting infrastructure's culture are both external and internal. Externally, contracting tends to be adversarial, putting the risk on the contractor and creating a zero-sum game of winners and losers. This dynamic trickles down through organizations, affecting individual mindsets and organizational cultures (which in turn reinforces the combative contract process). Internally, infrastructure companies are struggling to evolve; leaders tend to be risk averse, which has slowed adoption of new technologies such as robotics, augmented reality, advanced analytics, and automation.

Across the industry, the imperative is clear: Sophisticated use of technology is becoming a differentiating force. And increasingly complex and competitive projects involve more stakeholders and place more emphasis on collaboration and collective outcomes. In addition, the high rate of M&A activity in the industry means that organizations must figure out how to integrate very different workforces and get them to work together effectively. Organizational culture is at the center of all of this.

In our conversations with senior leaders across infrastructure, we have found that leading companies are prioritizing culture more than ever. They are hiring leaders who can champion and catalyze culture change, and increasing inclusion and diversity within their talent and leadership pools. Some companies are even rethinking their working relationships with external partners and contractors to embrace contracting based on alliance rather than opposition—a cultural shift that will only be possible if company leaders and employees are ready to work within a new, forward-thinking paradigm.

The importance of shaping culture

Too often in infrastructure, the role of culture in business performance is overlooked apart from occasional lip service. As such, a key step in evolving culture is to acknowledge its importance and prioritize it. Our research finds that when properly aligned with personal values, drives and needs, culture can unleash tremendous amounts of energy toward a shared purpose and foster an organization's capacity to thrive. On the other hand, an unhealthy or misaligned culture can impede strategic outcomes, erode business performance, diminish customer satisfaction and loyalty, and discourage employee engagement.

An approach to culture change at infrastructure companies

As has been asserted time and again in other industries, culture change must start at the top. The leadership team needs to embrace management discipline around culture just as it does for other key performance levers, such as strategy and financial operations. Ideally, conversations about culture are integrated into the natural flow of the business—during regular management team meetings, the annual strategy session, and other follow-up strategy discussions. And while a one-day workshop alone cannot evolve the culture, retreats and seminars focusing on culture can convince teams at all levels of the need for a culture shift.

"We have these partnering sessions, which are basically retreats where you go somewhere and you get to know the people on the team, and you come out of there on good terms after having learned a new process or two," an airport CEO told us. "I'm convinced people who have been with us forever roll their eyes, but personally, I think it's a good start."

It's also important to select forward-looking leaders for key roles. Cultures that foster learning, agility, and innovation require leaders who are comfortable with ambiguity and encourage creativity. Organizations may also have to change their processes; one leader we interviewed suggested that organizations hold twice as many meetings about opportunity than about risk to foster a culture that prioritizes flexibility and experimentation over safety and order.

When building both the leadership team and the next-generation workforce that will usher the company into its next stage of development, infrastructure and capital project leaders must prioritize diversity and inclusion. Diversity is important for many reasons: Experts agree that a wide breadth of perspectives helps a company anticipate trends and adapt more nimbly to challenges.[1] According to McKinsey research, companies in the top quartile for gender diversity are 15 percent more likely to post financial returns above their respective national industry medians. Increasingly, infrastructure companies are bringing in leaders from other industries—such as telecommunications and banking—who can contribute a diversity of thought to infrastructure initiatives. As organizations become more diverse across all these dimensions, there is less implicit understanding about how to work together and be successful in the organization, so companies need to define and manage their culture in alignment with business needs.

As one global resources company executive explained, "Diversity is a key for us—both gender and cultural diversity have been an ambition from day one. We need to make sure that those voices are heard throughout the organization, and that our structure isn't solely top down."

Embracing alliance-based contracting

Another significant obstacle to growth for capital projects and infrastructure is traditional contract arrangements. Indeed, adversarial contracting can make it difficult and costly for players to take risks such as implementing new technology. The urgent need for progress is thus driving the industry toward a new contract process: Some companies in Asia and the United Kingdom, for example, have adopted the Institution of Civil Engineers' New Engineering Contract system, which establishes a "family" of contracts that define the legal relationships and respective responsibilities of all parties involved. In this arrangement, members of the alliance have equal voices and share in the performance of the collective—across the sector—as a whole.

Ventures that have successfully used this arrangement include the Anglian Water @one Alliance, a water project that achieved annual savings of up to 3 percent and reduced operational carbon output by 41 percent (a benchmark for the entire sector). Also using this contract is the city of Hamilton, New Zealand, which recently began a large-scale, 10-year infrastructure project that could eventually create nearly 4,000 new houses and save millions through increased efficiency. In these scenarios, contractors and the wider supply chain are linked through framework agreements. The groups are thus aligned through a common set of objectives and performance incentives, so they are incentivized to collaborate and share knowledge.[2]

Conclusion: Challenging the status quo

As the infrastructure industry faces increasing challenges, the most successful organizations will embrace a management discipline around culture. They will select and develop leaders who align with

the target culture, reinforce the culture through organizational design and processes, and prioritize diversity and inclusion. Companies that adopt these changes and move toward a more open culture will be prepared to ride the waves of change rather than being overwhelmed and left behind.

As one UK-based construction leader said, "In infrastructure, there is still this belief that change is optional and people can do it on their own. We need to accept that this is a new world and a group of voices is better than just one. Making this change will require a cultural shift, but it will move the industry forward." ■

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[1] Arnaud Despierre, Greg Stanmore, and Hugh Thorneycroft, "The three important infrastructure investments you might not be making," June 15, 2017, spencerstuart.com.

[2] Full-on alliance contracting might not be feasible for every organization, but most can work with partners more collaboratively. For more, see Lukasz Abramowicz, Jim Banaszak, TG Jayanth, and Homayoun Zarrinkoub, "Collaborative contracting: Making it happen," July 2018, on McKinsey.com.

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The infrastructure transition

In an era of rising customer demands, the infrastructure industry needs to support new solutions, reshape capital markets, and take a long-term term approach to asset development.

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Few would argue against the virtues of renewable, resource-efficient, sustainable infrastructure and the central role it will play in future-proofing our society. The empirical data is unequivocal, be it the fact that more than half of energy-generation capacity added in the past four years has been renewable;[1] that it's often cheaper, safer, and more efficient to treat and then recycle industrial wastewater on-site instead of hauling it to the local municipal treatment facility;[2] or that it can be cheaper, fresher, and less polluting to grow lettuces in local greenhouses rather than shipping them from California to your favorite supermarket in Maine.[3]

Still, some industry leaders question the inevitability of an infrastructure transition—that is, toward more decentralized, more resilient, more efficient, less-polluting, and more privately financed and privately governed infrastructure. It's often easier to stick with the status quo than to accept and integrate new approaches, and the whole domain of building, owning, operating, and supporting infrastructure was set up to serve a different world—big, dirty, monolithic, and government-controlled—rather than the world that economics and innovation demand.

The current era of infrastructure doesn't look like nature-defying hydroelectric plants or pollution-belching coal-fired power plants. Instead, it looks like your neighbor's five-kilowatt solar system, the 44-kilowatt-hour battery in your electric car, the smart thermostat in your home and office, and the wind turbine you pass on your way to work, all intelligently intertwined on a dynamic electricity grid.

These solutions are neither new nor unproven, and faster, cheaper, better infrastructure is here—but it's not yet ubiquitous. Why? Because inertia is powerful and entrenched interests are deep. Because some still need convincing that infrastructure users have far more choices than ever before. We need to engage with leaders on the economics of the infrastructure transition and continue to support industry in the development of new solutions. We need to reshape capital markets to support innovative, smaller-scale projects in anticipation of a future in which projects are likely to be more digital, decentralized, and privately funded. And we must balance the unabated momentum across industry, the capital markets, and government toward increasingly shorter-term incentives, favoring instead a long-term approach that supports fact-based, incentive-aligned approaches to building and managing long-lived assets.

Infrastructure must become increasingly customer focused and flexible

One of the first lessons MBA students learn is that the customer is always right. They also learn that providers of products or services win customers by delivering unique value.

But most infrastructure providers still don't think of their users as customers, referring to them instead as taxpayers, toll payers, or ratepayers. This definition ignores the fact that more and more infrastructure customers have choices in the infrastructure they use, from energy to transportation to food systems to waste management. This is particularly true of the biggest users of energy—large companies and wealthy individuals—whose high spending gives them the greatest incentive to reduce energy costs. These are the organizations and individuals installing solar panels on their roofs and batteries in their basements. Utilities are forced to respond, as their monopoly on centralized infrastructure is undermined, by revising their offering and approach to customers.

Progress on sustainable energy is not limited to the wealthy or to developed nations. In developing countries, people are turning to modular

infrastructure, such as solar power and mobile broadband, rather than centralized, fixed utilities and landlines. If legacy infrastructure providers don't start offering modular options, entire markets could very likely develop without them.

The smartest players are adapting now, before they have to. The leaders of the infrastructure transition see their customers as people—or companies managed by people—who want infrastructure services that are reliable, modular, and economically efficient. The solutions that offer customers the most compelling economic value proposition and consistent availability will therefore win, new or old.

Renewable, sustainable infrastructure has undeniable virtues

In the past, the rules of economics forced us to build large-scale, centralized projects to deliver the cheapest, most reliable power to the greatest number of people. Today, economies of scale often result from standardized manufacturing rather than from single-asset size, thanks to the tremendous growth of manufacturing in related end markets such as consumer electronics, personal computing, and mobility. Last year, for example, the United States installed 10.6 gigawatts of solar power,[4] the capacity of five Hoover Dams,[5] built in just one-fifth of the time.

Industry still has work to do in developing solutions that are resilient, modular, decentralized, and privately funded. Beyond simple awareness of the alternatives, operators are looking for proof of concept—and these examples abound. Recent projects in California alone include the installation of solar panels on thousands of schools[6] and a burgeoning fleet of electric buses at the University of California.[7] Both efforts have resulted in lower maintenance and service costs for operators and customers alike. As examples continue to proliferate, industry players that bury their heads in the sand will fall behind.

Capital markets must be reshaped to support innovative, smaller-scale projects

Even if we can't predict the future, one conclusion is clear: more change is imminent, and we must adapt to that change with more flexibility. Big, monolithic, centralized infrastructure represents the precise opposite of what is required. Designing, planning, permitting, funding, constructing, and commissioning a new large-scale infrastructure project takes at least five years, if not ten. It is therefore extremely difficult for conventional projects to take advantage of emerging technologies and capabilities. Many conventional projects in development today will be obsolete before an opening-ceremony ribbon is even cut.

We need entrepreneurs and innovators to develop projects that create compelling economic benefits for their users—but to do so, we need to reshape capital markets so that these projects can attract the necessary financing. Two primary parties are crucial here: financiers and regulators. Banks need to underwrite a more diverse, albeit aggregated, set of customer credits, much as we've seen done in real estate. And regulators need to facilitate a faster time to market so new solutions can benefit users more quickly. Setting such policies will require careful consideration of the current obstacles—such as environmental regulations that delay development—and a thoughtful approach to ensure that relaxed regulations accelerate the development of sustainable projects rather than the traditional, large-scale, dirtier projects that prompted the environmental regulations in the first place.

Create incentives that reward long-term thinking

Finally, we must confront the unabated momentum across industry, capital markets, and government toward short-term incentives. Some politicians

may favor large, centralized infrastructure projects because they serve as tangible, highly visible signs of progress or achievement in an election year. In the private sector, quarterly or even annual earnings obscure the key performance indicators of long-term assets, which accumulate value and revenue over the course of decades.

Government leaders need to step back and focus on strategic, multidecade planning. Citizens and the media must demand more accountability for the long-term decisions these leaders are elected to make. And investors need to be able to put money at risk today to reap returns over many years, not just mark-to-market every day. If you value a bridge that's under construction, it's not worth very much; you're testing its value before it even connects in the middle.

Incentives need to build trust—with capital markets, regulators, industry players, and, ultimately, the consumers and businesses that use the infrastructure systems. Those who are setting incentives and those who are accepting them have a role to play, and we can be more thoughtful and holistic than conventions currently suggest.

Like most industries, infrastructure will increasingly focus on the customer. Technology costs are down, and the efficiency and resilience of sustainable solutions are proven. The minimum efficient scale to power a home, office building, or factory is dramatically smaller than in the past.

A new era of infrastructure is upon us, and customers are increasingly demanding cheaper resources, more reliable systems, less pollution, improved health outcomes, more choice among vendors and approaches, and freedom from a monolithic regime. To meet those demands, we need different go-to-market strategies, different partnerships, different economic models, and different time horizons—in short, an infrastructure transition.

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[1] Ray Chen, "Natural gas and renewables make up most of 2018 electric capacity additions," U.S. Energy Information Administration, May 7, 2018, eia.gov.

[2] "Water reuse and recycling: Community and environmental benefits," US Environmental Protection Agency, Water Division Region 9, last updated April 20, 2018, epa.gov.

[3] "Local food: 5 benefits of farm-to-table eating," *San Diego Union-Tribune*, April 21, 2015, sandiegouniontribune.com.

[4] "U.S. solar installations down in 2017," Institute for Energy Research, March 21, 2018, instituteforenergyresearch.org.

[5] "Hoover Dam: Frequently asked questions and answers," US Department of the Interior Bureau of Reclamation, last updated March 18, 2015, usbr.gov.

[6] Jake Richardson, "More than 5,000 US schools have solar-power installations," CleanTechnica, June 15, 2018, cleantechnica.com.

[7] Cody Kitaura, "Electric bus service will connect UC Davis with Sacramento," University of California, Davis, June 19, 2018, ucdavis.edu.

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Critical resilience: Adapting infrastructure to repel cyber threats

As the digital world becomes increasingly connected, it is no longer possible for infrastructure owners and operators to remain agnostic in the face of evolving cyber threats. Here's what they can do to build an integrated cyber defense.

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The BBC recently reported that researchers have discovered major security flaws—which affect flood defenses, radiation detection, and traffic monitoring—in the infrastructure for major cities in the United States and Europe.[1] Of those flaws, nearly ten are deemed "critical," meaning that a cyberattack on these systems would have a debilitating impact on essential infrastructure, including power grids, water treatment facilities, and other large-scale systems. It seems like the stuff of disaster films: A major city loses power. Huge amounts of the population panic. The roads clog. Planes are grounded. Coordinating a rescue effort—even communicating with the public—would be a colossal task.

While such scenarios may seem far-fetched, they are indeed reality. In 2015, Ukraine's power grid was the target of such an attack—in the hours that followed, nearly a quarter-million people were left without electricity—yet this and similar stories rarely reach the public consciousness.[2] As a result, there is little pressure from constituents and cyber threat operators are not top of mind.

The number and severity of cyber threats continue to grow exponentially as the world becomes increasingly connected. According to recent estimates from the research firm Gartner, by 2020 there will be 20.4 billion internet-connected devices, and approximately 37 percent of these will be used outside consumer settings—including large numbers dedicated to infrastructure monitoring and control.[3] While the proliferation of connected devices has created unprecedented productivity and efficiency gains, it has also exposed previously unreachable infrastructure systems to attack from a range of malicious groups with varying motivations.

Owners, planners, builders, and financiers routinely channel ample resources into mitigating any number of risks to an infrastructure asset. Yet they rarely if ever place as much care into anticipating potential cybersecurity incidents. There are many reasons for the lack of attention to cybersecurity. One is a common consensus in the industry that the technology governing physical infrastructure is fundamentally different from the technology used in other industries. In reality, it is not. While new technology solutions are emerging to deliver and operate infrastructure, these solutions still rely on the operating systems common to nearly all sectors.

Similarly, infrastructure leaders tend to think that they need industry-specific expertise when it comes to hiring cybersecurity specialists. But while having industry-specific expertise is helpful, it should not be viewed as essential; the tool kits across industries are largely the same. Owners and operators might not have the resources they need to make significant strides in their cybersecurity programs if they focus only on recruiting highly specialized talent, especially as it relates to people who can design and execute responses to cyber threats.

As it stands, infrastructure has a long way to go to catch up to other industries in terms of future-proofing for a cyber threat. To accomplish this, cities and organizations will need to integrate their defenses. They will need to recruit and retain new talent and develop a cybersecurity program. Furthermore, ensuring that infrastructure achieves and sustains resilience to cyberattacks in the midst of rapid digitization requires that designers and operators make a proactive mindset shift about cybersecurity—before hackers impose one.

Vulnerabilities do not expire or become obsolete

When considering digitized infrastructure, owners typically focus their energies on envisioning the improvements in efficiency and customer experience that can be realized by new technologies. Cyber

attackers, on the other hand, focus on uncovering the ways that new technology use cases rehash the same weaknesses and vulnerabilities of the old. Indeed, the problems faced by cybersecurity professionals—for example, authenticating users or protecting sensitive data from unauthorized access—largely stay the same over time, regardless of the technology in question. In a 2018 report, vulnerability scanning firm EdgeScan noted that approximately 54 percent of the vulnerabilities that it identified in customer networks that year originally became publicly known in the past ten or more years.[4] This is the cybersecurity equivalent of allowing yourself to remain susceptible to an infectious illness a decade after a vaccine becomes available. As a result, attack patterns that worked during the previous year will likely still work (in a modified form) against newly digitized infrastructure connecting to the internet today.

The takeaway is that infrastructure owners, engineers, and operators, many of whom are acutely aware of cybersecurity vulnerabilities in their information technology environments, must consider the operational technology that powers their digitized infrastructure to be vulnerable to the same issues.

Hackers have long exploited this insight. In February 2017, a cybersecurity researcher developed a ransomware variant that could successfully target and manipulate the control systems of a water treatment plant.[5] In theory, his malware could be used by an attacker threatening to poison a municipal water supply unless the ransom was paid. This may sound like a familiar scenario, because ransomware has been an increasingly common and disruptive cyber threat faced by business for the past three years. Even so, it is not possible for leaders to test for every possible risk or outcome. They will need to limit their attention to the most pressing threats. And the best way to determine those threats is to look at the issues affecting other, similar deployments of technology. By identifying similarities between new and old use cases for technology, infrastructure designers can ensure that cyber risks that were resolved in previous years don't recur in the infrastructure space.

Building cyber defenses for infrastructure

To build adequate defenses, infrastructure owners and operators should start by assuming that a cyber attack is imminent. Then they must build a unified, integrated cyber defense that best protects all relevant infrastructure assets. Going through the process of identifying what is relevant will often require the asset owner to understand what supporting infrastructure is also vulnerable—critical utilities, for instance—and ensure that it is reasonably protected as well. For example, a hotel that relies entirely on a local utility for its power supply may decide that it makes sense to find a redundant power source. In turn, the asset owner will be able to look beyond what would strictly be considered their responsibility, and consider the broader network in which they are included. By going beyond their "battery limit," so to speak, the hotel can gather more information about relevant vulnerabilities and threats.

Moreover, both utility owners and governments can work together in this area to create more—and more widely distributed—utility networks. If they can better isolate network vulnerabilities, they can help ensure service to any undamaged portions.

Start with the assumption that a cyber incident will occur

Since the March 2011 earthquake and tsunami that caused widespread damage to the northeast coast of Japan, including the Fukushima Daiichi nuclear plant, the country has constructed an estimated 245 miles of sea walls at a cost of approximately

$12.7 billion.[6] The same prudence is needed to protect infrastructure from cyber attacks. As a point of comparison, one cybersecurity research organization estimates that the cost of ransomware damages alone in 2019 could exceed $11 billion.[7] But in spite of an increasing torrent of cyber attacks afflicting internet-connected businesses and individuals globally, infrastructure owners largely continue to think of a cyber-attack as a mere possibility rather than a certainty.

By starting with an assumption that a future cyber attack *will* degrade, disable, or destroy key infrastructure functionality, owners and contractors can take action early to build resilience into their systems. For example, backups can be implemented for critical connected components, computers can be designed to fail safely and securely when compromised, and preparedness exercises can train operators to act decisively to ensure that cyber attacks aren't able to compromise connected infrastructure to threaten lives or property.

When planning incident response, leaders should look beyond the infrastructure sector for lessons learned from cyber incidents that caused outages in other sectors of the economy. The steps required for shipping firm Maersk to respond to a June 2017 ransomware outbreak are particularly informative. In order to purge itself of malware, the company executed a ten-day effort to overhaul its entire information technology (IT) infrastructure—a software reinstallation "blitz" that should have taken approximately six months under normal conditions.[8] While infrastructure owners are unlikely to have the same technology footprint as a global shipping company, understanding the steps required to respond to a major cyber incident can provide perspective on the level of effort and courses of action that may be required to respond to an attack in the infrastructure space.

An integrated defense is the only defense

Every infrastructure network has an associated IT network within which its owners and operators conduct their day-to-day business, such as sending and receiving emails and writing reports. Likewise, most organizations operating an IT environment—and some organizations operating a connected infrastructure environment—have cybersecurity programs in place to protect their data and technology assets. However, two discrete cybersecurity programs can't match the effectiveness of one unified program to protect both environments.

While the technology components deployed in the IT and infrastructure environments may differ significantly in their purpose and complexity, they're vulnerable to the same risks when connected to the internet. In the best known instance of this from recent years, hackers that breached the network of retailer Target Stores in 2013 made their initial entry through an internet-connected control system for the stores' air conditioning systems.[9] By connecting the infrastructure management network to the network through which Target executed its corporate functions and processed credit card payments, IT staff unwittingly elevated a minor risk into one with the potential to create catastrophic losses. While the Target breach was a case of attackers traversing an infrastructure environment to target the IT environment, attackers could just as feasibly have made the opposite leap, compromising an office network before leveraging connections to attack infrastructure.

Why wasn't Target's HVAC system cordoned off from its payment system network? The efficiencies gained from connecting networks are clear and undeniable, so preventing these types of technology interactions isn't a practical option. Instead, infrastructure owners must craft a cybersecurity program that takes a comprehensive view of all technologies in

the environment by working to understand how they're connected to each other and to the outside world. Then they must deploy security controls and defensive countermeasures to mitigate risks attributable to IT and connected infrastructure in a prioritized fashion.

Just as designers must take into account the physical resilience of infrastructure assets, owners should integrate cyber resilience. One way of ensuring this happens is to make cyber resilience an integral part of the design process. In addition to better incorporating protections, the Internet of Things has created a digital, keyboard-based operating culture that is often devoid of manual alternatives. Asset owners, notably those responsible for critical infrastructure, such as power plants and hospitals, should consider establishing core functionality that is either resistant to cyber attacks or that allows for an asset to more readily withstand the impact of a cyber attack. Some hospitals in urban areas, for example, might have digitally controlled HVAC systems, including all vents and windows. Having windows that can be opened manually—with the option to override digital controls and use mechanical switches or toggles to open them—could help create ventilation and allow operations to continue in the event of a cyber attack.

How to get started

We've identified three key steps for infrastructure owners starting the process of building their integrated cyber defense.

Recruit new talent. The cybersecurity industry is already severely constrained for talent, and infrastructure owners and operators often compete against other industries that offer higher-paying positions. Therefore, infrastructure groups need to get creative with where they look for cybersecurity talent. Infrastructure players might look to "cyber utilities," for instance, which are industry-aligned working groups that pool information and resources to improve cybersecurity effectiveness for their membership. These member-driven organizations—such as the Intelligence Sharing and Analysis Centers (ISAC) sponsored by the US Department of Homeland Security—were originally intended to serve as industry-sector-aligned cyber threat intelligence fusion centers for member companies. So, for instance, banks could join the financial services ISAC. However, the concept could be employed on a smaller scale to allow infrastructure owners in a particular region to share cybersecurity talent and resources for cybersecurity functions besides intelligence. For example, a cyber utility consortium in any given metropolitan area—hypothetically comprising a city government, a municipal utility district, and a publicly traded electricity company—could share a single cybersecurity team, rather than each entity competing to recruit their own.

Form a cyber response team. The first hours after the discovery of a cyber attack are the most critical in effectively mitigating losses, and their importance is magnified in the case of attacks against infrastructure where loss of life may be a possible second- or third-order effect. For this reason, selection and training of an incident response team *before* an incident occurs is key. Teams should include cybersecurity professionals skilled in cyber investigation and analysis, but they must also include experts familiar with the broader functioning of the infrastructure asset itself along with leaders who can make timely decisions about issues such as whether to shut down infrastructure or notify the public about an incident.

Cyber response teams should be subjected to regular incident exercises to build the muscle memory necessary to respond effectively and to uncover

potential weaknesses in response processes. The cyber utility concept described above might be specifically helpful in forming a response team, since skill sets such as cyber forensics are in particularly short supply.

Cultivate a mindset shift across the organization. Cybersecurity for infrastructure is often seen as a trendy topic—every other year something happens that makes headlines and then, weeks later, the industry has returned to the status quo. Owners and operators take a hard look at the situation and then lose interest when no clear path forward presents itself. This needs to change.

Two specific actions are key in beginning and subsequently sustaining the mindset shift required. To begin the mindset shift, organizations need to develop a perspective on what a cyber attack would actually look like *for them*. Cyber war gaming and table top exercises have long been a staple for developing this perspective in corporate environments, and they can be similarly effective for infrastructure. Effective exercise scenarios emulate the actions of timely real-world attackers to impose a series of difficult decisions on the team, creating numerous (and sometimes painful) learning opportunities. Through cyber war gaming, participants often learn that their organization lacks key response elements such as clear delineation of responsibilities in crisis situations, plans for how and when they should communicate with stakeholders or the public, and even procedures for shutting down compromised systems. The best programs deepen learning by establishing a regular cadence of exercises (e.g. quarterly or semi-annually) to accustom participants to the stress and confusion of a crisis situation and to continuously identify opportunities for improvement.

Once organizations begin to understand how bad an attack could be for them, they must remain focused on steady improvement. To sustain the mindset shift begun with cyber war games, infrastructure owners must integrate cyber resilience metrics into their regular performance measurement programs. As the cliché goes, "What gets measured gets done." By requiring their teams to continuously evaluate the organization's cyber resilience, leaders can ensure that the topic remains front of mind. Leading organizations take this a step further by integrating cyber metrics into the performance metrics for *specific individuals*, creating a culture of personal responsibility where bad cybersecurity can actually affect managers' compensation and prospects for promotion.

In a world steadily digitizing and becoming more interconnected, cyber attacks should be thought of as a certainty akin to the forces of nature. Just as engineers must consider the heaviest rains that a dam may need to contain in the next century or the most powerful earthquake that a skyscraper must endure, those digitizing infrastructure must plan for the worst in considering how an attacker might abuse or exploit systems that enable infrastructure monitoring and control. This shift in thinking will begin to lay the path to connected infrastructure that is resilient by design.

Cyber threats don't become obsolete or irrelevant in the same way that the technology underlying them does. So, in the context of cybersecurity, future-proofing infrastructure is primarily about ensuring that the steps taken to inject resilience into a system remain connected with the relevant threats of today and yesterday, rather than threats that may manifest tomorrow.

By starting with the assumption that not only will cyber attacks against infrastructure occur but also that they will likely be successful, infrastructure designers and operators can learn to trap many risks before they have the chance to develop into catastrophes. To do this, infrastructure owners and operators must first understand how old vulnerabilities will affect new technology and then develop integrated cybersecurity plans to apply the appropriate level of protection to their entire technology environment. The result will be safer and more resilient connected infrastructure delivering reliable services to customers for years to come.

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[1] "Dave Lee, "Warning over 'panic' hacks on cities," BBC, August 9, 2018, bbc.com.

[2] "Ukraine power cut 'was cyber-attack'," BBC, January 11, 2017, bbc.com.

[3] *Gartner says 8.4 billion connected "things" will be use in 2017, up 31 percent from 2016*, Gartner, 2017.

[4] *2018 vulnerability statistics report*, edgescan, 2018.

[5] Michael Kan, "Researcher develops ransomware attack that targets water supply," CSO, February 14, 2017, csoonline.com.

[6] Megumi Lim, "Seven years after tsunami, Japanese live uneasily with seawalls," Reuters, March 8, 2018, reuters.com.

[7] Steven Morgan, "Global ransomware damage costs predicted to hit $11.5 billion by 2019," Cybersecurity Ventures, November 14, 2017, cybersecurityventures.com.

[8] Charlie Osborne, "NonPetya ransomware forced Maersk to reinstall 4000 servers, 45000 PCs," ZDNet, January 26, 2018, zdnet.com.

[9] Brian Krebs, "Target hackers broke in via HVAC company," Krebs on Security, February 5, 2014, krebsonsecurity.com.

Getting infrastructure projects right: A legal adviser's view on standardization

To promote wider adoption of document and process standardization in the infrastructure industry, public- and private-sector organizations should foster greater collaboration during the early stages of project development.

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Governments, multilateral agencies, development finance institutions, and the private sector have made substantial efforts to improve the process of infrastructure projects from the predevelopment stage through implementation. These efforts include the creation of standardized infrastructure project frameworks—with guidance on key process stages (such as procurement) and risk allocation, as well as standard form documentation. Realistically, every infrastructure project is unique, and there are elements of each—for example, cost sharing or capital expenditure terms—that will always be project-specific. Yet the use of standardized tools where feasible can significantly reduce project development timescales and bring transparency into procurement and contracting processes for host governments and procuring bodies.

Despite such efforts to date, project development too often continues to be reactive rather than well planned, prioritized, and efficiently executed. To reap the full benefits of standardization, public- and private-sector participants must work together in a more meaningful way. By making better use of standard models, promoting knowledge sharing, and investing more in the predevelopment stage, infrastructure projects can proceed much more efficiently.

Barriers to standardization

Significant investments have been made in developing standardized frameworks, model contracts, and guidance. While the infrastructure sector would be well served by maximizing the use of these tools, several barriers currently stand in the way:

- **Existing frameworks, model contracts, and guidance are often overlooked in the development of new infrastructure.** Instead, stakeholders make assumptions about what private-sector developers or lenders will accept and then enshrine such suppositions into frameworks or legislation. Understanding the best way to use existing resources in a specific context requires experience, and individual jurisdictions and government agencies without that experience often opt to create their own models.

- **Guidance on risk allocation published by international organizations is not necessarily accepted by investors, contractors, governments, or lenders.** Numerous international organizations—the Organisation for Economic Co-operation and Development, the International Institute for Sustainable Development, the United Nations Economic and Social Commission for Asia and the Pacific, and many others—have published guidance on allocating risks when developing projects. Perhaps due in part to the proliferation of guidance, no industry or market consensus has emerged on which organizations should be the leading voice (or voices). The sector also exhibits a degree of skepticism regarding the extent to which risk frameworks on infrastructure projects can be standardized, so the prevailing tendency is to treat each project as bespoke.

- **Even when stakeholders heed general guidance and use model contracts, adapting them to a specific deal can be a challenge.** With a cross-sector or generic standardized contract, for example, the provisions are often based on assumptions about the underlying project (for instance, that it includes both construction and services components) that are not always applicable. In addition, parties will often plead special circumstances on a particular transaction to justify departures from standard terms. The potential efficiencies

of using a standard form can easily be squandered if parties are not well advised on what modifications are genuinely necessary. Standardized documentation does not eliminate the need for properly experienced and empowered negotiating teams.

Toward a more collaborative approach

Developing and using standardized models comes with inherent challenges. Nevertheless, infrastructure leaders have no choice but to embrace the adoption of standardized risk allocation and documentation at greater scale to achieve more efficient and effective infrastructure development. (See sidebar, "Public–private collaboration on standardization.")

Making best use of existing models

Infrastructure-program design must involve people with relevant expertise to ensure that existing standard models are used and customized to the specific requirements of a particular jurisdiction and sector. Private-sector participants with extensive, varied and often global experience in infrastructure development, can be an invaluable partner to governments in this process.

Of course, one of the biggest challenges facing the public sector is that getting standardization right requires significant investment at an early stage, when budgets are often constrained. The initial investment should yield future cost savings and better outcomes, but tangible impact may not be achieved in the short term. The private sector therefore needs to better articulate the benefits of standardization and convince the public sector to collaborate more closely in a program's earlier stages. The private sector must also reinforce best practices by continuing to share examples of successful collaboration with the infrastructure community.

Sharing knowledge and making a commitment to risk-allocation standards

In the absence of a leading authority on risk-allocation standards, individual infrastructure projects tend to be undertaken without reference to a standard model or approach.

Some reticence toward standardized risk allocation is rational. A standard approach requires striking a balance between the parties' competing needs, and some may think a stand-alone negotiation could result in a better deal. For standardization to work, all parties must agree that the benefits will outweigh any (possibly illusory) downsides.

Industry participants should actively explore ways to facilitate knowledge sharing and encourage collaboration across the sector, particularly as technological tools are developed that could be applied across many areas.

Implementing standard models: Investing in the predevelopment stage

Even with the use of standardized models and risk allocation, individual projects will always include unique features that require some customization. As such, a common pitfall of using standardized documentation is the perception that the work has already been done, so stakeholders may deploy less experienced or scaled-back negotiating teams to broker specific transactions. This is invariably a false economy. Instead, procuring bodies should aim to build well-advised teams that can identify potential customization needs at an early stage and avoid unnecessary negotiation and rework.

Participants should also explore new ways to facilitate greater investment in the early stages of projects. For example, the private sector could contribute to the cost of advising governments throughout the process, with such expenditures being recovered in the tender process or as part of the financing.

Public–private collaboration on standardization

Argentina recently established a new public-private partnership (PPP) program and enacted legislation to facilitate investment in renewable power. While the longer-term outcomes of these initiatives remain uncertain, particularly in light of the country's current economic instability, the process of establishing and launching these programs exemplifies the benefits of close cooperation between the public and private sectors. In both efforts, the government of Argentina worked closely with the Inter-American Development Bank and the private sector. A few key lessons emerged:

- *Apply best practices from other projects.* With broad experience working on PPP projects across Latin America, the team was familiar with models used elsewhere: their features, what had worked well, and why. This experience guided the choice of structure and standard terms.
- *Tailor to the local context.* The team understood the political and economic context in Argentina, so it was able to properly tailor the program to meet the country's specific requirements and circumstances.
- *Balance the task at hand with the big picture.* The PPP program was designed so that the detailed work on standard documentation focused on the immediate priority—toll roads. At the same time, the overarching "master trust" structure was designed to be replicable across sectors as new priorities emerge. The intention is to develop new standard documentation for different sectors as required, using the existing model as a base and then making minimal changes to tailor it to different infrastructure assets.
- *Focus on bankability.* The PPP program was specifically designed to tap into capital markets funding, so having advisers who were familiar with the market meant that the documentation was bankable from day one.
- *Remove politics from the equation.* The involvement of a multilateral agency helped depoliticize the initiatives. This effect was particularly apparent with the renewables law, which was approved shortly before elections with support from all sides. Establishing standardized programs for infrastructure can help to bridge political divisions, as long as the terms of the program are properly socialized with stakeholders prior to adoption in order to achieve buy-in.
- *Strive for transparency.* The involvement of private-sector participants that were accustomed to scrutinizing projects for compliance with international standards in a range of areas, from anti-bribery and -corruption to the environment, gave the market confidence in the program's transparency and robustness.

Bringing in funders at the outset can also build confidence among investors and debt providers. When parties are familiar with the standard structures and terms for a given project, the financing phase typically runs much more smoothly and efficiently.

Where potential financiers are more engaged with early stage project development, this may encourage them to take a more proactive role in designing funding packages that can be offered to governments or developers. We have already seen innovation in this area. The World Bank's Scaling Solar program, for example, offers a package that includes document templates, competitive financing, and insurance products. In the United Kingdom, the national government established a funding aggregator scheme to support the Priority Schools Building Programme through a single bond-financed funding platform that can be used to finance separate batches of schools.

Improving standardized infrastructure investment frameworks could promote the further development of liquidity platforms from a wider variety of debt providers and investors.

Conclusion

While much has been done to develop standardized infrastructure project frameworks, too much skepticism about closer cooperation remains on both sides. A renewed focus on promoting collaboration between the public and private sectors when developing and implementing standardized models is crucial to reaping the full benefits of standardization. ■

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.

Affordable housing: A prerequisite for resilient cities

A shortage of affordable housing is taking a toll in every geography and on every segment of society. Several strategies can help governments free up supply of land, resources, and productivity.

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Affordable housing is crucial to future-proofing our communities. Worldwide, the McKinsey Global Institute has estimated that some 330 million urban households currently live in substandard housing or stretch to pay housing costs that exceed 30 percent of their incomes.[1] This lack of affordable housing constitutes a significant risk for cities and needs to be addressed to make them more resilient to increasing migration flows and societal divisions that arise in many geographies. Income polarization can be exacerbated if lower-income households cannot find a decent place to live. In today's globalized world, migration can be highly successful when people on the move are well integrated into their chosen destination—which requires education, housing, and jobs. But a lack of these inputs can also backfire and lead to divisions that can manifest in everything from social unrest to extreme poverty.

National and local governments around the world often address housing gaps by focusing on demand and financing. Housing subsidies, privileged financing, or various forms of rent control offer much-needed relief to low-income households. But these strategies are expensive and difficult to sustain—and they do not address the core issue of an underlying housing shortfall.

It will take a dramatic increase in the number of available housing units to achieve greater affordability. Of course, the simplicity of this statement belies the complexity of executing on it. Supply-side solutions can help address three challenges that all cities have in common: finding available land, removing barriers, and making the construction sector more productive.

Find the land

Access to well-serviced land near centers of employment is typically the biggest constraint on housing development and one of the major drivers of cost. In places such as Rio de Janeiro and Auckland, the cost of land often exceeds 40 percent of total property prices. In extreme cases such as San Francisco, land is so scarce that it can account for as much as 80 percent of a home's price. Globally, we estimate that unlocking land to its fullest extent could reduce the cost of owning a standard housing unit by up to 20 percent. Based on our work in urban environments, we have identified several places to focus.

The most crucial area to prioritize is transit-oriented development. It is critical for congested cities to promote density around transit rather than encouraging sprawl and longer commutes. Transit-oriented development may involve redeveloping existing residential structures or encouraging new builds by permitting higher floor-space ratios, loosening height restrictions, or allowing greater density in specific target zones. Hong Kong's Mass Transit Railway has a long track record in using transit-oriented development to finance infrastructure and provide housing. Auckland is upgrading its infrastructure with the City Rail Link, cofinanced by value-uplift taxes, and developing high-rise buildings around new and current transit hubs.

Other actions that can help cities unlock land include getting more out of underutilized sites, putting vacant urban parcels to work, making public land available, transforming industrial sites, going greenfield, and encouraging single-family-home owners to add accessory dwelling units.

Remove the barriers

Cities have to develop governance structures that represent all stakeholders (not just the most entrenched, powerful, or vocal) and streamline the actual execution. Several approaches can help.

1. **Engage more stakeholders and overcome NIMBYism.** Stakeholder opposition and the not-in-my-backyard phenomenon (NIMBYism) are often roadblocks to housing development. Although most people agree in the abstract that

more affordable housing is a good thing, the voices of existing homeowners who want to preserve the status quo often drown out those of newcomers, young adults, low-income service workers, and renters who need more housing. Instead of public hearings and ballot initiatives that carry veto power, cities can mount affordable housing bodies specifically chosen to represent a broader set of stakeholders; mandate a larger role for employers in the community input process; and use widely distributed surveys and analytics tools to track citizen sentiment and real-world use patterns. One city, for example, builds support by proactively educating citizens, stressing the need for new housing and the effect it will have on the children and grandchildren of residents. These strategies can help communicate how housing decisions are in tune with the needs of the community and lessen the influence of entrenched interest groups.

2. **Align for better delivery: Delivery labs and integrated housing agencies.** Housing strategies are enormously complex, involving initiatives and policies across financing, urban planning, infrastructure development, land-use regulation, building codes, delivery and contracting approaches, and more. Several cities have found success with the "delivery lab" model, which addresses this lack of coordination by bringing together 30 to 40 people across these specialties for fast-paced, intensive working events. Labs are designed to translate high-level housing strategies into detailed initiatives and implementation plans—and to set key performance indicators. The outcomes from successful labs are a good foundation, but actual implementation is crucial. A city government can accelerate progress by empowering an agency or unit with a mandate to guide housing delivery from end to end.

3. **Speed up.** A maze of regulation is typically associated with land acquisition, zoning, and building codes. Cities can streamline their processes to fast-track land-use approval and permitting, creating a more predictable and less burdensome process. Establishing "single-window" clearance (that is, consolidating approvals from multiple agencies into one clear interface) and digitizing permit applications and status tracking are clear places to start. Cities can also establish "by-right" special development zones in select areas where deviations from city zoning and land-use codes are permitted with minimal review.

4. **Scale up and create incentives for efficiency and innovation.** Cities can support construction industry innovation by providing the land and infrastructure that allow for scale, tendering out city-scale developments, and consolidating high-volume demand. Where cities themselves invest in housing or supporting infrastructure, they can employ value-based tendering (which places greater emphasis on the quality and past performance of suppliers), add contractor and owner incentives to traditional contracts, and make provisions to improve transparency and collaboration.[2] An even bolder approach involves contracts with an integrated project delivery model.[3] Finally, by mandating use of efficient technologies and innovations in their procurement contracts, cities can hasten private-sector adoption and investment in cost-saving tools.

Evolve the construction industry

Productivity within the construction sector is consistently poor around the world. Labor productivity growth averaged 1.0 percent a year over the past two decades, compared with 2.8 percent for the total world economy and 3.6 percent for manufacturing. Some of this outcome is due to external factors such as regulation as well

as cyclical swings in public and private demand. Informality and corruption sometimes distort the market. At the industry level, construction is highly fragmented, contracts have misaligned incentives, and inexperienced owners and buyers find it hard to navigate an opaque marketplace. At the firm level, we often see poor project management, inadequate design processes, and a lack of investment in technology, R&D, and workforce skills.

Across the board, stakeholders should focus on two methods to evolve the construction industry.

- **Push forward with best practices to boost productivity.** Several approaches can improve on-site execution, starting with a rigorous planning process and the completion of all prework before starting on-site. To ensure that key activities are achieved on time and on budget, companies should agree on key performance indicators, particularly for subcontractors, and hold regular performance meetings to monitor progress and solve issues. The construction industry also needs to accelerate digital adoption. This includes the use of building information modeling tools for design as well as analytics and the Internet of Things for onsite monitoring of materials, labor, and equipment productivity.[4]

- **Transition to a production-system approach.** Construction is almost always approached as a series of discrete and bespoke projects. But the biggest boost in productivity comes with the concept of a manufacturing-inspired mass-production system. Such a system involves more standardized elements, panels manufactured and assembled offsite, and limited finishing work conducted on-site. Modular construction has been around for decades but has developed to scale in only a few countries. Indeed, a new breed of players and approaches could help it conquer more geographies. A range of start-ups are replacing "a site under a roof" production approaches with robotic production, digital customization, and supply-chain management, while also replacing concrete with lightweight materials to alleviate logistics. They also carefully optimize engineering to balance plant production efficiency and assembly on-site with material and transport cost implications. Some governments provide incentives for new methods of construction, such as prefabrication and modularization, by clarifying upcoming volumes and reducing permitting times. Saudi Arabia, for example, is working closely with local and international industrial construction suppliers, providing offtake agreements and incentives conditional on meeting required volumes and rates, and to ensure quality, developing quality rating systems for buildings.

To safeguard a resilient future, cities urgently need to ramp up home building to improve residents' quality of life, remain inclusive, and ensure that housing shortages do not become a drag on economic growth and social cohesion. The tools and strategies outlined here can be pursued in parallel—and given the extent of unmet demand today, there is no time to lose.

[1] For more, see "Tackling the world's affordable housing challenge," McKinsey Global Institute, October 2014, on McKinsey.com.

[2] For more, see "Rewiring contracts for collaboration," September 2017, McKinsey.com.

[3] For more on integrated project delivery, see Lukasz Abramowicz, Jim Banaszak, TG Jayanth, and Homayoun Karrinkoub, "Collaborative contracting: Making it happen," July 2018, McKinsey.com.

[4] For more, see *Voices on Infrastructure: Harnessing the promise of digital*, March 2018, McKinsey.com.

The energy-storage opportunity: What engineering and construction players should know

As the costs of energy-storage systems continue to fall, engineering and construction companies will need to improve their operations to stay competitive.

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Energy storage is rapidly growing in importance for the power sector. Some commercial uses for energy storage are already economical. Still more uses will become attractive for utilities and industrial customers as lower system costs, combined with developments such as the rollback of solar incentives that reward customers for exporting power to the grid, make it financially sensible to store power for on-demand use.

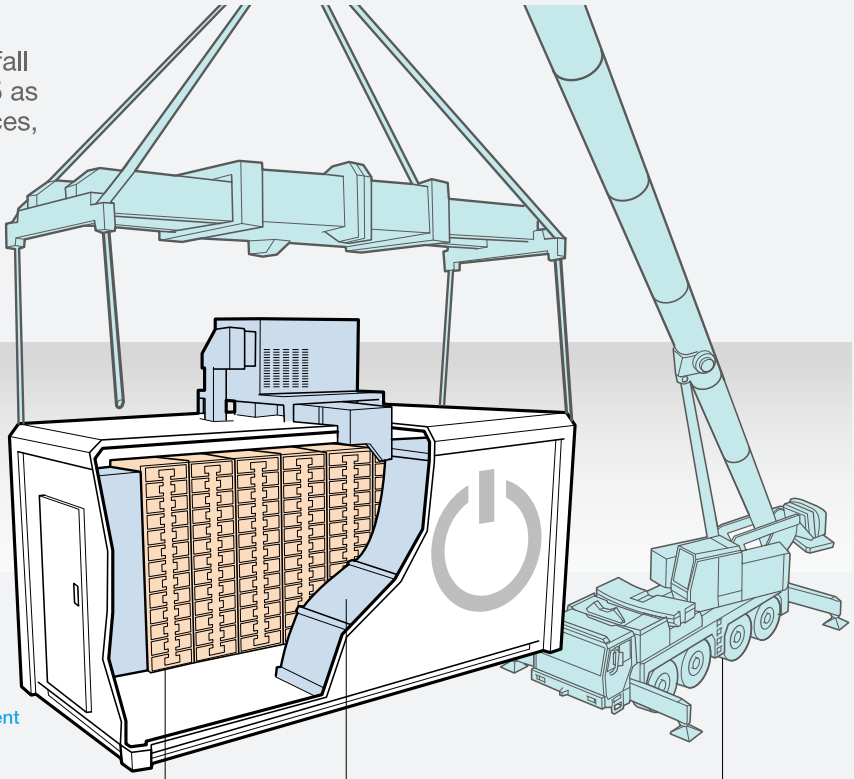
The growth of energy-storage projects will create new opportunities for engineering and construction companies if they can deliver the capabilities and efficiency needed to compete in this evolving market. The pace of change should be significant: we expect the fully installed costs of energy-storage systems to continue the rapid decline that occurred from 2012 to 2017 (exhibit).[1] In our base-case scenario, the installed per-kilowatt-hour cost of an energy-storage system would decrease roughly 55 percent by 2025. There is also a plausible best-in-class scenario in which additional process-efficiency gains and hardware innovations reduce the cost of an installed system by more than 70 percent. We anticipate the following cost declines for major system components:

- **Battery-pack costs** decline by more than 50 percent by 2025 in the base case as global competition intensifies, leading to larger-scale manufacturing, consolidation, improvements in manufacturing processes and technology, and commoditization of products. The best-in-class scenario envisions that battery makers incorporate multiple chemistries and formats (for example, reduced-cobalt cathodes and solid-state batteries), gain more efficiencies from automation and added scale, integrate their supply chains, and even move some operations like electrode manufacturing in-house. Expected reductions in the cost of capital facilitate the financing of improvements to battery-pack manufacturing processes.
- **Balance-of-system (BOS) hardware costs** drop by more than 50 percent in the base case. Design improvements remove unnecessary costs and complexity from inverters, wiring, containerization, climate controls, and other components. Further competition from incumbents and new low-cost manufacturers also pressure pricing for storage hardware. In the best-in-class scenario, the use of new materials and technologies (such as silicon carbide for inverters), the accelerated growth of low-cost manufacturers, and innovations in design (such as the development of prefabricated, modular components) enable additional cost savings.
- **Soft costs** drop 60 percent in the base case. As utilities optimize the use of battery storage, they streamline their procurement processes and require less time and effort from developers. The additional cost reductions expected under the best-in-class scenario stem from developers' efforts to digitize tendering and the emergence of standard approaches to permitting and interconnection.
- **Engineering, procurement, and construction (EPC) costs** fall in the base case because efficient, experienced EPC firms achieve economies of scale and reduce on-site labor by pursuing standardization in design and construction. Alliances with committed developers also provide EPCs with the confidence to invest in capabilities and resources that improve efficiency. The best-in-class scenario accounts for larger-scale EPC enterprises, the development of hardware and software with plug-and-play compatibility, and prefabricated components that reduce manual installation steps on-site.

The more the cost of an average energy-storage system goes down, though, the less room EPC companies and project developers will have to undercut competitors. That will make for a tough competitive environment—

Exhibit

The total cost of energy-storage systems should fall 50 to 70 percent by 2025 as a result of design advances, economies of scale, and streamlined processes.



Where battery-storage-system costs will be affected, range

(ranges indicate estimated price decreases under base-case and best-in-class scenarios)

Soft costs: Customer acquisition and development, interconnection, overhead, taxes, and duties

Developers spend less time educating increasingly savvy customers, digitized tendering speeds up bids, and permitting and interconnection get faster with standardization.

Decrease by 2025: 60 to 75 percent

Battery pack: Battery-management system, cells, and modules

Large-scale manufacturing, consolidation, and improvements in processes and technology drive costs down.

Decrease by 2025: 50 to 70 percent

Balance-of-system hardware: Climate control, containerization, controller and controls, and inverter

Design improvements remove unnecessary costs and complexity. New low-cost competitors put pricing pressure on incumbents.

Decrease by 2025: 55 to 70 percent

EPC: Engineering, procurement, and construction

EPC companies create economies of scale and reduce on-site labor by pursuing standardization in design and construction. Prefabricated, plug-and-play components also lessen manual effort.

Decrease by 2025: 40 to 55 percent

but a rewarding one for EPC companies and project developers that achieve significant cost reductions. As we explain below, EPC companies will need to streamline their practices, get greater value from their spending on key inputs, and standardize system designs, while project developers should cut their customer-acquisition costs and change their procurement practices to capitalize on falling battery and hardware costs.

EPC companies should adopt more efficient practices, such as lean construction (for example, optimizing crew sizes and eliminating downtime and wasted effort), prefabrication of major system elements, simplified bidding, and streamlined interconnection processes. Some of these practices will take hold naturally as companies gain experience. Purchasing components in higher volumes will reduce per-unit costs. Alliance-contracting relationships should enable companies

to work with sophisticated, low-cost installation partners across many projects.

EPC companies and project developers should also adopt design practices that save time and effort. Standardizing certain aspects of storage systems (for example, container and climate-control specifications) will lessen the need for expensive custom engineering. Ensuring that designs meet but do not exceed customers' requirements will help them avoid using components that are unnecessarily expensive. Modular hardware, along with hardware and software that are made to be compatible, will also eliminate manual installation steps.

For their part, storage-project developers should use technology to acquire customers more efficiently. Advanced analytics, for example, will help developers identify prospective customers and target them with attractive offers. Developers should also improve existing digital tools with automated capabilities for estimating savings and developing preliminary system designs (for example, simulating customer loads to help with system sizing, or using images from satellites and drones to lay out sites). For utility-scale projects, developing storage along with renewable-energy generation will boost profits by spreading out customer-acquisition costs, making more efficient use of land and site infrastructure, and improving the ability to optimize intermittent renewable generation (for example, time shifting generation).

Storage developers and system integrators should adopt more flexible approaches to procurement that allow them to take advantage of rapidly declining battery and BOS hardware costs. Like their peers in the solar market, some storage developers struck forward-pricing agreements with battery and component makers in the hope of achieving certainty over their costs—and came to regret these agreements as costs fell. Storage developers should be mindful of this risk as they plan ahead.

The cost projections we have described suggest that the market for battery storage will expand. While we are still assessing the potential for energy storage to open a new frontier for renewable power generation, energy storage should become a significant feature of the energy landscape in most geographies and customer segments. As battery packs grow cheaper, EPC companies and project developers will have to manage their costs well to stay competitive. Opportunities to do this, some of which we have outlined in this article, are plentiful—and real. Seizing them will require innovation and investment across the storage value chain, particularly in the next one to three years, when early-mover advantages will be there for the taking.

For more on this topic, see "The new rules of competition in energy storage" on McKinsey.com.

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[1] This decline could be held up for several reasons. For example, utility and power-market regulators might enact rules or policies such as those governing permitting and interconnection that make storage systems costly and time-consuming to install. Investments in manufacturing might produce smaller improvements in efficiency than they did in the solar photovoltaic market. Tariffs could boost the cost of imported batteries and balance-of-system hardware from low-cost manufacturing locations. Having assessed the potential for these developments, we think it is unlikely that they will materially impede cost reductions for energy-storage systems, and so we have not accounted for them in the two scenarios described in the article.

New York site visit: The rise of supertall towers

An estimated $52.5 billion will be spent on construction in New York City this year—the largest amount in the city's history. In addition to greater spend, the city has seen a trend toward building taller. In 2014, New York City had only four supertall towers, defined as 300 meters or taller. Just four years later, the city has 24 supertall towers in various stages of completion or development—an increase of 500 percent.

According to the Council on Tall Buildings and Urban Habitat (CTBUH), this is part of a global trend; 2017 was the tallest year in the history of construction. Of the 100 tallest towers in the world, 50 are in China. The United Arab Emirates has the second-tallest skylines, with 22 supertall towers, and the United States is in third place with 15.

On September 12 and 13, McKinsey's Global Infrastructure Initiative cohosted an Innovation Site Visit with AECOM to introduce global leaders to two of New York's largest and most ambitious projects—Hudson Yards and the World Trade Center (WTC). Hudson Yards is the largest private real estate development in US history; when complete, it will encompass more than 18 million square feet of commercial and residential space. WTC, the world's most closely watched urban-renewal project,

consists of a 16-acre mixed-use development with five iconic office towers and the 9/11 Memorial Plaza.

As part of the site visit, participants discussed the challenges facing the supertall building industry and agreed that project owners should focus on several key actions:

- **Understand the global trends.** According to the CTBUH, the key factors driving supertall towers are a city's gross domestic product (GDP), available land area, global connectivity, and land-use regulations that allow tall buildings. Densely populated global cities with growing GDPs and height-friendly regulations are seeing the greatest growth in supertall towers. In New York, the boom in tall construction can be partially attributed to adaptive building laws that open the door to taller construction in exchange for much-needed investments in infrastructure–such as transit improvements and pedestrian plazas.

- **Plan new developments to support modern ways of living and working.** Led by millennials, demand is rising for urban areas that meet both work and life needs. In addition to offices and residential areas, new developments should include elements such as retail, entertainment, schools, healthcare facilities, and open recreational space.

- **Invest in mass transit and other core infrastructure.** Mass transit and related infrastructure are critical to real estate development. New York City's investments in transit infrastructure and transit-oriented development have attracted a flow of foreign and domestic investment, helping fuel New York's supertall tower boom. While government has a leadership role in making such investments, New York's experience shows that private developers often follow with co-investment and partnerships to improve the transit systems and other surrounding infrastructure.

- **Explore different financing models.** Major capital projects have different financing needs at different phases, often requiring a variety of complex structures. Both Hudson Yards and WTC demonstrated creativity in moving anchor tenants from older buildings to new developments to create traction. They also met the needs of individual tenants by using bespoke financing models—ranging from fixed pricing for standard condo models to equity partnering on a building.

- **Tackle delivery challenges using innovation and technology.** The industry is ripe for disruption, and significant advances have already been made using design assist, building information modeling (BIM), prefabrication, lean construction, real-time information, and innovative safety approaches. In New York, BIM and virtual and augmented reality have improved logistical planning and efficiency throughout the construction process. As real estate projects across geographies struggle with similar challenges and develop new solutions, designers, developers, and contractors would benefit from hearing new ideas and sharing knowledge.

- **Use economies of scale to invest in building superior customer experiences.** Neighborhood-level developments like Hudson Yards and the WTC demonstrate how projects can go beyond the basics and invest in building customer communities. Substantial investments in curated retail offerings, marquee restaurants, and iconic structures such as the Vessel and Memorial Park have transformed major commercial real estate projects into vibrant global destinations that inspire visitors and attract new tenants. Superior customer service is another strategy that elevates

the experience for visitors. For example, participants noted and appreciated the warm greeting they received from the well-dressed staff at Hudson Yards.

- **Consider colocation to drive efficiencies.** Outcomes are often better when contractors and supply-chain contributors join the discussion early on. Colocation of designers, engineers, and contractors has resulted in collaborative problem solving and better performance on projects ranging from Heathrow's Terminal 5 to the WTC. Owners have seen positive results when they set the expectation for collaboration at the outset, using the contracting process and structures to encourage key stakeholders to work together.

- **Beware of challenges.** Some participants warned of challenges on the horizon, ranging from developers lacking the finances or inclination to upgrade older buildings to cities not keeping up with critical needs like mass transit or affordable housing. Planners and regulators need to account for these hurdles in their planning and budgeting processes. ■

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