WHAT LIES AHEAD?

Progressive Megacities, one of four scenarios created for the project, envisions significant growth in urbanization fueled by technological developments such as drones and smart-city sensors.

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ASCE's Future World Vision: Infrastructure Reimagined project invites engineers to engage in an in-depth examination of the most important trends shaping the globe and how those trends might play out over the next 10, 25, and 50 years. The goal? To thoroughly understand the implications of these trends on the profession and help civil engineers prepare themselves, and the built environment, for what lies ahead. •••• **BY LAURIE A. SHUSTER**

CLIMATE CHANGE. Alternative energy. High-tech construction. Autonomous vehicles. Smart cities. Changes to funding.

Any of these issues on their own might have significant effects on the practice of civil engineering as they evolve over the course of the next 10, 25, or even 50 years. But taken together, their interactions with one another and their impacts on design and construction could be profound—potentially revolutionary.

So ASCE is encouraging engineers to begin now to examine those trends that have the greatest potential for impact on the built environment and how those trends might intersect, interact, and influence one another, creating fundamental shifts in the ways in which civil engineers will need to learn, practice, and manage their profession in the coming decades. The effort is called Future World Vision: Infrastructure Reimagined (futureworldvision.org).

The project began when ASCE and its Industry Leaders Council (ILC) convened a team of staff and volunteers, from inside and outside the engineering and construction professions, to determine which cultural, social, economic, environmental, and technological trends might be most important in shaping the future of the professions. This interdisciplinary team identified more than 100 such trends, and eventually narrowed them to the most important 25. ASCE's Board of Direction then hired Altman Vilandrie & Co.—a strategic management company based in Boston that specializes in telecommunications, media, and technology—to further narrow the list of trends to six and explore those trends more deeply.

Altman Vilandrie identified all the possible outcomes of those six trends over the course of 10, 25, and 50 years, and combined them in different ways to create four possible future scenarios. (See the "The Four Scenarios" on page 48.)

The trends and the scenarios are detailed in a report, *Future World Vision: Infrastructure Reimagined*, which serves as just the first phase in ASCE's Future World Vision project—a starting point to guide engineers in deeply examining the challenges and promises that the future holds for the profession.

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The six trends that were deemed the most important to the profession were:

- climate change
- alternative energy
- high-tech construction
- autonomous vehicles (AVs)
- smart cities
- public funding

These trends could each go in any number of directions. Over the course of 50 years, climate change effects may improve or worsen, for example. And AVs may impact trucking or mass transit systems before affecting individual drivers. The four scenarios created from this endeavor—called Resilient Cities, Progressive Megacities, Dispersed Settlements, and Unequal Enclaves—explore these many possible outcomes.

"This came out of a series of discussions at the ILC at which we became convinced that the external environment, for both civil engineering and infrastructure in general, was on the verge of more significant change over the next decade or so than what we have seen in the past fifty, hundred, or maybe even more years," says Gerald Buckwalter, A.M.ASCE, the strategy director for Northrop Grumman, who served on the National Infrastructure Advisory Council within the U.S. Department of Homeland Security for Presidents George W. Bush and Barack Obama before joining ASCE's ILC. Buckwalter led a team that advised ASCE as it moved forward with this intial phase of the project. "When those kinds of changes are headed your way, it's time to do some serious future analysis."

The greatest value of scenario planning—a method that is often used by large contractors and the government itself, and that Buckwalter has implemented at Northrop Grumman—comes from "the thought process you go through to consider which trends are most important and will have the most impact on your profession, what range of outcomes they might have, and how they might impact each other as they interconnect," he says. "We want to share that thought process with the ASCE community at large so everyone can benefit from the process."

It is clear that advances in materials, visualization techniques, design and construction automation, energy generation, transportation methods, and other technologies will lead to significant changes that will affect the design and construction fields and the infrastructure that will support communities in the future. "This is our chance to start early and figure out what's the most desirable future for the built environment," Buckwalter says. "Then you can tease out of that: What is the proper role for civil engineers and for ASCE? And then from that, you can tease out: What are the engineering capabilities and skill sets that current and future civil engineers will need?"

Modular construction may be made faster and more efficient by shop-fabricated pieces delivered to jobsites by drones.

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IF AUTOMATED DESIGN FUNCTIONS CAN BE LINKED SEAMLESSLY WITH AUTOMATED CONSTRUCTION TECHNOLOGIES, THE RESULT COULD BE TRULY TRANSFORMATIVE.

TWO DEVELOPMENTS that permeate many of the trends are the evolution of artificial intelligence (AI) and the increased amounts of data generated by the "internet of things" (IoT)— specifically, the "internet of infrastructure" (IoI). Increasingly, infrastructure or segments of infrastructure are being designed to include sensors that are linked via wires or Wi-Fi to other components that, for example, monitor their health or control their operations. And the data that these IoI devices generate must be monitored, collated, and interpreted.

"One of the trends that I think will cause massive change of some sort or another is the coming use of massive data and data analytics associated with all the sensors that will be built into infrastructure of every kind," Buckwalter says. "That creates a whole new paradigm that we're going to have to figure out."

Already, sensors in buildings, bridges, pipelines, and even rivers and streams deliver massive amounts of data to infrastructure designers, owners, and operators. In the future, Buckwalter says, "There will be communication from the infrastructure to civil engineers, and there will also be inanimate-object-to -inanimate object communication. They will share status with each other. Then all of a sudden, your infrastructure systems are [almost] living, because they communicate with each other and respond to each other.

"Some of our civil engineering techniques of measurement will go away because the measurements will be self-supported," Buckwalter says. "That's coming."

And soon, more sophisticated systems will do more than just transmit data. "If you add to that whatever you define artificial intelligence to be, starting with simple things like autonomous cars and growing into thinking machines that are much more sophisticated, that will have a huge impact on the infrastructure that we need to build, maintain, or change," Buckwalter points out.

Advances in machine learning will only add complexity. "It's a logical consequence that computers will be able to interface with one another and make some decisions that humans now make. Most people feel there will be something like that within a fifty-year timeline. So what decisions do we want machines to make?"

DECISION-MAKING isn't the only thing that AI could take over, according to David J. Odeh, P.E., S.E., F.ASCE, a structural engineer and principal of Odeh Engineers Inc., in North Providence, Rhode Island, and an expert in design automation and such visualization technologies as virtual reality and augmented reality. Odeh was also part of the team that advised ASCE on this project. "Some aspects of design are partly automated today and can be further automated by artificial intelligence," he predicts. "And when you combine that technology with the computer modeling tools we have today, you can have very powerful engines that can be very disruptive in the design of infrastructure."

And if automated design functions can be linked seamlessly with automated construction technologies, the result could be truly transformative. Odeh predicts "the direct linking of design automation tools with construction and fabrication technology—things like computer-controlled fabrication equipment, robotic construction equipment, and automated robotic devices that construct pieces and parts of infrastructure and then assemble them together in the field."

This would mark the next step in the current trend toward factory-built infrastructure components. "We're already seeing advances in the modularization of construction," Odeh says. "Buildings can be constructed in factories in a controlled environment, much like ships and automobiles. That gives us great productivity gains. If they are advanced to the point where they become more commonplace and usable, that combination can be disruptive to the industry."

If that happens, many might question if there will still be roles for civil engineers and builders at all. The answer is yes, but those roles may be radically different than what they are today. "It's the same story that we've had with technology for decades," Odeh says. "New technologies become available that either automate or supplant things previously done by people. Thirty or forty years ago, if you went into an engineering office, you'd see tens of employees at drafting tables, drawing plans. If you went into the same office today, those drafting tables would be gone because of the advent of CAD [computer-aided design] and BIM [building information modeling]. But what was created was a whole new generation of technology professionals who became experts at using CAD and BIM and at making them more efficient, which has improved the practice of design."

The role of civil engineers will evolve, he points out. "Yes, some roles may go away, but engineers have the opportunity to participate in new fields that are going to become more important. We don't know what all of those will be, but by doing something like the Future World Vision, we can start to map out a picture of what that future might look like, so [that] we can start preparing our young engineers now for those possibilities."

Moreover, robotic construction techniques can make construction, an inherently dangerous profession, safer. One can envision drones delivering materials to the tops of skyscrapers under construction or building an arch bridge over a canyon using 3-D printing equipment. Already, companies like suitX, a division of U.S. Bionics, are developing human "exoskeletons" that people can wear to enhance their strength, agility, and safety on the job—and the company is targeting the construction market. Haptics, which allows humans to use the movements of their bodies to control the actions of robotic machines remotely, could eventually be used to enable crews to build infrastructure in dangerous conditions without actually endangering themselves.

And those automated construction techniques may well be influenced by advances in building materials. "We talk a lot in the office and in the field about how the formulas we use, the science for them, changes at a much slower pace than the new materials themselves," says Jesse Taylor Gormley, P.E., ENV SP, M.ASCE, a staff engineer with Pennoni, a Philadelphia-based engineering consultancy, and a member of ASCE's advisory team for the Future World Vision project. And if the use of 3-D printing in construction increases, the nature of the materials that builders use

IF THE USE OF 3-D PRINTING IN CONSTRUCTION INCREASES, THE NATURE OF THE MATERIALS THAT BUILDERS USE MAY CHANGE. "THE MATERIALS WE ARE ABLE TO 3-D-PRINT WITH COULD HAVE A HUGE IMPACT ON CONSTRUCTION." —GORMLEY

may change, he points out. "The materials we are able to 3-D-print with could have a huge impact on construction," he says.

Over the past decade there have even been significant advances in traditional building materials. "I read about a new steel alloy that can go into its plastic deformation range and then recover," Gormley says. "That should cause long-term deformation, but somehow it doesn't. 'Wow' was my reaction."

Other materials are advancing as well. "We're doing amazing things with self-healing concrete," Gormley says.

Better, more durable materials can go a long way toward helping build more sustainable, resilient communities, which is likely to be required in the future as the environment changes.

ANOTHER TREND that is generating a great deal of attention from many leaders inside and outside the engineering world is transportation automation. Whether it's vehicle-to-infrastructure communication, AVs for personal or mass transit use, or hyperloop-style pod tunnels, innovation in how people and goods will be moved efficiently is on the rise. And as those changes continue, there will be impacts on everything from the kinds of roads and bridges that need to be designed to the kinds of places

The Four Scenarios

The report *Future World Vision: Infrastructure Reimagined,* which serves as the first phase of ASCE's Future World Vision project, describes and examines four possible future scenarios that can serve as a starting point to guide engineers in an intense analysis of how trends in climate change, alternative energy, high-tech construction, autonomous vehicles (AVs), smart cities, and public funding might develop over 10, 25, and 50 years—and how those trends might interact with one another to transform the role of civil engineers. A full description of these scenarios can be found in the report (futureworldvision.org). Here is a brief summary of each scenario.

SCENARIO 1: Resilient Cities

In this scenario, climate change begins to have a significant deleterious effect on cities, especially those along the coasts. At first, reaction to these changes is slow, but eventually, as the impacts increase, demand for long-term investments in protective measures increases, and governments are forced to respond. Smarter and more resilient infrastructure is produced, but the cost of waiting is high.

In this scenario, in 10 years' time, intense droughts and extreme storms occur more often, reducing agricultural productivity. Governments and companies begin to invest more resources into material-science research, in the hope that more resilient materials might be used to efficiently mitigate climate change impacts. Interest in using public–private collaborations to upgrade city infrastructure so that it can withstand climate change impacts grows.

By 25 years from now, droughts and agricultural failures are more widespread, putting a significant strain on food and water supplies. Sea-level increases threaten the very existence of coastal communities. At the same time, rural populations begin migrating to cities in growing numbers, increasing stresses on urban services. Support for energy-efficient, carbon-neutral solutions intensifies.

By 50 years out, the public and private sectors have finally united to create adaptation measures to the harsh environmental changes. New materials help buildings and infrastructure withstand extreme weather events, and smart-city technology, plus autonomous public transit, helps meet the needs of a growing urban population.

The report states that in the Resilient City scenario, engineers will be called on to solve problems and design infrastructure related to encroaching seawater, extreme storms, and growing urban populations. They will need to work with experts who design safe digital controls for potable water networks, and water infrastructure that can respond to changing demands. They will need to elevate roads, bridges, ports, and other infrastructure that is vulnerable to increases in sea levels and build or improve seawalls, levees, and other barriers.

The use of new building materials and techniques will be required, and this will entail higher up-front costs. Engineers will need to embrace life-cycle cost analysis and become adept at explaining its value to stakeholders. Engineers will need to lead the charge to sustainability and engage in collaborative research into carbon sequestration, negative emissions technology, and alternative energy advancements.

A resilient city might be one that floats: Bjarke Ingels, the founder of the Danish architecture firm Bjarke Ingels Group (BIG), recently released a rendering of a prototypical floating city made out of mass timber and bamboo that would resist floods, earthquakes, and tsunamis.

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SCENARIO 2: Progressive Megacities

In this scenario, the global trend of urbanization accelerates; megacities form and grow. Governments adapt swiftly and efficiently, using technology and efficient urban planning to their advantage. City services are personalized through the use of advanced technologies. City drivers give up their cars in favor of ubiquitous, autonomously operated public transit. The infrastructure previously devoted to driving and parking cars is repurposed for housing and green space. Automated construction processes and strong materials boost construction in the cities, which are fueled entirely by no-emission energy generated by nuclear fusion.

In 10 years' time, the public and private sectors form effective partnerships to develop housing, food, and other support services for the megacities. Smart-city technology is being used to manage scarce resources and maximize city services. Flooding is minimized by infrastructure built using high-tech construction methods and advanced materials. Technology for AV advances.

By the time 25 years have passed, public–private partnerships (P3s) are financing autonomous public transit and nuclear fusion facilities. Such changes to the climate as higher temperatures and variable rainfalls impact agriculture and water supplies, though flooding is minimized. Smart-city technology is still being used to maximize city resources.

By 50 years out, the megacities each have populations of 50 million or more. Energy concerns are negligible, thanks to fusion, which is inexpensive and clean. Advances in construction technologies allow for inexpensive, fast, efficient construction, which helps the cities adapt to population growth.

The focus of this scenario is the continuation of the current trend in population migration to cities, resulting in megacities. Governments spend more on research into new power-generation methods, autonomous transit, advanced construction materials and methods, and smart-city technology. The report envisions the use of robots and augmented reality visualization tools as commonplace, and this will improve worker safety.

Given that increase in automation, engineering firms will need to rethink the best use of their human resources, the report points out. Preparing designs for the new spaces opened up by the demolition of cars-only infrastructure to make way for automated vehicles and pedestrians is one option.

The connection of infrastructure, buildings, and transportation via the "internet of things" (IoT) will make the dangers of hacking more real, requiring civil engineers to take a systems integration approach and to collaborate with professionals in other fields to ensure that the world's infrastructure remains secure.

SCENARIO 3: Dispersed Settlements

In this scenario, urban life degrades to the point at which many residents leave the cities for relatively isolated but somewhat self-sustaining enclaves. Using solar technology, these settlements generate their own energy, and residents commute virtually to their jobs—but few other technological advancements take place. Cities are stagnant and unsafe.

By 10 years from now, critical infrastructure remains unrepaired and unmaintained, and safety is a widespread issue. Government is unresponsive, and cities are overburdened and inefficient, leading many to leave. Research into alternative energy continues, and energy storage becomes commercialized.

Within 25 years, local groups build remote settlements, each with its own government. Solar energy and technologies for storing that energy enable those in the settlements to live "off the grid." Private telecommunications firms build new infrastructure on top of old and resolve security issues for those networks, enabling mass telecommuting by settlement residents to jobs in the cities. Climate change effects turn out to be more limited than originally predicted.

Within 50 years, the new settlements are more evenly distributed and governed effectively. Solar panels are embedded in all sorts of infrastructure, making energy cheap and clean. Some smart-city technologies are being used within the settlements.

In this scenario, the report envisions the opposite of megacities;

civil engineers will design smaller, more isolated minicities. Because of the ubiquity of telecommuting and the reliance on distributed energy networks, cybersecurity will become a critical concern. Engineers will need to plan smaller communities with sustainable, affordable, and safe infrastructure.

SCENARIO 4:
Unequal Enclaves

In this final scenario from the report, governments fail utterly. There is a mass migration of those who can afford to leave the cities toward new settlements, leaving only those less fortunate behind. Cybersecurity is a significant problem, derailing attempts at telecommuting; instead, those with the means to do so commute long distances in automated vehicles to jobs in the cities. Urban centers are battered by the effects of climate change and a lack of investment. Privatization increases, and with it, some design, construction, and smart-city innovations are on the rise—but the benefits accrue primarily to the wealthy.

Within 10 years, cities are experiencing increased flooding and other natural disasters as well as cyberattacks, and governments are unable to respond. Automated vehicles exist but are expensive, leading the wealthy to begin to leave the cities. With fewer residents to pay taxes, city governments become unable to keep up with aging infrastructure and climate change impacts.

Within 25 years, the wealthy are ensconced in their settlements, which are built by high-tech construction methods, and residents continue to commute to declining cities. Research begins on alternative energy methods. Cash-strapped city governments rely on private firms to provide services that government once provided, with mixed results.

Within 50 years, the settlements feature modern infrastructure, solar energy, and smart-city technologies. The cities offer services that cater to the wealthy commuters, and some of those services benefit poorer residents as well. As the effects of climate change continue, efforts at resiliency are aimed only at those areas where they make the most economic sense.

This scenario is arguably the most challenging, focusing on increases in the trend toward economic and social inequality. The report envisions limited government funding and increases in natural and digital disasters, which together force cities to make very difficult decisions. Cities must prioritize their spending on recovery and resiliency efforts as critical infrastructure ages past its useful lifetime.

The role of civil engineers in this scenario is to advocate for the equitable distribution of resources, for example, pointing out the advantages of AV infrastructure over traditional transportation modes, or the money saved over the long term by smart-city technologies. Civil engineers could also develop the transportation infrastructure that leads from the enclaves to the cities and the systems that would enable AVs and human-driven cars to coexist.

Civil engineers would also need to collaborate with cybersecurity experts, climate risk experts, robotics designers, and city planners to ensure that all these systems work together as efficiently as possible. And they would need to develop expertise in automated construction and repair techniques, energy and water efficiency, and nontraditional power-generation methods and the infrastructure that supports them. —LAS

where people will live. "If you go back a handful [of] years, people were muttering about the hyperloop, but then that discussion died down," Gormley notes. "Then autonomous vehicles arose, and they seemed to bulldoze everything forward. Now, all of a sudden, I'm hearing there is a plan to have a Philadelphia-to-Pittsburgh hyperloop connection in five to ten years! And that it will make that trip in half an hour. That changes your whole commuting perspective."

Such shifts in transportation methods could have acute impacts on civil design. "If autonomous vehicles become dominant in the future and that is combined with new forms of mass transit like maglev trains and hyperloops, that will fundamentally impact the way cities are built," Odeh says. "It will change even something as fundamental as how streets, sidewalks, and bridges will be designed."

WHEN IT COMES TO TRENDS that might have the greatest overarching implications, perhaps none is so challenging to contemplate as climate change. Temperature changes, sea-level increases, droughts and floods, worsening storms, melting permafrost, rising groundwater levels, and a host of other impacts are likely to affect everything from food and water supplies to wastewater and stormwater systems, transportation, energy, and more. "Look at where South Africa was just a few years ago, when they were approaching running out of potable water for a whole city," Gormley notes. "That's a very real scenario."

The United States is better prepared for a water shortage, he says—for now. "But not if we let our infrastructure continue to deteriorate."

No one knows for certain exactly how climate change impacts will manifest over the long term, but many cities and towns are feeling the effects now and planning for more. "I think the mind-set has shifted on climate change," Gormley says. "It used to be very much in the realm of mitigation: What can we do to prevent these changes from happening? As we come to accept that these changes are already happening—and at a rapid pace—the strategy increasingly includes adaptation."

And for that, funding will be needed. Whether that funding comes from governments, private entities, or some combination of both is a topic tackled in various ways in the four scenarios. "Some of them illustrate a future in which we find a way to make public financing of infrastructure reliable and effective and regulations are enhanced to help us," Odeh says. "Then there are definitely scenarios in which government financing continues to be challenged, as it is today, and the role of private financing becomes more important and actually supplants much of the public financing. That is a different type of world."

Engineers would need to continue to advocate, as they do now, for adequate public funding. "ASCE believes very strongly that public financing is critical to maintaining and upgrading our infrastructure for the future," Odeh says.

If autonomous cars become ubiquitous in the future, there would be no need to leave them in urban parking spots all day. Parking garages or the land they occupy could be repurposed for offices, residences, and green spaces.

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PERHAPS ONE OF THE most fundamental shifts that these converging trends, and their interactions with one another, are likely to create is a new type of civil engineer—one who is expert at data analysis, adept at collaborating and coordinating with professionals from a wide range of other professions, and able to see how systems interact with other systems to create something larger and more complex—an approach known as systems engineering. "Civil engineers will have to become masters of systems engineering and systems integration," Buckwalter says. "It's a very converged world that's coming. Systems interface with one another and work together. A civil engineer might not just be talking to a structural or a mechanical engineer but to a chemist and a biologist. We see the early stages of it already."

Integrating infrastructure systems together and thinking through how they will affect one another is an important role for civil engineers. "It's far more complex than what they have done before, and someone has to do it," Buckwalter points out. "If civil engineers don't, someone else will rise up to fill the gap. But civil engineers are logically the right ones to do that."

Odeh couldn't agree more. "In order to be effective in the future world, our engineering and construction professionals need to become masters of how systems come together and interact with each other," he explains. "We can't limit our study and practices to one focused area." And that ability to integrate systems together can't be automated, he points out. "That's what makes engineers so important—their ability to put all the pieces together."

Odeh sees the idea of system integration as "an opportunity for civil engineers to be leaders, not just in what we do for a living but in helping to plan what the world might look like in the future.

"We have to engage in a dialogue with people outside our traditional sphere if we want to be leaders: government strategists, planners, large corporations, futurists, technologists—even artists and other creative professionals who have a vision of what the world could be like," Odeh says. "We want to have a seat at that table because it's critical to our profession and its future." CE

EXPERIENCE THE FUTURE AT ASCE'S ANNUAL MEETING

ASCE will present an immersive experience at its annual convention that will introduce members to one of the virtual worlds that is being created as part of the next phase of the Future World Vision project. Learn more about "The Floating City" in Miami, October 10–13. [asceconvention.org]

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