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Animal infrastructure

Plus
35 Innovators Under 35

Death to the smart city

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On my street, out on the western edge of what passes for suburbs in San Francisco, there are cameras just about everywhere you look.

I'm part of this privatized surveillance system. An aging Dropcam peers out of my front window. It's not clear I even need it: across the street, three other cameras look back. These little sentries are aimed at the street, but they also have unblinking views into my living room. Were someone to try to burglarize my home, one of those cameras would likely capture it.

In fact, when my car was broken into recently, I was able to get footage of the crime from my next-door neighbor. Had it happened on the opposite side of my home, I could have gotten it from my other neighbor, who has a Ring doorbell. Really, it could have been parked just about anywhere on my street, where more than 20 cameras of various types stare out from windows, door frames, eaves, and entryways. These are just the ones I can easily see.

(One Ring camera in my neighborhood at least has the decency to announce itself. Every time I walk past with my dog, a speaker declares, "You are being recorded!" Thanks? I guess?)

When we talk about the cameras that riddle London or Hong Kong or Marseille, we're typically referring to gear that's owned and operated by the government. The modern city is a surveillance device. It can track your movements via your license plate, your cell phone, your face.

But go to any city or suburb in the United States and there's a different type of surveillance happening, one powered by networks of privately owned cameras sold directly to citizens by the likes of Amazon and Alphabet. There are doorbell cameras, wildlife cameras, and just garden-variety security cameras.

Privacy critics talk with some degree of alarm about the surveillance state and surveillance capitalism, but this is a surveillance culture we have chosen to opt into. Journalists and advocates have been decrying the erosion of our privacy for years now. There have been endless stories about the ways Ring encroaches on privacy—among others, by working directly with local police departments.

But we keep buying the cameras.

And we're not just recording; we're broadcasting. Social apps have muscled into neighborhood watch territory in recent years. You can use Ring's Neighbors app to share the crimes you've captured with the world—or at least your neighborhood. Nextdoor is similarly often a hotbed of package theft videos, futile documentation for prosecutions that will likely never take place. The Citizen app, a real-time location-based "personal safety network" that fires off notifications about emergency events, encourages people to go out and *actively record and livestream incidents* on their phones.

While these private cameras are now often used to document evidence of crimes, there is little in the way of proof that they have done anything to make our neighborhoods safer (see page 9).

Mat Honan
is editor in
chief of
MIT Technology
Review

Independently of local governments, we have built our neighborhoods into panopticons: everyone watching everything, all the time.

This isn't inevitable—my neighbors and I have chosen to line our street with cameras. Cities are, at the end of the day, an accumulation of the choices millions of us have made.

This issue of the magazine is about the choices we face.

Just as we can choose to fill our cities with cameras, we can also choose to push back against surveillance (page 28). We can choose to preserve the corner-store culture in India, which is under siege from a wave of grocery delivery apps (page 58). We can prioritize cars, or we can make cities friendlier to wild animals by building experimental bridges that allow them safe passage over highways (page 50). We can build more charging stations for electric vehicles (page 20) and build homes more efficiently (page 38). We can plant more trees (page 13).

Cities are choices, big and little, made individually and collectively. We hope this issue helps you to choose wisely.

Correction: The article "How Bitcoin mining devastated this New York town," featured in our May/June 2022 issue, said that each Bitcoin transaction consumes 1,173 kilowatts. The correct unit is kilowatt-hours.

ROBYN KESSLER

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MIT Technology Review Insights

The Green Future Index 2022

The Green Future Index 2022 is the second edition of the comparative ranking of 76 nations and territories on their ability to develop a sustainable, low-carbon future. It measures the degree to which economies are pivoting toward clean energy, industry, agriculture, and society through investment in renewables, innovation, and green policy.

The index ranks the "green" performance of countries and territories across five pillars:

- Carbon emissions
- Energy transition
- Green society
- Clean innovation
- Climate policy

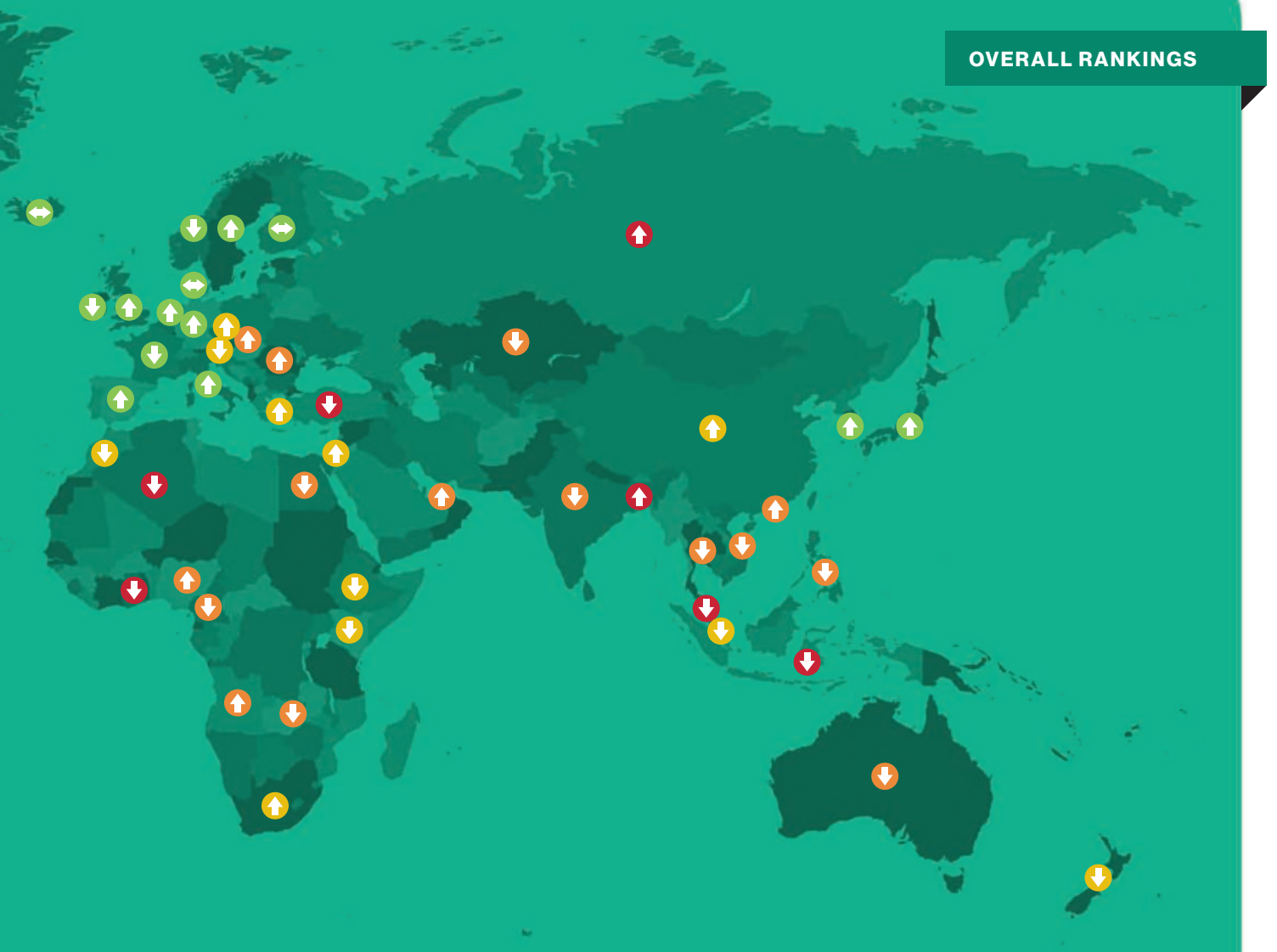
Overall top 10

Rank 2022	Rank 2021	Territory	Score
1	1	Iceland	6.9
2	2	Denmark	6.6
3	10	Netherlands	6.4
4	17	United Kingdom	6.3
5	3	Norway	6.2
6	6	Finland	6.2
7	4	France	6.1
8	11	Germany	6.1
9	12	Sweden	6.1
10	31	South Korea	6.0

- Nearly 36% of UK's power came from clean sources in the third quarter of 2021, with the aim of reaching 100% by 2035.
- In January 2022, Finland took on €217 million in pre-financing, which will partially go to efforts to decarbonize the energy sector.
- South Korea and Japan have seen significant rises in their innovation scores, thanks to their world-beating green IP contributions.

Experience the interactive index, view the data, and download the full report at: technologyreview.com/gfi

OVERALL RANKINGS



Green society top 10

Rank 2022	Rank 2021	Territory	Score
1	3	South Korea	7.0
2	1	Singapore	6.8
3	2	Ireland	6.8
4	8	Germany	6.5
5	7	United States	6.5
6	17	Iceland	6.4
7	4	Taiwan	6.4
8	5	Philippines	6.3
9	6	Czech Republic	6.3
10	13	Canada	6.2

- This pillar ranks each country on how well it is pivoting toward clean energy, industry, agriculture, and society.
- Leaders in the green society pillar are over-represented by nations that have incorporated strong civil planning and societal development goals into policy, regulation, and public infrastructure spending.
- Singapore and South Korea are the world's best-ranked recycling economies.

While the index ranks a total of 76 countries and territories, this map only features a selection of the overall data.

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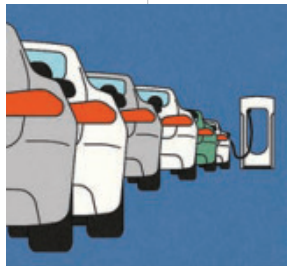
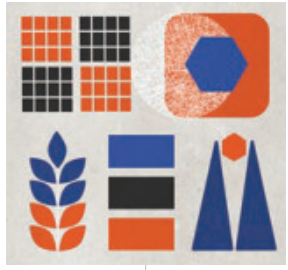
"What is the city but the people?"
—WILLIAM SHAKESPEARE





Front

Death to the smart city

Back

Cover illustration by Beto Fame

The Download

The data center on the third floor

In pursuit of speed, more and more server farms are winding their way into cities.

By Michael Waters

In 1930, the telegraph giant Western Union put the finishing touches on its new crown jewel: a 24-story art deco building located at 60 Hudson Street in lower Manhattan. Soon after, over a million telegraphs each day shuttled in and out, carried by a network of cables, pneumatic tubes, and 30 employees in roller skates who sped across the building's linoleum floors.

Today, much of it is home to vast halls of computer servers. It is a physical manifestation of the cloud: when you stream a TV show, upload a file to Dropbox, or visit a website, chances are you will be relying on the processing power of a data center just like it. Hundreds of companies rent out space in 60 Hudson Street, and it is one of a growing number of buildings, sometimes called "colocation centers" in industry parlance, that host data centers in or near major population centers.

When you think of data centers, you probably picture a giant server farm in a rural area where electricity is cheap and tax breaks are plentiful. Big tech companies like Google, Amazon Web Services, Microsoft, and Meta have placed millions of square feet worth of server space in places like Northern Virginia or Hillsboro, Oregon. But now, to reduce lag times, companies are increasingly weaving nodes in their network into the fabric of cities. The One Wilshire building in Los Angeles, for example, formerly home to a network of law offices, now oversees one-third of all internet traffic between the US and Asia.

To the uninitiated, these urban physical internet nodes probably don't look like much at all. And that's by design. Equinix, the largest owner of colocation data centers with 10.9% of the world market, operates data centers that generally aren't supposed to draw attention to themselves. In Dallas, the company owns a sprawling industrial building just outside the city center that doubles as a data center hub and the headquarters of a for-profit college. In Tokyo, the operation is largely conducted

The Western Union Building, 60 Hudson Street, c. 1931.

LIBRARY OF CONGRESS

on various floors within the city's sea of skyscrapers, "so you wouldn't even know it's there," says Jim Poole, the company's vice president of business development. In Sydney, Australia, Equinix is building a new data center in an expressionist style not unlike that of the city's famed opera house. And around one of its facilities in Amsterdam, Equinix built a moat—less for security, Poole says, than to make the building match its surroundings, given that Amsterdam is a city of canals. "For the most part, people actually do try to make their buildings fit the environment," he says, adding that sometimes local regulators even require it.

The demand for such facilities, especially in urban centers, is growing quickly: last year, spending on colocation data centers jumped 11.7%. The biggest cloud companies are not far behind. Amazon Web Services has been pushing shrunk-down data centers, which it calls Local Zones, close to major population areas; so far, it has placed them in 32 cities across the US. The trend has even piqued the interest of Walmart, which may soon start renting out sections of its superstores to host data centers for third-party companies.

One explanation for the flurry of demand, Poole says, is that consumers themselves have changed. As more of our lives have gone online, "people's tolerance for latency has continued to go down," he says. The main drivers are those applications where a delay in the milliseconds can prove critical: you might not notice a quarter-second lag on Netflix, but you certainly will if you are using an online sports betting app, trading stocks, or participating in a multiplayer game like Fortnite.

Companies like Google, Amazon, and Microsoft, for instance, are betting on cloud gaming, which involves streaming games over the internet without a console or a phone to provide processing power. But many popular games, such as first-person shooters, "require a lot of quick reaction times and therefore really fast connectivity," says Jabez Tan, the head of research at the firm Structure Research. And games like that will not function on a streaming service without the help of large numbers of data centers.

Or take the metaverse—the favorite, if sparingly sketched-out, new talking point of Nvidia, Meta (previously Facebook), and other tech giants. If a virtual-reality world is ever going to achieve mass appeal, it's going to need to mirror the immediacy of our own. That means intricately detailed graphics, nimble motion, and audio reactions with hardly a millisecond of buffering. All told, writes Raja Koduri, a senior VP at Intel, we need "several orders of magnitude more powerful computing capability" to make it possible.

It's this demand for computing power, Tan says, that has spurred the "decentralization" of data center networks: tech companies are looking around at their existing infrastructure and saying, "Hey, we're not able to give to people in Jakarta, or people in Manila, the same performance levels that people in Singapore [are] enjoying."

"It's almost like an accordion," says Pat Lynch, who studies data centers for the commercial real estate research firm CBRE. Data centers are still being built in places like rural Oregon. But now they are "expanding out."

The way these new data centers blend into the urban and suburban landscape of office buildings or custom warehouses or industrial parks is a double-edged sword. The approach might make sense from a security standpoint. It also spares people from looking at the eyesore of vast halls crammed with computer servers.

The downside of this invisibility, though, is that we aren't often forced to think about what all our internet use is costing us. Data centers account for 1.8% of all electricity use in the US and 0.5% of the country's greenhouse-gas emissions, according to a report last year—far from a negligible amount. Some strategies could help, such as reusing the heat that they produce in copious quantities. But getting to that point would require stepping back from the rush to build and truly intertwining data centers—with all the heat they generate, the energy they consume—into our existing urban ecosystems. ■

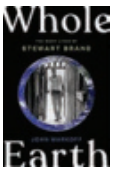
Michael Waters is a writer based in New York.

Book reviews

What a Mushroom Lives For: Matsutake and the Worlds They Make

By Michael J. Hathaway
Princeton Architectural Press, 2022

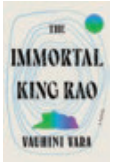
Human exceptionalism posits that only humans can use tools, feel pain, imagine the future, and communicate through language. But what would it mean to recognize a greater diversity of active world-making that extends into the realm of plants, fungi, bacteria, and others? Hathaway, an anthropologist, persuasively argues that fungi are neither passive nor inferior: they make choices, they collaborate, and they can help combat climate change and transform soil, economies, and consciousness. A book as mind-altering as psilocybin.



Whole Earth: The Many Lives of Stewart Brand

By John Markoff
Penguin Press, 2022

Brand, the creator of the seminal *Whole Earth Catalog* (1968), also served in the military, lives on a houseboat, supports nuclear power, and wants to bring back the woolly mammoth. Making a list in his personal journal of where he thought he'd failed, he includes "drugs, communes, spiritual practice, New Left politics, solar water heaters, domes, small farms, free schools, free sex, on and on." But if success, as technologists would have it, means one should fail early and often, Brand has hit the pinnacle.



The Immortal King Rao

By Vauhini Vara
W. W. Norton & Company, 2022

Vara's debut novel is set in an alternate reality in which a Board of Corporation rules by algorithm, and the former tech CEO (and the titular King Rao) behind it all has one final experiment left. Our narrator is his teenage daughter Athena Rao, who feels she must unravel her father's complicated past—and what it means for her future.

Can a community solve crime?

As trust in the police continues to erode, people are increasingly going online to seek justice.

By Sonia Faleiro

CARLY BECK

One evening last summer, my family was enjoying a picnic in the park near our house in London when two dogs attacked our blind 15-year-old Jack Russell terrier, Zoey. They pounced on her, locking their jaws. As my husband threw himself on the dogs, I begged the owner to intervene. He refused—until he realized I was calling the police. Only then did he restrain his animals, one of which had started to chase my four-year-old daughter. A few hours later Zoey was dead, leaving us devastated.

We felt even worse when the police didn't attempt to track down the owner of the killer dogs, despite having images from my phone to go on. In the eyes of the UK justice system, Zoey's killing was a low-level crime because an animal, rather than a human, had died. The realization galvanized us: if the police wouldn't find the culprits, then we would.

Increasingly, communities are turning to technology to help solve problems that the police are unable—or unwilling—to attend to. So that's what I did: I went online, joining an increasing number of people who are using local networks to solve crimes that have affected them, such as robberies, reckless driving, and even plant theft.

One in 10 posts on the neighbor-networking site Nextdoor is related to crime and policing matters. I had nearly 800 neighbors on that platform and was also in several neighborhood groups on Facebook, whose members totaled 74,000. In all, my description of the attack on Zoey was shared hundreds of times. By circulating information about it, my neighbors and I were participating in a ritual that is modern only in terms of the technology it now relies on.

In the UK, as in other places, collective action is filling a gap left by a diminishing police presence. A significant reason for this is that budget cuts have forced a decline of nearly 23% in the police workforce, according to Unison, the country's largest union. London's Metropolitan Police has been the worst affected, with over 3,000 jobs lost between 2012 and 2016. This includes 3,350 jobs for community support officers—a role created specifically to make the police more visible. These officers had been brought in to work with the community, says Menaal Munshey, a criminologist with the United Nations. "But because of the cuts, that link has been broken. And the community feels like it's on its own."

That frustration is likely why anonymous tipsters opted to reach out to me, a complete stranger, rather than go to the police. Previous appeals to the police had apparently fallen on deaf ears.

Of course, such information sharing isn't always a good thing. A study published last year by Dutch academics Ronald van Steden and Shanna Mehlbaum confirmed what is already observed: neighborhood groups have "undesirable social and moral by-products" such as discrimination, stigmatization, exclusion of strangers, and excessive social control. "If people are constantly encouraged to be aware of anything and anyone 'out-of-the-ordinary', such a process may slowly but surely open the doors for harsh surveillance practices to creep into people's normal lives. This, in turn, stimulates the erection of a digital pillory, a witch-hunt for (assumed) paedophiles, exclusive forms of 'stranger danger' and other potential for voyeuristic mob activism. It is not difficult to recognise that democratic values of openness, tolerance and mutual respect are at stake here."

The problems, when they do arise, aren't confined to any one neighborhood, city, or country, and they are often in response to cultural fissures that were already present. In India, for example, unfounded rumors that circulated on local WhatsApp groups in 2018 fed old fears of a specific kind of bogeyman that Indians have grown up hearing about: a *bacha chor*, a person who kidnaps children to harvest their organs. The rumors led to the murder of at least two dozen people in different parts of the country and forced WhatsApp to limit the number of times that users in India could forward a message. The challenge for

Nextdoor in the United States, meanwhile, is that it has become a magnet for racial profiling. In 2015, Nextdoor addressed the issue with changes that included asking users who mentioned race in their posts to provide additional details.

The reality is that the root causes of these crimes continue to go unaddressed. It isn't just police resources that need to be reassessed, but social welfare programs such as gang mediation, drug and alcohol treatment, and children's services, all of which have also fallen victim to governmental service cuts. And while neighborhood groups can have a positive impact on social cohesion, there is no proof that they actually reduce crime. Danielle Pyke, a police community support officer with the Met, says it's rare for Nextdoor users to provide information that leads to patrols, arrests, or drug busts.

When online groups do work, by mobilizing people to share information, they can be a success. Thanks to the information I gathered with the help of my community, my family and I were able to submit a dossier to the police, forcing them to act. The owner of the animals that mauled Zoey was charged with two counts of owning dangerously out-of-control dogs that had caused injuries, and he was ordered to appear in court in April.

Unfortunately, however, on the evening before the case went to trial, we received a call from the prosecuting lawyer informing us that she had no choice but to close the case because police had failed to submit the paperwork required. The failure of the Met to do basic admin, despite being given several months, denied my family our day in court and Zoey the justice she deserved. ■

Magic mirrors

Gender-bending filters can be a revelation to people questioning their gender identity.

By Elizabeth Anne Brown

Every few months, a social media giant drops a new beauty filter with gender-tuning capabilities. TikTok's "Bearded Cutie" gives you heavy brows and scruffy facial hair; the feminizing version of Snapchat's "My Twin" lens smooths skin to porcelain and adds subtle glam makeup. For many, these filters are a lark, quickly forgotten once they stop trending. But others find themselves drifting back to the apps again and again, staring at their gender-bended reflection. Something, they feel, has suddenly crystallized.

FaceApp in action

Oliver Haimson, an assistant professor at the University of Michigan who studies transgender identity and experiences online, says that for trans, gender-nonconforming, or gender-curious folk, filters can be a way to play with gender expression without the investment and skill that makeup requires or the time, hormones, and luck it takes to grow facial hair. He explains that filters are an important and widely used tool for identity exploration.

Some trans people credit filters with finally "cracking their egg"—a rite of passage in the trans community when someone admits to themself that their gender identity is different from what was assigned at birth. "The Snapchat girl filter was the final straw in dropping a decade's worth of repression," says Josie, a trans woman in her early 30s from Cincinnati. "[I] saw something that looked more 'me' than anything in a mirror, and I couldn't go back."

Filters can also provide a much-needed dose of gender euphoria, the rush of joy a trans person feels when their external appearance aligns with their gender identity. Others use filters to help map potential physical transitions. "The filters on FaceApp showed me how little my face needed to change in order to present more feminine," says Etta Lanum, a 32-year-old from the Seattle area. "It demonstrated how a change in eyebrows and facial hair alone could get me where I needed to be."

Using these filters has its pitfalls as well. Some trans people feel that the technology sets them up for disappointment and dysphoria, showing "results" that are physically impossible to achieve even with plastic surgery, artful makeup, or hormone therapy. But given that an ever increasing percentage of our lives is lived online, who's to say the filtered version isn't the "real" you? ■

Elizabeth Anne Brown is a science journalist based in Copenhagen, Denmark.

GAVIN LEE LEWIS

What one tree can('t) do

By Susie Cagle

Trees are one of the most effective and readily available carbon capture tools we have but there isn't enough land for all the trees we'd need.

Aging clocks aim to predict how long you'll live

These clocks promise to measure biological age and help identify anti-aging drugs, but there are lingering questions over their accuracy.

By Jessica Hamzelou

Age is much more than the number of birthdays you've clocked. Stress, sleep, and diet all influence how our organs cope with the wear and tear of everyday life. Factors like these might make you age faster or slower than people born on the same day. That means your biological age could be quite different from your chronological age—the number of years you've been alive.

Your biological age is likely a better reflection of your physical health and even your own mortality than your chronological age. But calculating it isn't nearly as straightforward. Scientists have spent the last decade developing tools called aging clocks that assess markers in your body to reveal your biological age.

The big idea behind aging clocks is that they'll essentially indicate how much your organs have degraded, and thus predict how many healthy years you have left. Among the hundreds of aging clocks developed in the last decade, though, accuracy varies widely. And researchers are still grappling with a vital question: What does it mean to be biologically young?

Most aging clocks estimate a person's biological age based on patterns of epigenetic markers—specifically, chemical tags called methyl groups that are layered onto DNA and affect how genes are expressed. The pattern of this methylation across thousands of sites on DNA seems to change as we age, although it's not clear why. Some clocks promise to predict life span by estimating how a person's body has aged, while others act more like a speedometer, tracking the pace of aging. Clocks have been developed for specific organs of the body, and for multiple animal species.

Proponents of aging clocks are already trying to use them to show that anti-aging interventions can make individuals biologically younger. But we don't yet know enough about clocks, or what they tell us, to make such claims.

ANDREA D'AQUINO

Measuring age

Most aging clocks are designed to predict chronological age. But Morgan Levine at the Yale School of Medicine in New Haven, Connecticut, says: "To me, that's not the goal. We can ask someone how old they are."

In 2018, Levine and her colleagues, along with Steve Horvath, a biostatistician at the University of California, Los Angeles, developed a clock based on nine biomarkers, including blood levels of glucose and white blood cells, as well as a person's age in years. They used data collected from thousands of people in the US as part of a different study, which followed the participants for years. The resulting clock, called DNAm PhenoAge, is better at estimating biological age than clocks based solely on chronological age, says Levine.

A one-year increase in what Levine calls "phenotypic" age, according to the clock, is associated with a 9% increase in death from any cause, as well as an increased risk of dying from cancer, diabetes, or heart disease. If your biological age is higher than your chronological age, it's fair to assume you're aging faster than average, Levine says.

But that might not be the case, says Daniel Belsky at the Columbia University Mailman School of Public Health in New York City. He says there are many reasons why biological age might exceed a person's years. Belsky and his colleagues have developed a tool to more accurately measure the rate of biological aging, based on work that tracked the health outcomes of 954 volunteers at four ages between their mid-20s and mid-40s. The researchers looked at biomarkers believed to indicate how well various organs are functioning, as well as others linked to general health. Then they developed an epigenetic "speedometer" to predict how these values would change over time.

Noisy clocks

Others have used changes in their results to infer that their rate of aging has slowed,

usually after they started taking a supplement. But in many cases, the change can be explained by the fact that many epigenetic aging clocks are "noisy"—prone to random errors that distort their results.

The problem is that at each point on the DNA where methyl groups attach, very slight changes take place over time. These subtle changes can be magnified by errors in methylation estimates. It ends up being a huge problem, says Levine, and results can wind up being off by decades. To solve this problem, they are "breaking apart" existing clocks and comparing them. They hope to work out what different clocks are measuring, and how to build better ones in the future.

While Levine and her colleagues work to get rid of the noise, she's also trying to understand what aging clocks actually tell us. What does it really mean to have a lower biological age? And how can this knowledge be applied?

While aging clocks may be a good indicator of your overall health, they simply aren't accurate enough to count on in most cases. "I think they haven't realized their full potential yet," says Levine.

That potential could lie in health checks, says Horvath: clocks could be used alongside blood pressure and cholesterol tests to help people understand how fit they are, or whether they are at risk of disease.

"Epigenetic clocks will never replace clinical markers, [but] the clocks add value to them," he says. "I think five years from now we will have human-blood-based clocks that are so valuable that they could be used [clinically]." In the meantime, eating a healthy diet, avoiding smoking, and getting enough exercise remain some of the best ways to stave off aging. We don't need new aging clocks to prove that those strategies can help keep us well. *Read the full story at www.technologyreview.com.* ■

These plastic batteries could help store renewable energy on the grid

Startup PolyJoule wants to expand grid storage beyond lithium batteries.

By Casey Crownhart

A new type of battery made from electrically conductive polymers—basically plastic—could help make energy storage on the grid cheaper and more durable, enabling a greater use of renewable power.

The batteries, made by Boston-based startup PolyJoule, could offer a less expensive and longer-lasting alternative to lithium-ion batteries for storing electricity from intermittent sources like wind and solar.

The company is now revealing its first products. PolyJoule has built over 18,000 cells and installed a small pilot project using inexpensive, widely available materials. The conductive polymers that PolyJoule uses in its electrodes replace the lithium and lead typically found in batteries. By using materials that can be easily created with widely available industrial chemicals, PolyJoule avoids the supply squeeze facing materials like lithium.

PolyJoule was started by MIT professors Tim Swager and Ian Hunter, who found that conductive polymers ticked some key boxes for energy storage. They can hold a charge for a long time and charge up quickly. They are also efficient, meaning they store a large fraction of the electricity that flows into them. As plastics, the materials are also relatively cheap to produce and sturdy, holding up to the swelling and contracting that happens in a battery as it charges and discharges.

One major drawback is energy density. The battery packs are two to five times larger than a lithium-ion system of similar capacity, so the company decided that its technology would be better suited for stationary applications like grid storage than in electronics or cars, says PolyJoule CEO Eli Paster. But unlike the lithium-ion batteries used for that purpose now, PolyJoule's don't require any active temperature control systems to make sure they don't overheat or catch fire, he adds. "We want to make a really robust, low-cost battery that just goes everywhere. You can slap it anywhere and you don't have to worry about it," Paster says.

Some research points to $20 per kilowatt-hour of storage as a long-term target that would help us reach 100% adoption of renewable energy. It's a milestone that other alternative grid-storage batteries are focused on. Form Energy, which produces iron-air batteries, says it can reach that goal in the coming decades.

PolyJoule may not be able to get costs that low, Paster acknowledges. It's currently targeting $65 per kilowatt-hour of storage for its systems, reasoning that industrial customers and power utilities may be willing to pay that price because the products should last longer and be easier and cheaper to maintain. The company has focused on building a technology that's simple to manufacture. It employs a water-based manufacturing chemistry and uses commercially available machines to assemble its battery cells, so it doesn't need the specialized conditions sometimes required in battery manufacturing.

It's still unclear what battery chemistry will win out in grid storage. But PolyJoule's plastics mean a new option has emerged. ■

London walking

The city is taking a more pedestrian-friendly approach to the streets.

By Rachael Revesz

For pedestrians, walking in a city can be a frenetic and stressful experience. Crossings puncture the route. Parked cars block the view; curbs may have to be navigated. The city is an obstacle course.

Transport for London (TfL), the public body behind transport services in the British capital, has cottoned onto this, recently piloting new rules at 18 crossings around the city. Instead of waiting for the "green man" as a signal to cross the road, pedestrians will encounter green as the default setting when they approach these crossings. The light changes to red only when the sensor detects an approaching vehicle.

This "pedestrian priority" approach is a first in the UK, and after a trial of nine months, the data is encouraging: there is virtually no impact on traffic, and pedestrians save a total of 1.3 hours a day at the average crossing and are 13% more likely to comply with traffic signals.

Compliance can help keep people safe from a very real risk: 868 pedestrians were killed or seriously injured in 2020 in London alone. That was a steep drop from 1,350 in 2019, most likely thanks to covid lockdowns and a decrease in the number of people driving to work. But London is aspiring to match Oslo or Helsinki, where not a single pedestrian was killed in 2019. To achieve "Vision Zero," TfL is reducing the dominance and speed of motor traffic by adding cycle lanes, closing roads to cars, and building pedestrian infrastructure. For example, it delivered 77 new or improved pedestrian crossings between 2016 and 2020, and it reviews the signal timing at more than 1,000 crossings every year.

Op-Ed

There are many ways for cities to be "smart"

A singular focus on high tech will dilute the vibrancy of our cities and limit their potential.

By Riad Meddeb and Calum Handforth

The term "smart cities" originated as a marketing strategy for large IT vendors. It has now become synonymous with urban uses of technology, particularly advanced and emerging technologies. But cities are more than 5G, big data, driverless vehicles, and AI. They are crucial drivers of opportunity, prosperity, and progress. They support those displaced by war and crisis and generate 80% of global GDP. More than 68% of the world's population will live in cities by 2050—2.5 billion more people than do now. And with over 90% of urban areas located on coasts, cities are on the front lines of climate change.

A focus on building "smart cities" risks turning cities into technology projects (see Karrie Jacobs's story on page 44). We talk about "users" rather than people. Monthly and "daily active" numbers instead of residents. Stakeholders and subscribers instead of citizens. This also risks a transactional—and limiting—approach to city improvement, focusing on immediate returns on investment or achievements that can be distilled into KPIs.

Truly smart cities recognize the ambiguity of lives and livelihoods, and they are driven by outcomes beyond the implementation of "solutions." They are defined by their residents' talents, relationships, and sense of ownership—not by the technology that is deployed there.

This more expansive concept of what a smart city is encompasses a wide range of urban innovations. Singapore, which is exploring high-tech approaches such as drone deliveries and virtual-reality modeling, is one type of smart city. Curitiba, Brazil—a pioneer of the bus rapid transit system—is another. Harare, the capital of Zimbabwe, with its passively cooled shopping center designed in 1996, is a smart city, as are the "sponge cities" across China that use nature-based solutions to manage rainfall and floodwater.

Where technology can play a role, it must be applied thoughtfully and holistically—taking into account the needs, realities, and aspirations of city residents. Guatemala City, in collaboration with our country office team at the UN Development Programme, is using this approach to improve how city infrastructure—including parks and lighting—is managed. The city is standardizing materials and designs to reduce costs and labor, and streamlining approval and allocation processes to increase the speed and quality of repairs and maintenance. Everything is driven by the needs of its citizens. Elsewhere in Latin America, cities are going beyond quantitative variables to take into account well-being and other nuanced outcomes.

In her 1961 book *The Death and Life of Great American Cities*, Jane Jacobs, the pioneering American urbanist, discussed the importance of sidewalks. In the context of the city, they are conduits for adventure, social interaction, and unexpected

This is a start. Over the last 20 years, the focus in London has been far more on battling car traffic than on improving the pedestrian experience. Almost two decades ago, in 2003, a daily congestion charge for vehicles was introduced. Subsequent emissions rules have pushed the most polluting vehicles out of the city, and the zone they are prohibited from entering was expanded last October. More than 1,500 cameras help enforce the rules, while CCTV sensors are used to better understand traffic flow and management.

London is aspiring to match Oslo or Helsinki, where not a single pedestrian was killed in 2019.

Efforts to protect walking space have not been as sophisticated or long-standing. During the pandemic, local authorities were granted emergency powers to install bollards or planters and close roads to allow social distancing (most sidewalks around the UK are not wide enough for pedestrians to stay two meters apart). The results were highly divisive in some communities, as well as in the press and the local elections held in May. But it's hard to argue with the fact that these new "low-traffic neighborhoods" are associated not only with a 50% decrease in traffic-related injuries but also with lower car ownership, a decrease in street crime, and healthier streets to play and walk on.

Local politics aside, a pedestrian-first approach is gaining traction. The UK's National Highway Code was updated earlier this year, mandating that those who pose the greatest risk on roads—drivers—take the most responsibility to look out for others.

In London, TfL hopes to expand the use of pedestrian priority crossings. The trial shows that with the help of political leadership, small changes can help to make our cities more walkable, street by street. ■

Rachael Revesz is a freelance journalist based in Edinburgh, Scotland.

encounters—what Jacobs termed the "sidewalk ballet." Just as literal sidewalks are crucial to the urban experience, so is the larger idea of connection between elements.

However, too often we see "smart cities" focus on discrete deployments of technology rather than this connective tissue. We end up with cities defined by "use cases" or "platforms." Practically speaking, the vision of a tech-centric city is conceptually, financially, and logistically out of reach for many places. This can lead officials and innovators to dismiss the city's real and substantial potential to reduce poverty while enhancing inclusion and sustainability.

Truly smart cities recognize the ambiguity of lives and livelihoods, and they are driven by outcomes beyond the implementation of "solutions."

In our work at the UN Development Programme, we focus on the interplay between different components of a truly smart city—the community, the local government, and the private sector. We also explore the different assets made available by this broader definition: high-tech innovations, yes, but also low-cost, low-tech innovations and nature-based solutions. Big data, but also the qualitative, richer detail behind the data points. The connections and "sidewalks"—not just the use cases or pilot programs. We see our work as an attempt to start redefining smart cities and increasing the size, scope, and usefulness of our urban development tool kit.

We continue to explore how digital technology might enhance cities—for example, we are collaborating with major e-commerce platforms across Africa that are transforming urban service delivery. But we are also shaping this broader tool kit to tackle the urban impacts of climate change, biodiversity loss, and pollution.

The UrbanShift initiative, led by the UN Environment Programme in partnership with UNDP and many others, is working with cities to promote nature-based solutions, low-carbon public transport, low-emission zones, integrated waste management, and more. This approach focuses not just on implementation, but also on policies and guiderails. The UNDP Smart Urban Innovations Handbook aims to help policymakers and urban innovators explore how they might embed "smartness" in any city.

Our work at the United Nations is driven by the Sustainable Development Goals: 17 essential, ambitious, and urgent global targets that aim to shape a better world by 2030. Truly smart cities would play a role in meeting all 17 SDGs, from tackling poverty and inequality to protecting and improving biodiversity.

Coordinating and implementing the complex efforts required to reach these goals is far more difficult than deploying the latest app or installing another piece of smart street furniture. But we must move beyond the sales pitches and explore how our cities can be true platforms—not just technological ones—for inclusive and sustainable development. The well-being of the billions who call the world's cities home depends on it. ■

Riad Meddeb is interim director of the UNDP Global Centre for Technology, Innovation, and Sustainable Development. Calum Handforth is an advisor for digitalization, digital health, and smart cities at the UNDP Global Centre.

The future of the curb

A Black- and brown-led company aims to create a more inclusive world for cyclists.

By Jake Blumgart

In 2015, Brooklyn resident Shabazz Stuart regularly biked to his job at a local business improvement district. Then his bicycle was stolen—the third case of two-wheeled larceny he'd experienced in five years. The theft sent him back to mass transit while he saved up money to buy a replacement. It also put him on a new career path.

Paying hundreds or thousands of dollars to replace a bike can be a painful inconvenience for more privileged New Yorkers, but for working-class riders—especially delivery workers—it can be economically devastating. Thinking about the larger implications of his experience gave Stuart a business idea. In 2017 he created a company called Oonee with the goal of building out a missing piece of bicycle infrastructure in the US: secure parking.

Stuart and cofounder J. Manuel Mansyll developed a kit that can make modular parking "pods" to store anywhere from eight to 80 bicycles or scooters in a spot that's protected from rain and theft.

Each pod is operated with a smart access system that can be controlled with a keycard or a smartphone. The units are outfitted with security cameras, and insurance against theft is provided for users. Membership is free.

New York City began investing in bike lanes under the mayorship of Michael Bloomberg in the early 2000s, hoping to increase the proportion of people traveling by bike, but the question of where to put all those vehicles was never adequately addressed. As he built Oonee, Stuart looked at New York's practices with a newly skeptical eye. In other wealthy nations, he learned in his own research, many governments invest in cycling infrastructure much more comprehensively than even the most progressive US cities. If local policymakers weren't addressing cyclists' vulnerability to theft and the elements, how serious were they about encouraging bike transport?

"You cannot have a conversation about land use, outdoor dining, open streets, pedestrian plazas, bus lanes, without talking about car parking," says Stuart. "It's incredible to think we can have a serious conversation about biking as transportation without talking about bike parking."

But the company's mission is also about redressing the inequities of the cycling world, Stuart says. Bikes are often perceived as an amenity for gentrifiers, especially white upper-class professionals. But those with the lowest levels of income are the most likely to rely on bikes for commuting, and they are also much more likely to experience economic hardship if their ride is stolen.

"This misunderstanding of who relies on cycling for transportation reverberates to where we are today with a lack of cogent and compelling infrastructure to support cycling," says Stuart, who is Black. He says he has intentionally tried to staff Oonee in a fashion that reflects the demographics of the city and its bike riders.

Oonee is still in its early days, with about 4,000 users across a handful of pods in New York and Jersey City, just across the Hudson River. The contingent of dedicated users is smaller; Stuart says about 10% of the members represent 90% of the usage. But the stage is set for growth: the company already has plans to improve its geographic coverage, with nine more full-size pods as well as dozens of smaller ones called "Minis," which hold up to 10 bikes.

> "It's incredible to think we can have a serious conversation about biking as transportation without talking about bike parking."

There is a wider opportunity right now to make protected bike parking a norm in US cities, Stuart says. "The average person is socialized to bike-share, but 15 years ago that wasn't the case," he says. "We're going to raise the bar. Cyclists are going to say, 'Why isn't this in my city?'" ■

COURTESY OF OONEE

The gene-edited pig heart given to a dying patient was infected with a pig virus

The first transplant of a genetically modified pig heart into a human may have ended prematurely because of a well-known—and avoidable—risk.

By Antonio Regalado

The pig heart transplanted into an American patient earlier this year in a landmark operation carried a porcine virus that may have derailed the experiment and contributed to his death two months later, say transplant specialists.

David Bennett Sr. was near death in January when he received a genetically edited pig heart in a pioneering between-species transplant that has been hailed as a success—and was, at first.

A few days after his heart was replaced with one from a pig, Bennett was sitting up in bed. His new heart was pumping fantastically and performing like a "rock star," according to his transplant surgeon, Bartley Griffith of the University of Maryland School of Medicine.

But about 40 days later Bennett, who was 57, took a turn for the worse. After two months he was dead. In a statement released by the university in March, a spokesperson said there was "no obvious cause identified at the time of his death" and that a full report was pending.

Now MIT Technology Review has learned that Bennett's heart was affected by porcine cytomegalovirus, a preventable infection that is linked to devastating effects on transplants.

The presence of the pig virus and the desperate efforts to defeat it were described by Griffith during a webinar streamed online by the American Society of Transplantation in April. The issue became a subject of wide discussion among specialists, who think the infection was a potential contributor to Bennett's death.

"We are beginning to learn why he passed on," said Griffith, who believes that the virus "maybe was the actor, or could be the actor, that set this whole thing off."

The heart swap in Maryland was a major test of xenotransplantation, the process of moving tissues between species. But because the special pigs raised to provide organs are supposed to be virus-free, it now appears that the experiment was compromised by an unforced error. The biotechnology company that raised and engineered the pigs, Revivicor, declined to comment and has made no public statement about the virus.

10-gene pig

The detection of the pig virus in Bennett's heart is not necessarily all bad news for xenotransplantation. If the virus played a role in the failure, it could mean a virus-free heart xenotransplant could last much longer. Some surgeons think the latest gene-modified organs could in theory keep beating for years—and more rigorous procedures should be able to screen out the virus.

"If this was an infection, we can likely prevent it in the future," Griffith said during his presentation.

The biggest obstacle to animal-organ transplants is the human immune system, which ferociously attacks foreign cells in a process called rejection. To avoid rejection, companies have been engineering pigs—removing some genes and adding others—to give their tissue a stealth profile that hides from immune attack.

The version used in Maryland came from a pig with 10 gene modifications that was developed by Revivicor, a subsidiary of United Therapeutics.

Following promising tests of such pig organs in baboons, three US transplant teams launched the first human studies starting in late 2021. Surgeons at New York University and the University of Alabama each attached pig kidneys to brain-dead people, but the University of Maryland went a step further when Griffith stitched a pig heart into Bennett's chest in early January.

The specific type of virus found in Bennett's donor heart is not believed capable of infecting human cells. Instead, the problem is that pig cytomegalovirus is linked to reactions that can damage the organ and the patient—with catastrophic results.

Joachim Denner of the Institute of Virology at the Free University of Berlin, who has studied the effects of the virus on pig hearts transplanted into baboons, says that Bennett's death cannot be blamed on the virus alone. "This patient was very, very, very ill. Do not forget that," he says. "Maybe the virus contributed, but it was not the sole reason."

"This was a patient. It wasn't an experiment to us. All he wanted to do was live."

Bennett's cause of death matters, because if his heart failed as the result of immune rejection, researchers might need to return to the drawing board. Instead, it's now expected that companies like United Therapeutics and eGenesis, or academics working with them, will launch clinical trials of their pig organs within a year or two.

Bennett's doctors have called him a bold volunteer who showed plenty of fight. "These losses are hard," Griffith said during the webinar. "This was a patient. It wasn't an experiment to us. All he wanted to do was live. In fact, he was such a funny guy. On the way in to get his pig heart transplant, he looked at me and he said squarely, 'Are you sure I can't get a human heart?'" ■

Read the full story at www.technologyreview.com

Plugs across America

Electric vehicles appear poised to drive into the mainstream—but where will they plug in?

By Andrew Moseman

The United States has around 150,000 fuel stations to refill its fleet of fossil-fuel-burning vehicles. Despite the rapid growth of all-electric vehicles in America—400,000 of them were sold in 2021, up from barely 10,000 in 2012—the country has only 6,000 DC fast electric charging stations, the kind that can rapidly juice up a battery-powered car.

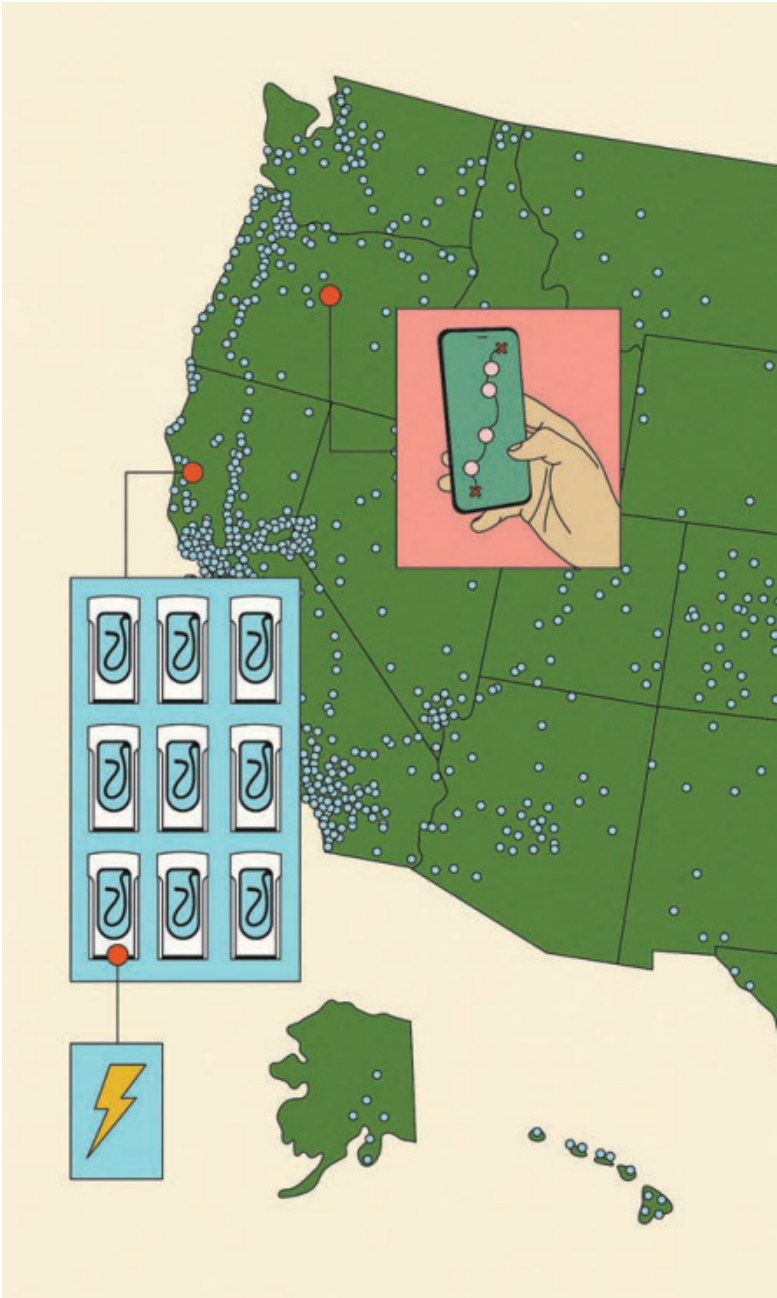
A glance at America's charging map reveals an abundance of charging deserts. This makes sense, as EVs still represent less than 3% of new car sales. Large cities have a growing number of fast chargers, but not nearly enough to accommodate a major influx of EVs. Away from cities, these chargers are strung along interstate highways closely enough to allow electric cars safe passage. Otherwise, they are nearly nonexistent in rural America. And EV stations have a problem that gas stations don't: "Even the fastest Tesla supercharger is still going to take 15 minutes to put a couple hundred miles on the vehicle," says Jeremy Michalek, a professor at Carnegie Mellon University and director of its Vehicle Electrification Group.

Michalek says American charging infrastructure lags far behind what's needed for the whole country to transition to electric driving. On the bright side, there is time to catch up, because not all Americans will embrace EVs at once. Most early adopters were those with access to a charger at home in their garage or parking space. Those owners can wake up with a full battery and only need to rely on public chargers when they leave town on an extended trip. But as the country gets to higher levels of EV adoption, the current infrastructure won't be enough. That is why Michalek says the US needs to prioritize bulking up the number of chargers at rest stops along well-traveled highways, especially as more people pile into electric cars for summertime road trips.

"As we get to higher levels of EV adoption, if we don't have enough chargers for peak demand, the wait times are going to be unlike what we see with gas stations," he says.

Charging dead zones will loom larger as more Americans consider an EV. Renters who do not have the option to install a home charger will be hesitant to go fully electric until they can feel confident a public plug will be there when they need it. And as more households drive only electric vehicles, it will be crucial that people can get to all the places they need (and want) to go.

The infrastructure bill that passed in November 2021 earmarked $7.5 billion for President Biden's goal of having 500,000 chargers (individual plugs, not stations) around the nation. In the best case, Michalek envisions a public-private collaboration to build a robust national charging network. The Biden administration has pledged to install plugs throughout rural areas, while companies constructing charging stations across America will have a strong incentive to fill in the country's biggest cities and most popular thoroughfares. After all, companies like Electrify America, EVgo, and ChargePoint charge customers per kilowatt-hour of energy they use, much like utilities.



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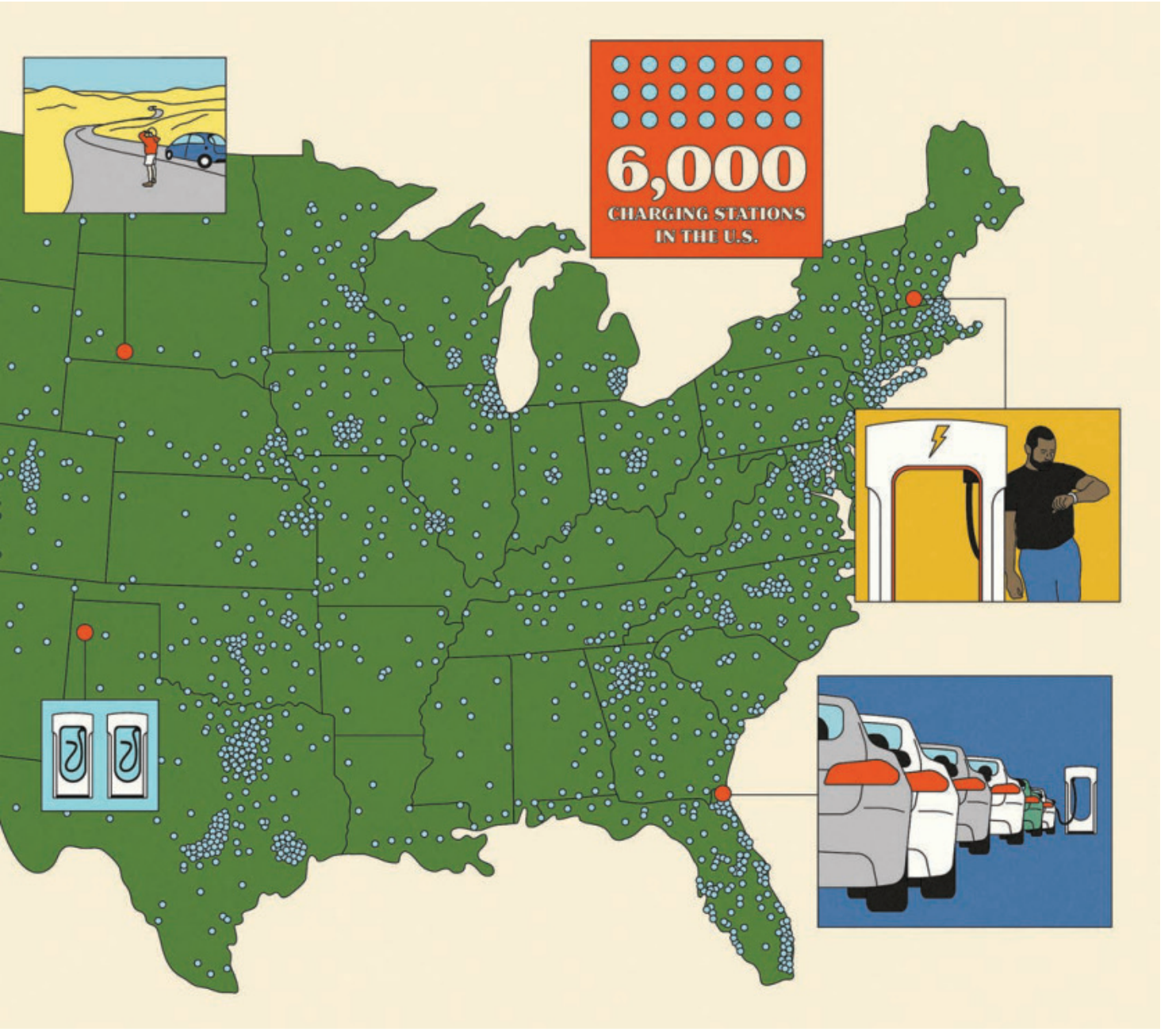


Most new electric vehicles promise at least 250 miles on a full charge, and that number should keep ticking up. The farther cars can go without charging, the fewer anxious drivers will be stuck in lines waiting for a charging space to open. But make no mistake, Michalek says: an electric-car country needs a plethora of plugs, and soon. ■

Currently, there are only 6,000 charging stations across the country, some with multiple chargers but others with only one or two. The Biden administration's dream of having a half-million charger plugs by 2030 may help ease the problem. But it's about where those chargers go, not just how many there are. For EVs to really take off in the US, it's crucial we shorten the gaps between stations now common along America's less populated expanses.

Andrew Moseman is a writer and an online editor for the California Institute of Technology.

Q&A

Cathy O'Neil

The author of Weapons of Math Destruction has a new book detailing how society has "weaponized" the idea of shame.

By

Allison Arieff

Yeah, it's all your fault

CHRISTOPHER CHURCHILL

Working in finance at the beginning of the 2008 financial crisis, Cathy O'Neil got a firsthand look at how much people trusted algorithms—and how much destruction they were causing. Disheartened, she jumped to tech, where she found the same blind faith in everything from targeted advertising to risk-assessment models for mortgage-backed securities. So she left. "I didn't think what we were doing was trustworthy," she says.

The feeling of being "a co-conspirator, an unwitting tool in the industry" lit the fire under her to write *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. Published in 2016, the book dismantled the idea that algorithms are objective, revealing instead—in example after example—how they can and do perpetuate inequality.

Before her book came out, says O'Neil, "people didn't really understand that the algorithms weren't predicting but classifying … and that this wasn't a math problem but a political problem. A trust problem."

O'Neil showed how every algorithm is optimized for a particular notion of success and is trained on historical data to recognize patterns: e.g., "People like you were successful in the past, so it's fair to guess you will be successful in the future." Or "People like you were failures in the past, so it's fair to guess you will be a failure in the future."

This might seem like a sensible approach. But O'Neil's book revealed how it breaks down in notable, and damaging, ways. Algorithms designed to predict the chance of rearrest, for example, can unfairly burden people, typically people of color, who are poor, live in the wrong neighborhood, or have untreated mental-health problems or addictions. "We are not really ever defining success for the prison system," O'Neil says. "We are simply predicting that we will continue to profile such people in the future because that's what we've done in the past. It's very sad and, unfortunately, speaks to the fact that we have a history of shifting responsibilities of society's scourges to the victims of those scourges."

Gradually, O'Neil came to recognize another factor that was reinforcing these inequities: shame. "Are we shaming someone for a behavior that they can actually choose not to do? You can't actually choose not to be fat, though every diet company will claim otherwise. Can you choose not to be an addict? Much harder than you think. Have you been given the opportunity to explain yourself? We've been shaming people for things they have no choice or voice in."

I spoke with O'Neil by phone and email about her new book, *The Shame Machine: Who Profits in the New Age of Humiliation*, which delves into the many ways shame is being weaponized in our culture and how we might fight back.

The Shame Machine: Who Profits in the New Age of Humiliation
Crown, $27.00

The trajectory from algorithms to shame isn't immediately apparent. How did you connect these two strands?
I investigated the power behind weaponized algorithms. Often, it's based on the idea that you aren't enough of an expert to question this scientific, mathematical formula, which is a form of shaming. And it was even more obvious to me, I think, because as a math PhD holder, it didn't work on me at all and in fact baffled me.

The power of bad algorithms is a violation of trust, but it's also shame. You do not know enough to ask questions. For example, when I interviewed a friend of mine, who is a principal whose teachers were being evaluated by the Value Added Model for Teachers in New York City, I asked her to get her hands on the formula that her teachers were targeted by. It took her many layers of requests, and each time she asked she was told, "It's math—you won't understand it."

In *The Shame Machine*, you argue that shame is a massive structural problem in society. Can you expand on that?
Shame is a potent mechanism to turn a systemic injustice against the targets of the injustice. Someone might say, "This is your fault" (for poor people or people with addictions), or "This is beyond you" (for algorithms), and that label of unworthiness often is sufficient to get the people targeted with that shame to stop asking questions. As just one example, I talked to Duane Townes, who was put into a reentry program from prison that was essentially a no-end, below-poverty-level manual-labor job done under the eye of armed men who would call his parole officer if he complained or took a bathroom break for longer than five minutes. It was humiliating, and he felt that he was treated as less than a man. This was by intentional design of the program, though, and was meant to train people to be "good workers."

COURTESY OF THE PUBLISHER

It's tantamount to a taser to one's sense of self. It causes momentary helplessness and the inability to defend one's rights.

Did covid-19 exacerbate the issues you highlight in your new book?
Well, it introduced more fast-changing norms, around masking, distancing, and vaccinations, so in that sense the shaming became pervasive. It was also obvious that the tribes that manifested on social media and inside politics took on these norms very differently, which caused huge shame wars online and in person. The way shame works is to move people who somewhat disagree further away from each other. In other words, shame backfires when there is no community trust. The more each side lobbed outrage and shame at the other, the further apart people grew.

In 2021, California became the first state to offer free lunch to all students, not just the economically disadvantaged, which has really helped to remove a long-held stigma. What are some other ways we design systems to be less about shame? Are there ways we can harness shame for social reform?
That's a great example! Another one that I suggest is to make it a lot easier to qualify for welfare [or] have a universal basic income, and to relieve student debt burdens. The systematic shaming of poor people in this country has meant there's little solidarity among poor people. That's almost entirely due to successful shaming campaigns. Poor people would advocate for debt relief and UBI themselves if we didn't have such a successful shame machine at work.

The chapter on "networked shame" explores how the algorithms of Facebook, Google, and others are continually optimized to spur conflict among us. How does this benefit them? What can be done to counteract it?

The way shame works is to move people who somewhat disagree further away from each other. In other words, shame backfires when there is no community trust.

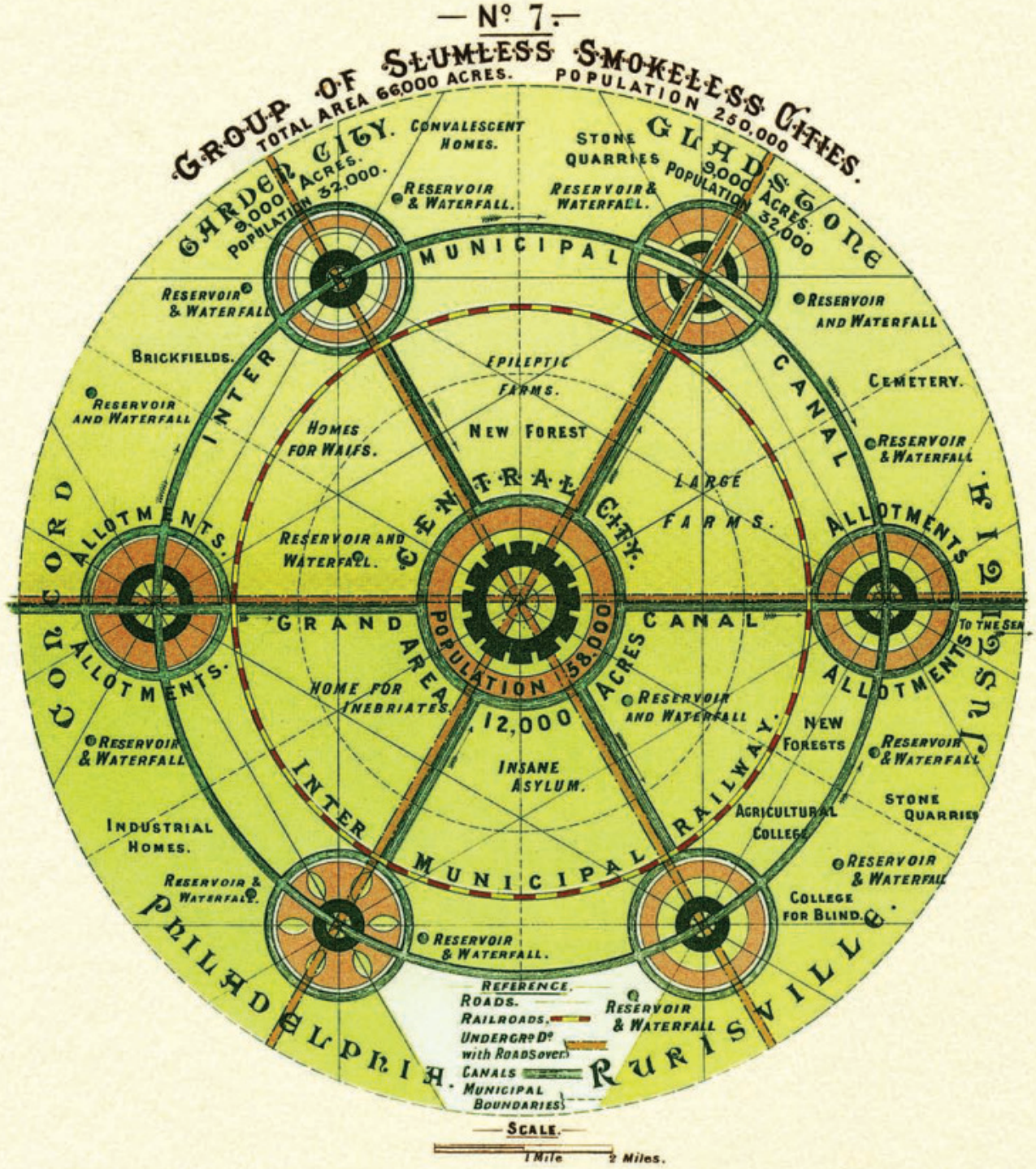
It's their bread and butter! If we didn't get outraged and spun out on defending our sense of worthiness and getting the likes and retweets based on performative and often destructive shaming, they'd make way less money. I want us to start seeing the manipulation by the big tech companies as a bid for us to work for them for free. We shouldn't do it. We should aim higher, and that means at them.

At an individual level, that means we refuse to punch down on social media if possible, or even boycott platforms that encourage that. At a systematic level, we insist that the designs of the platforms, including the algorithms, be audited and monitored for toxicity. That's not a straightforward suggestion, but we know that, for example, Facebook tried doing this [in 2018] and found it to be possible but less profitable, so they rejected it.

After *Weapons* was published you started ORCA, an algorithmic auditing company. What does the company's work entail?
Algorithmic auditing, at least at my company, is where we ask the question "For whom does this algorithmic system fail?" That could be older applicants in the context of a hiring algorithm, or obese folks when it comes to life insurance policies, or Black borrowers in the context of student loans. We have to define the outcomes that we're concerned about, the stakeholders that might be harmed, and the notion of what it means to be fair. [We also need to define] the thresholds that determine when an algorithm has crossed the line.

So can there ever be a "good" algorithm?
It depends on the context. For hiring, I'm optimistic, but if we don't do a good job defining the outcomes of interest, the stakeholders who might be harmed, and—most crucially—the notion of fairness as well as the thresholds, then we could end up with really meaningless and gameable rules that produce very problematic algorithmic hiring systems. In the context of, say, the justice system, the messiness of crime data is just too big a problem to overcome—not to mention the complete lack of agreement on what constitutes a "successful" prison stay. ■

This interview has been edited for length and clarity.



The story of cities is the story of

"how we convince ourselves, time and time again, that the big idea of the moment—the garden city, the city beautiful, the Ville Radieuse, the 15-minute city—will not only improve our daily lives but cure society's ills." p. 44

Above, one of a set of diagrams by Ebenezer Howard, "A Group of Smokeless, Slumless Cities" (1902), which encapsulated the concern with pollution and overcrowding in the early-20th-century industrial city.

Marseille vs.

Cameras for policing are on the rise across France.

Not everyone is welcoming them.

By
FLEUR MACDONALD

Photographs
GABRIELLE VOINOT

the surveillance state

Heading toward Marseille's central train station, Eda Nano points out what looks like a streetlamp on the Rue des Abeilles. Its long stand curves upward to a white dome shading a dark bulb. But this sleek piece of urban furniture is not a lamp. It's a video camera, with a 360-degree view of the narrow street.

Nano, a 39-year-old developer, wants to make residents of Marseille more aware that they are being watched. She is part of a group called Technopolice that has been organizing efforts to map the rise of video surveillance. With some 1,600 cameras in the city, there is plenty to find. Mixed in among them, Nano says, are 50 smart cameras designed to detect and flag up suspicious behavior, though she is unsure where they are or how they are being used.

Across the world, video cameras have become an accepted feature of urban life. Many cities in China now have dense networks of them. London and New Delhi aren't far behind.

Now France is playing catch-up. Since 2015, the year of the Bataclan terrorist attacks, the number of cameras in Paris has increased fourfold. The police have used such cameras to enforce pandemic lockdown measures and monitor protests like those of the Gilets Jaunes. And a new nationwide security law, adopted last year, allows for video surveillance by police drones during events like protests and marches.

For Nano the creep of increased surveillance has personal resonance. She grew up in Albania as it lurched between different political regimes in the 1990s. Her father, a politician, opposed the party that was in power for part of that time. "It was a very difficult period for us, because we were all being watched," she says. Her family suspected that the authorities had installed bugs in the walls of their home. But even in France, freedoms are fragile. "These past five years France has lived for much of the time in a state of emergency," she says. "I've seen more and more constraints put on our liberty."

Concerns have been raised throughout the country. But the surveillance rollout has met special resistance in Marseille, France's second-biggest city. The boisterous, rebellious Mediterranean town sits on some of the fault lines that run through modern France. Known for hip bars, artist studios, and startup hubs, it is also notorious for drugs, poverty, and criminal activity. It has one of the most ethnically diverse populations in Europe but is stranded in Provence-Alpes-Côte d'Azur, a region that leans far right. The city pushes back. Its attitude could be summed up by graffiti you might pass as you drive in on the A7 motorway: "*La vie est (re)belle*."

That all makes Marseille a curious testing ground for surveillance tech. When President Emmanuel Macron visited the city in September 2021, he announced that 500 more security cameras would be given to the city council. They would be placed in an area of the city that is home to high numbers of immigrants and has become synonymous with violence and gang activity. He struck a law-and-order tone: "If we can't succeed in Marseille, we can't make a success out of France."

The announcement was just the latest in a string of developments in Marseille that show an increased reliance on cameras in public spaces.

Activists are fighting back, highlighting the existing surveillance system's overreach and underperformance. Their message seems to resonate. In 2020, the city elected a new administration, one that had pledged a moratorium on video surveillance devices. But have the residents of Marseille succeeded, or are they simply fighting a rising tide?


CIRCULATION
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AUX VÉHICULES
ET DEUX ROUES MOTORISÉS
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MARSEILLE

Technopolice, a campaign and activist network launched by the digital rights advocacy group La Quadrature du Net in collaboration with other groups, got its start in 2019. Félix Tréguer, an associate researcher at the CNRS Center for Internet and Society, was one of those behind the campaign. He had been seeing increasing numbers of articles in the French media about new surveillance projects and was shocked at how uncritical they were. "[One] simply rehashed the press release from the Marseille council," he says.

What spurred him into action was an article in Le Monde in 2017 announcing the Big Data of Public Tranquillity Project, funded by a €1.5 million investment from the European Union, the city of Marseille, and the Bouches-du-Rhône region. It would crunch data from local police, firefighters, hospitals, and video cameras, using artificial intelligence in an attempt to better understand and predict security risks.

There was little focus in the Le Monde article on privacy protection, the possibility of data breaches, or the risk of bias—a special concern given Marseille's considerable North African population. Tréguer wrote to the newspaper, and the article was subsequently amended. But he became convinced that what was happening in Marseille was symptomatic of a wider phenomenon. "Many of these projects were starting to be implemented on a local level," he says. "No one in civil society really realized—even those belonging to activist circles and those who defended the right to privacy."

In February 2019, La Quadrature du Net and the League of Human Rights successfully fought a plan to roll out facial recognition to monitor entries and exits in two high schools, one in Marseille and another in Nice. Technopolice launched the same year, with the aim of documenting and resisting the spread across France of "safe city" projects, a bit of (often corporate) branding that is used to describe efforts to use data, AI, and surveillance to reduce crime.

In Marseille, Technopolice built a live map on which volunteers can mark the locations of cameras. The group also began

tracking surveillance projects in various cities that use artificial intelligence. There is now a Technopolice group in Montpellier and one in Belgium, and there will soon be one in Paris. Volunteers find and scrutinize records of surveillance initiatives in press releases, newspaper reports, and trade publications. The aim is to form "a record of these projects, which are very opaque," says Tréguer. "There is really a problem of democratic transparency."

The group thinks its activism has helped increase awareness of the issue. In 2019, it publicized and campaigned with a local group against plans in Saint-Étienne, a town near Lyon, for AI-assisted microphones that would detect suspicious

The team has had little luck getting to the bottom of the Big Data of Public Tranquillity Project.

sounds in the town center. These plans were eventually abandoned. And winning candidates in the 2020 local elections in Marseille ran on a platform that included putting a moratorium on video surveillance and establishing "citizens councils" to evaluate policing practices. But the team has had little luck getting to the bottom of the Big Data of Public Tranquillity Project despite numerous freedom of information requests. The description of the project on the council's website remains in the future tense—almost as if it had never been launched. Meanwhile, the number of surveillance cameras in the city has increased to the current 1,600-plus from just under 900 in 2016. As for the smart cameras, they are still scattered around Marseille even though, according to local councilor Christophe Hugon, they were used only in tests and have now been disabled. Despite repeated efforts, the Marseille council did not answer questions posed via telephone and email.


RUE DE LA RÉP


ZONE
30


LE CHAMP DE MARS

Jean-Jaurès Square in Marseille is a new model of ubiquitous surveillance. The once grotty square reopened last year after more than two years of redevelopment work. It now has seating areas and a playground. Trees have been geometrically arranged. And more than 20 cameras preside over the open-plan design.

"They can see into almost all the areas of the square, because visibility is part of the design," says Myrtille Picaud, a researcher on cities and surveillance at Sciences-Po, who is based in Marseille.

The cameras, however discreet, are troubling to some. "It is infantilizing," says one longtime resident, likening the system to watch towers around a prison. But the inmates of this panopticon don't necessarily play along. When night falls, it can get so rowdy some cafés close their outdoor spaces. Anticapitalist, feminist, antiracist, or simply funny graffiti covers the pavement. During the wild Festival de la Plaine, which was held illegally in spite of covid restrictions this year, spray paint cans were mounted on poles and used to coat camera lenses.

No official statistics have been made public about the impact that Marseille's cameras have had on crime. But there is reason to suspect it is not as much as officials might like. When the sociologist Laurent Mucchielli looked at the effect of video surveillance on an anonymous port city that bears telling similarities to Marseille, he found that in 2015 cameras were useful in the investigation of 2.2% of crimes where image searches had been requested. Other studies seem to back these kinds of figures; in 2020, a study by the research body attached to the French college of policing also estimated that just 1% of crimes were solved with the help of video images.

It's often suggested these cameras work to deter crime. Studies are inconclusive on this point. There does seem to be an effect on closed public spaces like parking garages and subways, but in some cases crime seems to be merely displaced, increasing in areas with fewer cameras.

In general, city surveillance prioritizes the capture of a certain class of criminal, says Picaud—those that commit crimes in public, even if their infractions are often minor. "One can see the overinvestment in these devices which target public space rather than other technologies which could target other crimes instead—like, for example, anything to do with tax evasion," she says.

Not long after the 2020 elections, the new mayor of Marseille called for an audit of video surveillance in the city. The council is still sitting on the study, which was delivered in October, but preliminary findings were published in the local newspaper The Provence. There are 42 dedicated agents; at any given time, fewer than five are on duty, and each is responsible for 35 screens. The system is not cheap; the newspaper highlighted the cost of installing each camera (over €20,000 per device), renting the optical fiber (€6.5 million a year), and maintaining the cameras, including cleaning and replacing bulbs (€2.8 million a year). Many of the images are not of good enough quality to use. And 272 cameras—over 15% of the total—are rarely consulted.

"It's techno-solutionism. There's a political problem, and they promise to find a technology—an app—to bring it under control," says Tréguer. "It is very expensive, and it uses a chunk of taxpayers' money to implement solutions that are dangerous for freedoms, increase control, and are in part ineffective."

The situation in Marseille doesn't seem to be unusual. In February, for example, the Cour de Comptes, an administrative body that audits public finances, highlighted similar issues, in a report on the video surveillance network in Paris. The auditors called its financing "unsuitable and expensive" and charged that no one had evaluated the cameras' impact on crime.

Marseille's government does seem to have cooled on the idea of video surveillance. The Big Data of Public Tranquillity Project, whose test period ran from 2018 to 2020, had been the pet scheme of the previous, right-wing mayor. The coalition of socialists, ecologists, and activists that rose to power in the 2020 city elections promised to pause video surveillance. This has been more difficult than initially anticipated, says Hugon, because of the difficulty of terminating contracts early.

At the same time, city officials have expressed some interest in making the system more efficient. Artificial intelligence is perhaps the only way of doing this on a large scale without adding significantly more personnel. Tréguer does not look forward to this possibility as technology becomes more advanced: "We are re-creating in some way a tentacular, bureaucratic police state without having to recruit dozens or hundreds of people."

The available technology is advancing quickly. The French startup Two-i, for example, offers an investigation function, which allows a surveillance team to use AI to search images for specific objects, like a man wearing a backpack or even sport shoes.

Press articles have alleged that the company has deployed face recognition in the city of Metz and was trialing it to read people's expressions on Nice's trams. Two-i cofounder Guillaume Cazenave says such reports are inaccurate. "In France, a certain shouty part of the press is waging a battle, and they write false things to frighten people," he says.

But there are signs that lawmakers and public bodies in France are looking at ways to facilitate the use of artificial intelligence in the surveillance of public spaces. A parliamentary paper in 2019 advocated establishing a framework for testing facial recognition, which is currently illegal. In the Paris Metro system in 2020, security cameras were AI-enabled to monitor whether passengers were wearing face masks (the technology is not meant to identity those not wearing masks but simply to provide anonymous statistics). The European Union is working on a set of laws called the AI Act that could limit the application of AI surveillance technology. But Technopolice suspects it could create loopholes if it does not ban the use of facial recognition outright.

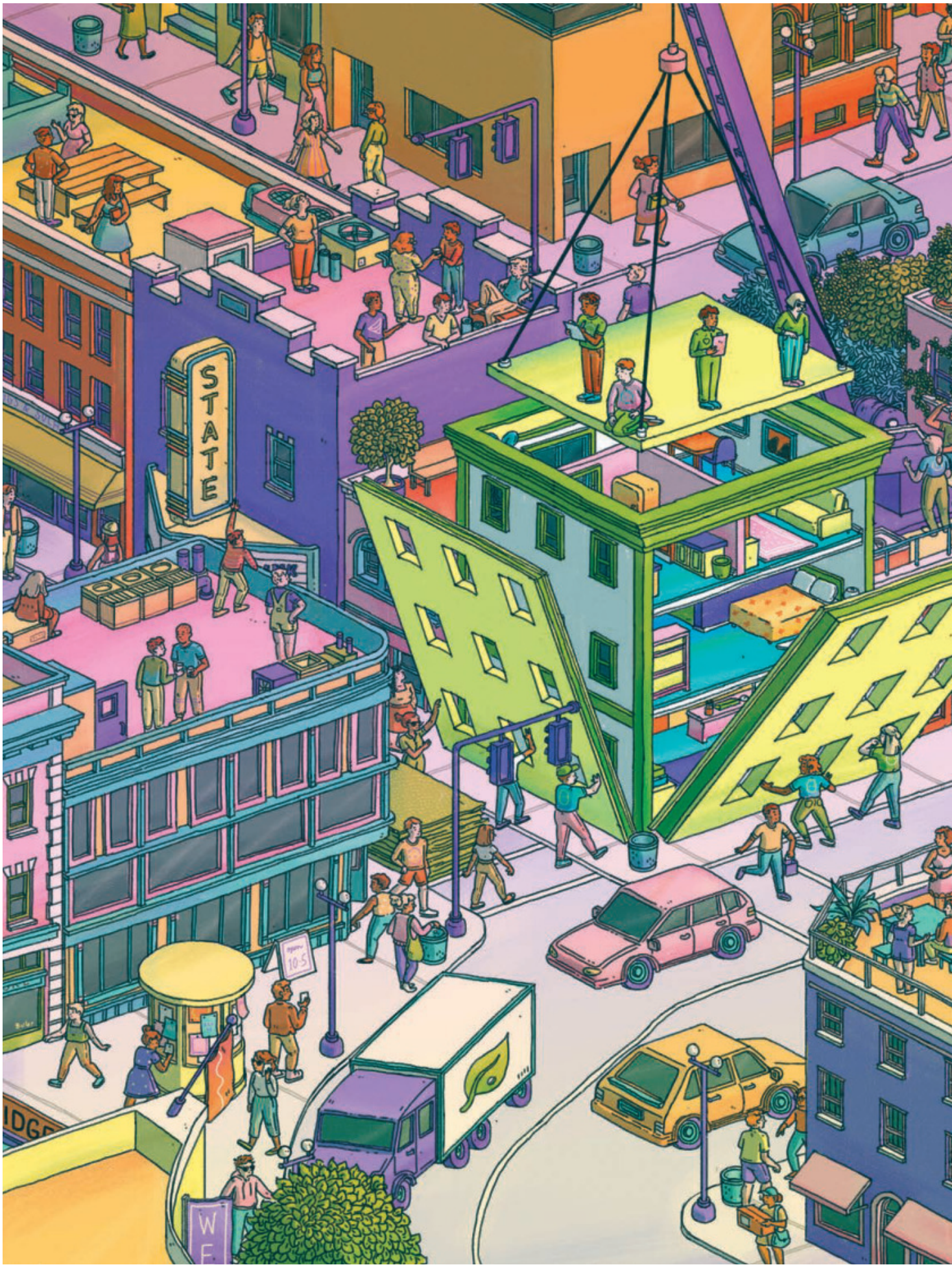
It is CNIL, France's data protection agency, that is tasked with ensuring that surveillance technology complies with the EU's General Data Protection Regulation, or GDPR. In 2017, for example, the town of Valenciennes accepted 240 cameras equipped with facial recognition technology from the Chinese company Huawei. The town insisted that the technology was not being used. Nevertheless, CNIL gave the local authorities a warning in 2021, and the project was quietly disbanded. But earlier this year CNIL launched a public consultation on the use of smart cameras in public places in order to clarify the legal framework for their use. Members of Technopolice see this move as a tacit acceptance of the need for such cameras.

"A certain shouty part of the press is waging a battle, and they write false things to frighten people."

The fight still continues for Technopolice. In the summer, they are planning to set up a series of meetings in the northern towns of Roubaix and Calais; the latter's council is considering devoting an extra half-million euros to video surveillance. La Quadrature du Net is working on a class action lawsuit against the government for the use of smart cameras in contravention of European law. In Marseille, the group continues working to drum up support; this summer there will be a conference and documentary screenings. There will also be more freedom of information requests to the Marseille council. Five of them, made in the last 12 months, are still pending. Meanwhile, the cameras roll on. ■

Fleur Macdonald is a writer based near Avignon, France.


PLACE
JEAN-JAURÈS


STATE

THE FUTURE OF URBAN HOUSING IS MORE EFFICIENT REFRIGERATORS

Adapting old, energy-inefficient buildings is less sexy but far greener than many high-tech solutions.

The scars and pockmarks of the aging apartments and housing units under the purview of the New York City Housing Authority don't immediately communicate the idea of innovation. The largest landlord in the city, housing nearly 1 in 16 New Yorkers, NYCHA has seen its buildings literally crumble after decades of deferred maintenance and poor stewardship. Just as the physical infrastructure has broken down, leading to busted elevators, picked-apart playgrounds, and crumbling façades, the agency has weathered a series of scandals in recent years over mold infestations and faked lead inspections. Hurricane Sandy in 2012 just added to the toll, flooding electrical and heating systems located in building basements. All told, this forsaken subsidized housing is in the midst of what local planners have called "demolition by neglect." It would require an estimated $40 billion or more, at least $180,000 per unit, to return the buildings to a state of good repair.

By Patrick Sisson

Illustrations by Meredith Miotke

It is far more sustainable to retrofit existing buildings than to tear down and rebuild. The retrofit of Ken Soble Tower—a waterfront high-rise for seniors built in Hamilton, Ontario, in 1967—resulted in a 94% reduction in the building's energy usage.

Years ago, there was evidence of innovation hidden inside these units—in the kitchens. By the late '90s, NYCHA realized that the existing fridges in many units were basically "gas guzzlers"—hugely inefficient, aging, and costly to the agency, which pays tenants' electricity bills. In a collaboration with the local utility, NYCHA held a contest for appliance manufacturers, asking them to create smaller, apartment-size units with superior efficiency; the winner would gain access to NYCHA and a cadre of other housing authorities interested in a purchase plan of at least 20,000 annually. Maytag won, with its then-novel Magic Chef model, which helped NYCHA cut costs by increasing energy efficiency—and also slashed emissions. Ultimately, 150,000 of the fridges were purchased between 1995 and 2003. It was a model of using the agency's heft and market power to drive innovation.

Now NYCHA wants to do the same with heating and cooling. The Clean Heat for All Challenge is asking manufacturers to develop low-cost, easy-to-install heat-pump technologies for building retrofits. The proposed devices, which would need to fit within a standard window frame, would replace the ubiquitous window AC unit and efficiently heat and cool an apartment without using refrigerants or directly burning fossil fuels. The agency is backing up the contest with a commitment to purchase and install at least 24,000 units of whatever model wins, part of a $250 million capital plan; meanwhile the New York State Energy Research and Development Authority, or NYSERDA, is helping recruit other housing agencies across the state and nation to sign on and promise to buy new units. "We expect to utilize this mechanism again and again next time we have to meet a massive market demand," says Emily Dean, NYSERDA's director of housing decarbonization.

The stakes for the agency, for the winning company, and for society itself could be huge. Investing in more-efficient heating and cooling in buildings is good for people and the planet; finding an equitable way to do so at the scales and speed needed to meet the climate challenge would be transformative.

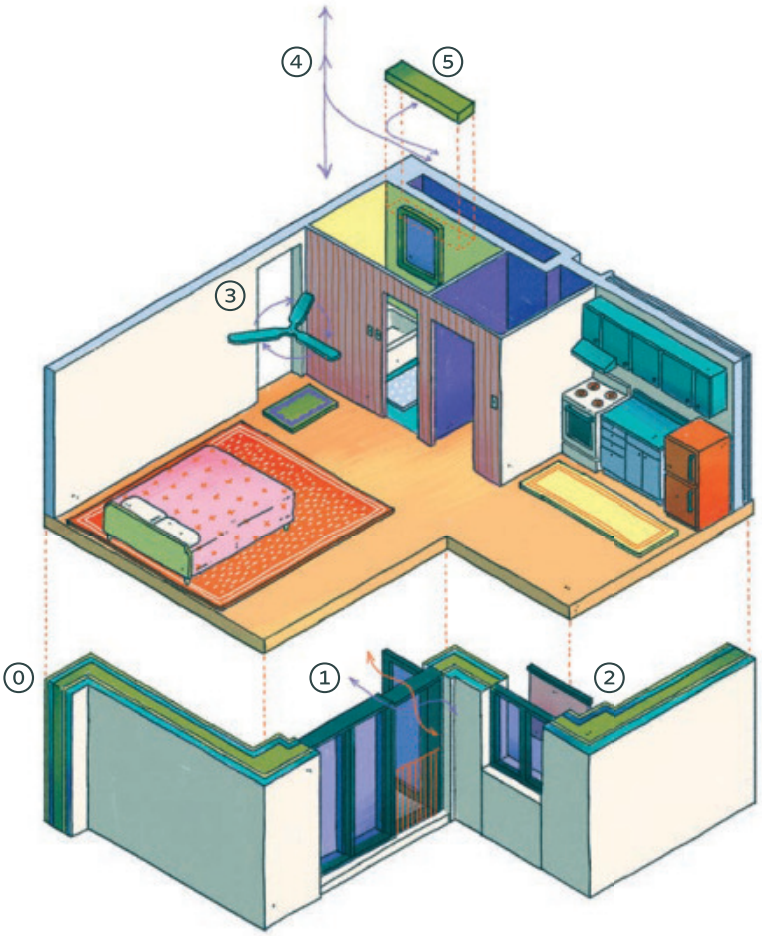
"Eight million people a year buy window AC in the US, the HVAC industry is $100 billion a year globally, and the number of AC units on the planet will triple by 2050—mostly small, room-sized units like what we're trying to push forward," explains Vincent Romanin, an engineer and the CEO of Gradient, one of the startups that submitted a design for the NYCHA challenge. "This is a huge market signal that can speed up the approach of these technologies."

That's not the only technological leap NYCHA and NYSERDA hope to make in coming years. RetrofitNY, a $30 million pilot program, seeks to support a new kind of whole-building energy retrofit that would basically attach airtight, weatherproof panels to the exteriors of older buildings—a technique invented and implemented in the Netherlands by a nonprofit called Energiesprong, which means "energy leap." Not only would this high-tech cocoon dramatically slash energy usage, but it could be put in place without asking residents to leave. The first test project set to be completed, Casa Pasiva in Brooklyn, should fully open in October, after a pandemic-era delay.

"Doing these kinds of retrofits across our portfolio seemed infeasible a few years ago," says Ryan Cassidy, director of sustainability and construction at RiseBoro Community Partnership, the nonprofit developer backing the Casa Pasiva project. "It may cost a little extra, but we have the means and methods right now."

Historically, the only innovation many felt was needed for aging housing stock was demolition and new "green" construction. But it's far more sustainable to retrofit existing buildings than to tear them down and build new ones. The climate crisis has created a fierce urgency around cutting

DOUBLESPACE PHOTOGRAPHY/ERA ARCHITECTS



Many efforts are underway to decarbonize buildings. An example is the Holistic Energy and Architectural Retrofit Toolkit (HEART), a cloud-based computing platform that includes decision-making and energy management features.

0. R38 effective envelope
1. Glazing with a low solar heat gain coefficient
2. Low-emissivity interior shades
3. Ceiling fans to circulate air within units
4. Lightly tempered air delivered through a centralized ventilation system
5. Decentralized cooling "boost" through a variable air volume unit activated by in-suite controls

SOURCE: ERA ARCHITECTS

carbon emissions, and any serious plan to do so needs to sink substantial money into adapting old, energy-inefficient housing. Bringing out the wrecking ball simply exacts too high a cost in both dollars and carbon.

Buildings, especially the aging and inefficient, account for nearly 40% of the nation's energy usage. More than half the country's available rental units are more than half a century old, and the Department of Energy estimates that 75% of the 130 million buildings in the US will be standing in 2050. Retrofits and upgrades aren't happening fast enough; currently, the DOE believes, 2.3 million homes get upgraded each year. Roughly 3 to 6 million annually would need to be retrofitted to meet emissions targets. That means the nation's developers and property owners need immediate, tested, efficient, and affordable solutions—and the financing and political will to fund them.

"Many of the solutions we need to decarbonize mass-market buildings already exist, and we're trying to support the ideas that can scale at speed," says Thatcher Bell, program director at The Clean Fight, an incubator for clean-energy startups that focuses on more-sustainable housing solutions. "Innovation is difficult, but adoption is more difficult."

Housing requires a great mobilization to meet this massive challenge. But so far, traditional tech disruptors haven't had the kind of success in this sector that they've seen in other industries. Katerra, a SoftBank-backed Silicon Valley housing startup that bragged it had radically reworked the building process, flamed out after raising $3 billion, a potent symbol of the struggles that have plagued startups in an industry that must contend with so many moving parts—labor, local regulations, supply chain issues, building codes. Social Construct, a startup birthed at the influential Y Combinator in San Francisco, attempted to streamline multifamily construction with automation and AI, but it filed for bankruptcy last year, citing pandemic pressures.

Programs that are beginning to move the needle on climate action—NYCHA's efforts, more-advanced public-focused models in Canada and Europe, and local incentive programs like a heat pump push in Maine or the wildly successful TECH Initiative, a $120 million program designed to help advance California's mission to achieve carbon neutrality by 2045—suggest that the Silicon Valley model of innovation may not work against one of the planet's most important problems. It's not exactly an issue of public versus private, but patient capital and policy-focused interventions can bring more equity, and perhaps quicker emissions cuts, than moving fast and breaking things. As Cassidy says of the Casa Pasiva project, there's no cool technology filled with buttons and controllers that residents can push; it's smart insulation and air sealing, "not something you're selling to venture capital."

"One part of the market is looking to provide long-term, affordable, sustainable housing, versus one that's profit driven, which doesn't lend itself to more long-term consideration of housing stock," says Yu Ann Tan, an associate with the carbon-free-building team at RMI, a think tank focused on clean energy. "Time is of the essence. Housing authorities can't wait for a huge, silver-bullet tech solution or a huge pot of money that may not materialize."

For much of the last century, one constant in housing and construction technology was the vision of making things more machine-like and automated. The idea was to introduce factory precision via prefabricated or modular construction, done primarily in a controlled environment rather than at a messy construction site. This would result in replicable, kit-of-parts models as interchangeable and easy to assemble as Lego bricks. Even Frank Lloyd Wright spent years tweaking and testing his own American System-Built prefabricated homes. Thomas Edison had a similar idea.

But Katerra, a hypergrowth startup, envisioned something grander: a series of factories across the nation, churning out assemblies and premade parts. At one point, the firm had hundreds of projects booked and had expanded into mass timber construction and even making its own light bulbs: it was a vertically integrated firm building vertically. Cofounders Michael Marks and Fritz Wolff thought they would bring their experience in tech supply chains and manufacturing to a new industry. Instead, Katerra—once valued at $6 billion—declared bankruptcy last summer.

"They had hubris and disdain for the industry, and no real vision for what their model would be," says Michelle Knapp, a construction specialist and cofounder of FunForm, a startup focused on building retrofits. "They were using technology to build an Edsel. If you're using robots to build an Edsel, you're still building an Edsel."

Katerra's all-encompassing vision of reforming the construction world, using billions of dollars in investment to build an entirely new production system from the ground up, showcased stereotypical Silicon Valley arrogance. It also has had a fraction of the impact of European models that seek to retrofit using a simple, straightforward, and standard set of parts.

The company shared a common blind spot with many American technologists, according to Gerard McCaughey, a serial entrepreneur and founder of Century Homes, an Irish pioneer of off-site construction: it disregarded innovation pioneered overseas. While American construction favored wood-frame building on-site with readily available raw materials—picture a Ford pickup piled with two-by-fours pulling up to a lot—more space- and material-constrained builders in Asia and Europe have perfected prefab and modular techniques. Katerra ignored these examples, which slowly built up expertise by focusing on specific sectors one at a time. Instead, it tried to reinvent the wheel, bringing every facet of the complex construction process in-house and building too many different models at once and causing massive cost overruns.

"It's not what you know or what you don't know that catches you," says McCaughey, who held talks with Katerra leaders. "There were things they were dead certain you needed to do, but [they were wrong]. Off-site isn't a one-trick pony. You have to crawl before you can walk. The least experienced guy in my company knew more about off-site construction than their senior leadership."

The Energiesprong model, which has retrofitted thousands of homes in the Netherlands and across Europe, relies on Stroomversnelling (the name means "rapid acceleration"), a network in which contractors, housing associations, parts suppliers, and even financiers work in close contact—a level of coordination that even Katerra's sprawling system didn't match.

"We're operating off a 'nice to have' energy-efficiency perspective rather than a climate change perspective—the 'house on fire, we need wartime levels of funding for homes' perspective."

Right now, the Energiesprong system can redo a building in roughly 10 days. Other startups and construction companies offer complimentary upgrades: Dutch firm Factory Zero, for example, makes prebuilt modules for roofs boasting electric boilers, heat pumps, and solar hookups. The greening of an older building is nearly plug-and-play.

It's part of a larger European model that starts with an ambitious emissions policy and supports it with incentives and funding for retrofits and new buildings via programs like Horizon Europe, in effect subsidizing novel building methods and creating a market for innovative windows, doors, and HVAC systems. A key component of its success has been governments' willingness to fund such upgrades for subsidized and public housing, typically postwar towers and townhomes in desperate need of improvement. But there are also other significant advantages in Europe: building codes are much more standardized across countries and the continent as a whole, including some progressive regulations pushing for the *passivhaus* standard, an ultra-efficient level of insulation and ventilation that drastically reduces the energy needed for heating and cooling. The entire housing ecosystem is smaller and more standardized too, making it easier to support more experiments. Energiesprong uses a single building model, a handful of contractors, and a relatively small pool of players across a small area.

Coordination would be exponentially harder in a single US city, much less the entire nation. "Europe takes a shotgun approach and funds numerous programs across the board," says Michael Eliason, a Seattle-based sustainable building expert and founder of Larch Lab, a design studio and think tank. It's an approach that spreads risk among different ideas, as opposed to concentrating venture capital on a handful of single-minded hypergrowth startups. "The US ends up being kind of a sniper rifle," he says. "Katerra fails and it impacts the entire prefab construction industry."

An emerging model in Canada seeks to replicate Europe's. CityHousing Hamilton, the municipal housing authority for the Ontario city, recently used national housing funds for a full retrofit of Ken Soble Tower, a waterfront high-rise for seniors that was built in 1967 and had fallen into disrepair. The project, which incorporated panelized

exterior cladding, new high-efficiency windows, and electrification of heating and gas stoves, brought the building to the *passivhaus* standard; with a 94% reduction in energy usage thanks to extreme efficiency, the total energy needed to cool and heat a unit is equivalent to three incandescent light bulbs. Gracious new bay windows offering seating, sweeping views, and daylight suggest there was no aesthetic price to pay.

Graeme Stewart of ERA Architects, who led the project and has studied the nation's hundreds of similar midcentury high-rises, says the project gave business to Canadian firms manufacturing high-tech windows and cladding, suggesting that such work could help seed a domestic industry for more green building projects. He's even spearheaded creation of the Tower Renewal Partnership, an organization dedicated to pursuing similar retrofits across Canada. But CityHousing Hamilton's development manager, Sean Botham, says that even with all the benefits they're seeing for the tower residents—better air quality, infection control, mental health, and cognitive function, and "views you just don't get in social housing"—the agency isn't likely to pay the 8% cost premium to upgrade other buildings in its portfolio without more funding support.

"The European version of this kind of building isn't a story anymore; it's just gravity," says Stewart. "Every jurisdiction has their own way to do this. In North America, high performance is a tax. How does this become a continent-wide imperative?"

At least in the United States, any progress seems destined to be decentralized for the foreseeable future. President Joe Biden's Build Back Better plan includes ambitious proposals to invest billions of dollars in retrofits, but the prospects of passing these proposals, even in piecemeal fashion, are dim, though the provision of $5 billion for weatherization in the infrastructure bill the Senate passed in November 2021 will make an impact, says RMI's Tan. Some scattered private firms are retrofitting their assets: RENU, a program with Taurus Investment Holdings, a global private-equity real estate investor, conducts energy retrofit audits when acquiring new buildings in its portfolio, seeing heat pumps and energy-efficient upgrades as a way to increase asset value and reduce maintenance costs. But it's an exception, and more urgency is needed.

"We're operating off the old paradigm of buildings—a 'nice to have' energy-efficiency perspective—rather than the climate change perspective, the 'house on fire, we need wartime levels of funding for homes' perspective," says Panama Bartholomy, founder and executive director of the Building Decarbonization Coalition.

But since building codes and incentives tend to be the purview of state and municipal governments in the US, experiments like the ones NYCHA and NYSERDA are embarking on become even more important. New York City's Local Law 97, one of a handful of city laws that set aggressive emissions targets for big-building owners and substantial fines if they don't comply, takes effect in 2024.

There are myriad challenges to making the panelized-retrofit solution work in the United States and reforming the way that housing innovation is funded and funneled throughout the entire built environment. Importing a concept from a country that's so different in its building typologies, economic incentives, and construction culture has challenges all on its own, says Knapp, who worked on an early RetrofitNY project.

According to a NYCHA spokesperson, the agency's decarbonization efforts are stymied by issues including the age of buildings, the need for electrical upgrades, and the lack of cost and performance data on panelized options. Nevertheless, NYCHA is already testing heat pumps at Fort Independence, as well as induction stoves at 1471 Watson Avenue (both in the Bronx), in anticipation of wider adoption. And the first RetrofitNY project tackling a NYCHA building, the Ravenswood Building in Queens, is scheduled to finish converting the six-story, 48-unit building by March 2024.

"We're seeing lots of interest in the supply side of the market, and the business model is shifting," says NYSERDA's Dean. "We're seeing the creation of a new class of solution providers, providing turnkey carbon-neutral retrofits for buildings with a performance guarantee and greater price guarantees."

The real question is whether efficiency gained through innovation, ambitious policies, and supportive funding can all come together in time to really make a dent in current retrofit efforts. Tan says some researchers have even looked at how to channel health-care dollars into such renovations, because improved air quality and mold reduction have such a profound impact on residents' health.

She points to a particular program, Philadelphia's Built to Last, as a good template for the way many of these projects could be funded in the future. A project of the Philadelphia Energy Authority, the program looks at the world of incentives that low-income homeowners could tap into to retrofit and repair, from weatherization benefits to efficient-appliance rebates. Alon Abramson, the program's director, says the program, which was delayed by the pandemic, is now working on 25 different homes, coordinating contractors, requirements, and project timelines to help restore housing that's often severely dilapidated.

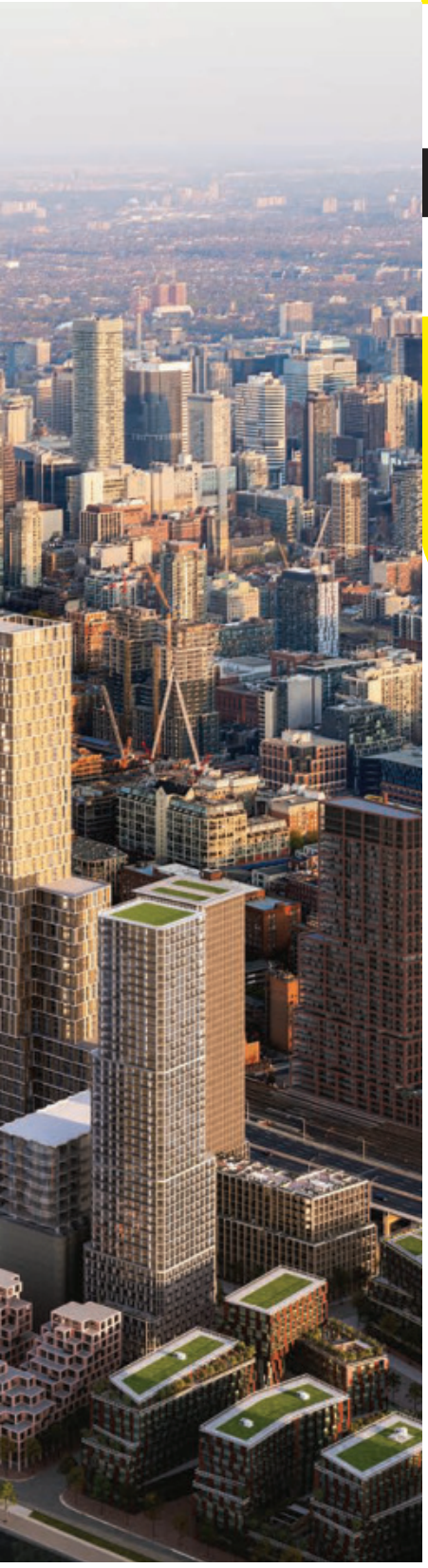
For people living in the houses now being renovated, it wasn't uncommon to lose access to heat or to a working oven, or have plumbing pipes crack so that running water was unavailable. They often faced huge energy bills because of poor insulation, cheap materials, and deferred maintenance, Abramson says. His experience just underscores the extent to which energy costs, both financial and environmental, place a burden on those with the least. It's a problem that has no easy fixes.

"We need to decarbonize our housing stock, but the systemic problems are pretty profound," says Abramson. "It's a technology problem to get heat pumps in these homes. That's a fundamental problem. But missing windows are a bigger issue." ■

Patrick Sisson is a Los Angeles–based writer. His work has been published in the New York Times, Bloomberg CityLab, and Vox.

An aerial view of the new proposed plan for the 12-acre site situated along the Toronto waterfront.

The next New Utopia



ALL RENDERINGS COURTESY WATERFRONT TORONTO

A new vision for Toronto aims to get right what Sidewalk Labs got so wrong.

By Karrie Jacobs

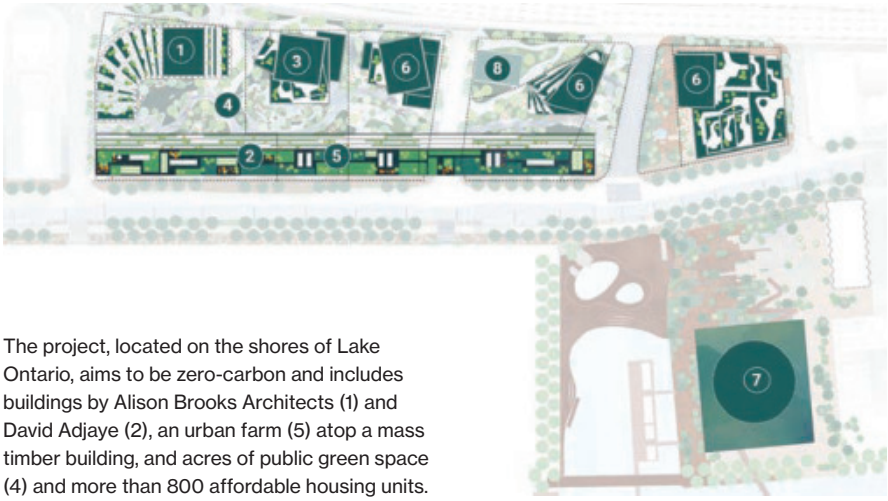
In February, the city of Toronto announced plans for a new development along its waterfront. They read like a wish list for any passionate urbanist: 800 affordable apartments, a two-acre forest, a rooftop farm, a new arts venue focused on indigenous culture, and a pledge to be zero-carbon.

The idea of an affordable, off-the-grid Eden in the heart of the city sounds great. But there was an entirely different urban utopia planned for this same 12-acre plot, known as Quayside, just a few years ago. It was going to be the place where Sidewalk Labs, the urban innovation arm of Alphabet, was going to prove out its vision for the smart city.

Sandwiched between the elevated Gardiner Expressway and Lake Ontario, and occupied by a few one-story commercial buildings and a mothballed grain silo, Quayside shouldn't have been that hard to develop. But controversy ensued almost from the moment in October 2017 that Waterfront Toronto, a governmental agency overseeing the redevelopment of 2,000 acres along the lake shore, announced that Sidewalk had submitted the winning proposal.

Sidewalk's big idea was flashy new tech. This unassuming section of Toronto was going to become a hub for an optimized urban experience featuring robo-taxis, heated sidewalks, autonomous garbage collection, and an extensive digital layer to monitor everything from street crossings to park bench usage.

Had it succeeded, Quayside could have been a proof of concept, establishing a new development model for cities everywhere. It could have demonstrated that the sensor-laden smart city model embraced in China and the Persian Gulf has a place in more democratic societies. Instead, Sidewalk Labs' two-and-a-half-year struggle to build



The project, located on the shores of Lake Ontario, aims to be zero-carbon and includes buildings by Alison Brooks Architects (1) and David Adjaye (2), an urban farm (5) atop a mass timber building, and acres of public green space (4) and more than 800 affordable housing units.

a neighborhood "from the internet up" failed to make the case for why anyone might want to live in it.

By May 2020, Sidewalk had pulled the plug, citing "the unprecedented economic uncertainty brought on by the covid-19 pandemic." But that economic uncertainty came at the tail end of years of public controversy over its $900 million vision for a data-rich city within the city.

It's hardly unusual for citizens to get up in arms about new development, and utopias fail for all sorts of reasons. But the opposition to Sidewalk's vision for Toronto wasn't about things like architectural preservation or the height, density, and style of the proposed buildings—the usual fodder for public outcry. The project's tech-first approach antagonized many; its seeming lack of seriousness about the privacy concerns of Torontonians was likely the main cause of its demise.

There is far less tolerance in Canada than in the US for private-sector control of public streets and transportation, or for companies' collecting data on the routine activities of people living their lives.

"In the US it's life, liberty, and the pursuit of happiness," says Alex Ryan, a senior vice president of partnership solutions for the MaRS Discovery District, a Toronto nonprofit founded by a consortium of public and private funders and billed as North America's largest urban innovation hub. "In Canada it's peace, order, and good government. Canadians don't expect the private sector to come in and save us from government, because we have high trust in government."

With its very top-down approach, Sidewalk failed to comprehend Toronto's civic culture. Almost every person I spoke with about the project used the word "hubris" or "arrogance" to describe the company's attitude. Some people used both.

The end of the smart city?

Time and time again, we convince ourselves that the big idea of the moment will not only improve our daily lives but cure society's ills. In England, the "garden city" movement introduced by the urban planner Ebenezer Howard in 1898 aimed to merge the countryside and the city while avoiding the disadvantages presented by both. The American version, the City Beautiful, sought to return beauty and grandeur to cities as a path to a more harmonious social order. Le Corbusier's rigid, high-density plan for the never-built Ville Radieuse (Radiant City) in Paris pursued urban utopia through architectural discipline. More recently, the "15-minute city" is a global movement in favor of planning cities so that everyone has access to work, school, retail, and recreation within a 15-minute walk or bike ride.

The smart city has been perhaps the dominant paradigm in urban planning over the past two decades. The term was originally coined by IBM in hopes that technology could improve the way cities functioned, but as a strategy for city-building, it's been most successfully deployed under authoritarian regimes (Putin is a fan). Critics say it tends to overlook the importance of human beings in the quest for technological solutions. Even when the architectural renderings were fabulous, the idea of the smart city has always had problems. The phrase itself suggests that existing cities are lacking in brain power, even though they have—throughout human history—been incubators for culture, ideas, and intellect.

The real problem is that with their emphasis on the optimization of everything, smart cities seem designed to eradicate the very thing that makes cities wonderful. New York and Rome and Cairo (and Toronto) are not great cities because they're efficient: people are attracted to the messiness, to the compelling and serendipitous interactions within a wildly diverse mix of people living in close proximity. But proponents of the smart city embraced instead the idea of the city as something to be quantified and controlled.

Smart city technology should do things like shorten commute times, speed the construction of affordable housing, improve the efficiency of public transit, and reduce carbon emissions by making building technology more efficient and providing less polluting transportation alternatives to the car. But often its proponents focus on what it *can* do rather than what it should. If Sidewalk's Quayside failure taught us anything, it's that these technologies need to respond better to human needs.

The first reactions to the Sidewalk project were, if not rapturous, still quite optimistic. Alex Bozikovic, the architecture critic for Toronto's Globe and Mail, believed Sidewalk Labs might offer a more exciting approach to development. This

DEREK SHAPTON

Jennifer Keesmaat, former chief planner for Toronto (top left), and Alex Ryan and Yung Wu of MaRS, North America's largest innovation hub (all of whom are working on the new waterfront project), believe that less tech reliance and more civic engagement could be the new way forward.

very publication included the project as one of its 10 breakthrough technologies in 2018, writing that "Sidewalk Labs could reshape how we live, work, and play in urban neighborhoods."

But over time, even the people who should have been Quayside's allies and boosters felt increasingly alienated. "There was a hubris to the way that they thought that they could solve all the problems in house," says the MaRS Discovery District's Ryan, whose job is to promote "innovation for the benefit of all."

By 2020 the project, which had yet to break ground, seemed increasingly untenable. And on May 7, two weeks before the Waterfront Toronto board was scheduled to take a vote on whether to shut it down, Sidewalk walked.

Sidewalk CEO Dan Doctoroff posted a farewell letter on Medium explaining that it had "become too difficult to make the 12-acre project financially viable without sacrificing core parts of the plan we had developed together with Waterfront Toronto to build a truly inclusive, sustainable community." He added: "And so, after a great deal of deliberation, we concluded that it no longer made sense to proceed with the Quayside project."

Most Quayside watchers have a hard time believing that covid was the real reason for ending the project. Sidewalk Labs never really painted a compelling picture of the place it hoped to build.

Quayside 2.0

The new Waterfront Toronto project has clearly learned from the past. Renderings of the new plans for Quayside—call it Quayside 2.0—released earlier this year show trees and greenery sprouting from every possible balcony and outcropping, with nary an autonomous vehicle or drone in site. The project's highly accomplished design team—led by Alison Brooks, a Canadian architect based in London; the renowned Ghanaian-British architect David Adjaye; Matthew Hickey, a Mohawk architect from the Six Nations First Nation; and the Danish firm Henning Larsen—all speak of this new corner of Canada's

Renderings from Waterfront Toronto are about trees, not tech. Planned high-rises frame a two-acre community forest, a public space by Denmark's SLA design studio.

The shift signaled by the new plan, with its emphasis on wind and rain and birds and bees rather than data, seems like a pragmatic response to the present moment.

largest city not as a techno-utopia but as a bucolic retreat.

In every way, Quayside 2.0 promotes the notion that an urban neighborhood can be a hybrid of the natural and the manmade. The project boldly suggests that we now want our cities to be green, both metaphorically and literally—the renderings are so loaded with trees that they suggest foliage is a new form of architectural ornament. In the promotional video for the project, Adjaye, known for his design of the Smithsonian Museum of African American History, cites the "importance of human life, plant life, and the natural world." The pendulum has swung back toward Howard's garden city: Quayside 2022 is a conspicuous disavowal not only of the 2017 proposal but of the smart city concept itself.

To some extent, this retreat to nature reflects the changing times, as society has gone from a place of techno-optimism (think: Steve Jobs introducing the iPhone) to a place of skepticism, scarred by data collection scandals, misinformation, online harassment, and outright techno-fraud. Sure, the tech industry has made life more productive over the past two decades, but has it made it better? Sidewalk never had an answer to this.

"To me it's a wonderful ending because we didn't end up with a big mistake," says Jennifer Keesmaat, former chief planner for Toronto, who advised the Ministry of Infrastructure on how to set this next iteration up for success. She's enthusiastic about the rethought plan for the area: "If you look at what we're doing now on that site, it's classic city building with a 21st-century twist, which means it's a carbon-neutral community. It's a totally electrified community. It's a community that prioritizes affordable housing, because we have an affordable-housing crisis in our city. It's a community that has a strong emphasis on green space and urban agriculture and urban farming. Are those things that are derived from Sidewalk's proposal? Not really."

Indeed, the philosophical shift signaled by the new plan, with its emphasis on wind and rain and birds and bees rather than data and more data, seems like a pragmatic response to the demands of the present moment and the near future. The question is whether this new urban Eden truly offers a scenario that will rein in global warming or whether it's "green" the way a smart city is "smart." How many pocket forests and neighborhood farms will it take to cool the planet?

Whatever its practical impact, renderings of the new version of Quayside suggest a more livable place. The development promises something incredibly obvious that the purveyors of the smart city missed: a potential for daily life to be pleasurable. As MaRS Discovery District CEO and tech entrepreneur Yung Wu puts it: "What is the vision that inspires people to want to live here, to work here, to raise their families and children and grandchildren here? What is it that inspires that?"

"It's not a smart city," he concludes. "It's a city that's smart." ■

Karrie Jacobs writes about design, architecture, and cities for Curbed, Architect, and the New York Times.

Wildlife crossings—the best-studied form of animal infrastructure—aim to reverse the damage done by roads. Do they?

By Matthew Ponsford • Illustrations by Andrew Merritt

WHY DIDN'T THE TOAD CROSS THE ROAD?

In the mid-2000s, toads were meeting a gruesome end near Ede, an old, leafy town in the middle of the Netherlands. Local residents came to the rescue. For a few weeks each spring, the town erected a set of temporary fences along a kilometer or so of road, in an area where the animals crossed over from their winter habitat in the south to three breeding ponds in the north. When the toads hit the barrier, they'd hop sideways for a few meters until they dropped into a bucket, one of 36 pitfall traps that lined the fence. Every day, volunteers would diligently carry the toads to the other side and send them on their way. It was a crude, somewhat laborious way of mitigating the hardship of being an amphibian in a world built for humans. But it was a lifeline that Ede residents were happy to provide for their warty neighbors—which, like so many other species worldwide, have suffered difficulties feeding, breeding, and migrating as their familiar landscape is carved apart by human infrastructure.

What followed has taken on the air of a cautionary fable among a small international community of ecologists and ecological designers. A few years in, Ede decided to swap its ad hoc screens for permanent barriers and replace the three dozen buckets with a pair of wildlife tunnels passing under the road. For ecologist Edgar van der Grift and other scientists monitoring the change, it was clear that the underpasses were popular. Many toads hopped happily toward their breeding ponds—even finding occasion to copulate mid-journey, a 2019 study notes. But when the researchers studied the effect that this new infrastructure was having on the toad population, they were alarmed by the results. "We saw a crash," says van der Grift, one of the world's leading experts in wildlife crossing structures. "In five, six years, the population went down from over 10,000 individuals to less than 1,000." In the years since, van der Grift has persuaded Ede to add a third tunnel, in a heavily frequented spot along the road. But discussions are still ongoing about how to reverse Ede's dwindling numbers.

For advocates of wildlife crossings, any such sign of failure inevitably sets alarm bells ringing far and wide. Countries have started to invest big in these bridges and tunnels. President Biden's November infrastructure bill allocated a landmark $350 million investment in animal crossings across the US, where some estimate roughly 1 million vertebrate animals die each day. In April, the National Wildlife Federation broke ground on a pioneering urban bridge—a $90 million custom-designed acre of "wilderness" that will float across 10 lanes of the US 101 freeway, linking two islands of mountain lion habitat north of Los Angeles. Early adopters Canada and the Netherlands are already home to decades-old networks of road-spanning projects, with arcs of chaotic forest reaching over highways. Australia, Brazil, China, and South Africa are following suit, hoping they can avoid the fate of seeing natural habitats sliced into sickly, disjointed fragments.

Around the world, cities are building a huge variety of structures intended to mitigate the impacts of urbanization and road-building on wildlife. The list includes green roofs, tree-lined skyscrapers, living seawalls, artificial wetlands, and all manner of shelters and "hibernacula," including 3D-printed hempcrete birdboxes for endangered owls in Melbourne and gigantic bat caves constructed like earthen igloos in the Texas hills.

But the data on how effective these approaches are remains patchy and unclear. That is true even for wildlife crossings, the best-studied and most heavily funded example of such animal infrastructure. Though road ecologists know these crossings can play a vital role in reducing roadkill, the story of their impact on wildlife conservation is still being told. This question is only growing more urgent: to meet the UN Sustainable Development Goals by 2040, a projected $97 trillion "tsunami" of new roads, railways, pipelines, and power lines will be needed, which would in effect double human infrastructure from 2012 levels, according to the World Wildlife Fund. That would put even more pressure on global biodiversity; one-sixth of all species at risk of extinction are threatened by human infrastructure development.

Wildlife crossings certainly look like success stories. Every day, remote-sensing cameras beam back images of animals taking advantage of them. There are the eager pioneers, like roe deer and foxes, which cross even before construction is completed. There are shy holdouts, like gray wolves or grizzly bears, which might take generations to become users. At Singapore's Mandai Wildlife Bridge, a total of 70 species—including pangolins, sambar deer, long-tailed macaques, fruit bats, and red jungle fowl (a close relative of the domestic chicken)—have crossed the road.

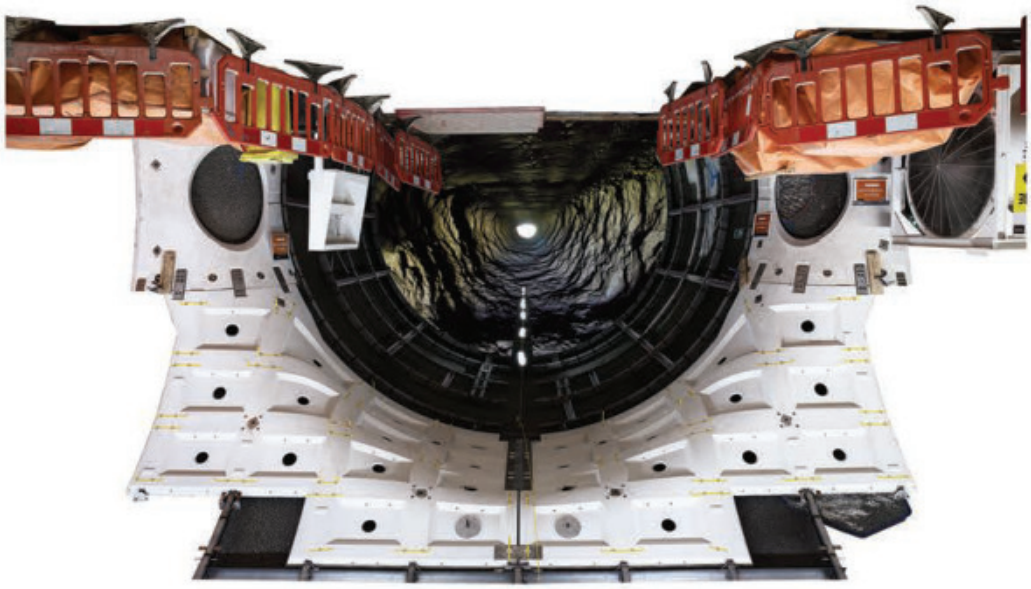
"Ten seconds after they're open, there's animals using them," says Darryl Jones, the author of *A Clouded Leopard in the Middle of the Road*, which tells the stories of deadly highways and lifesaving crossings from Brisbane, Australia, to Alberta, Canada. "The big new question now is—and this is the valid question—So what? Does that actually make a difference?"

One-sixth of all species at risk of extinction are threatened by human infrastructure development.

It takes less than half an hour by train to get from Amsterdam to the Gooi, a region of historic villages and medieval fortified settlements that's home to the Dutch TV industry. But this short ride takes you across one of the most intensively engineered landscapes on earth: over railroad girder bridges, across shipping canals, past windmills—both ancient stone structures and today's tubular steel turbines—and expanses of fields created by the polder-dike system that transformed the country's natural marshy wetlands into productive farmland.

For those interested in learning about the limits of wildlife crossings, the Gooi is a good place to start. The region boasts one of the world's densest collections of such infrastructure, with four bridges, two major underpasses, and a network of tunnels for badgers, amphibians, and reptiles, all within about 10 minutes' drive from the quaint local capital of Hilversum.

As van der Grift walks along the deck of one of these bridges, he points out fox droppings, blue herons, and trails where groups of roe deer walk in single file, retracing their footsteps each day. From this point, atop the bridge, the six-lane highway



Clockwise
from top left:

California's mountain lions, Kenya's elephants, Singapore's pangolins, and the Netherlands' amphibians are among the focal points of wildlife crossing developments.

below is invisible, shielded by the raised banks or "berms" on either side. But it can be heard, despite efforts to dampen the noise with the foliage of local beech and spruce. The crossing is studded with ponds, close enough together for toads to comfortably hop their way from one to the next.

The Netherlands built its first wildlife bridges to stop deer from becoming roadkill. But in the 1990s, the country began to shift to a more holistic ecological mindset, using bridges to link fragments of protected areas. In 2005 the Dutch parliament made such "defragmentation" a long-term nationwide policy, known as MJPO in Dutch. The program marked a shift to a strategic conservation-driven agenda, one that prioritized helping a broad sweep of species—including reptiles, bats, and butterflies—to move across the human-altered landscape. In modeling carried out for the Dutch transport ministry, van der Grift identified 215 bottlenecks where species struggled to pass, flagging them as places where crossings could make the greatest difference. Today there are 70 wildlife bridges in the country and more than 2,000 other structures, such as badger tunnels, rope bridges between trees, and aquatic underpasses.

To understand the real value a bridge has, it is important to step back and see the damage that arrives with each tarmac carriageway, says van der Grift, a gentle giant with a dry sense of humor earned in two decades of trying—with mixed results—to thwart animals' seemingly insatiable desire to throw themselves under cars. A road forms a barrier, one that animals either can't or do not want to traverse. "It inhibits animals to cross and to get in contact with each other," van der Grift says. The effects go far beyond roadkill. If the barrier is significant enough, it can make entire animal populations less viable, prone to inbreeding and decline.

Wildlife crossings can reduce this barrier effect, the thinking goes, making the road more permeable for a range of species. But few studies so far have been able to say conclusively whether this is really happening or not, he explains.

The devil is in the details. In the case of Ede, for example, there was plenty of amphibian traffic in the toad tunnels. But there were not enough structures—just two tunnels initially, hundreds of meters apart, rather than the 10 or more that scientists had recommended. "Many toads that move along the barrier and want to cross the road to get to the breeding pond—they basically gave up because they didn't encounter a crossing structure early enough," says Marcel Huijser, a leading US-based road ecologist and a longtime friend of van der Grift's.

Unexpected impacts and side effects crop up at nearly every crossing. Underpasses—often considered a cheaper alternative—seem to be less popular with many species and are rarely used by butterflies. Many aquatic mammals won't swim into a tunnel where they can't see the other end, but they can be convinced to walk through the same tunnel if a narrow ledge is built above the waterline. On one bridge in the Gooi, a big buck unexpectedly took over, exerting a territorial effect outside of rutting seasons. He acts as a gatekeeper, allowing does to cross but shutting off access to most males.

At the bridge we are standing on, van der Grift is tracking slow worms, armless and legless reptiles that wobble forward like clumsy snakes. Decades after being split by the road and railways, the populations on the east and west sides of the highway had developed distinct genetic profiles. When the bridge opened in 2016, he hoped to see the two populations start to mix. And indeed, DNA testing suggests they are. "We see now that the genetic patterns of the populations are getting closer to each other," he says. "So there is exchange."

But the ultimate goal is to ensure self-sustaining, healthy, viable animal populations. And it's still unclear whether the defragmentation efforts are accomplishing that. Van der Grift says he and colleagues wrote a plan for a nationwide empirical

NATIONAL WILDLIFE FEDERATION; AP PHOTO/JASON STRAZIUSO; JNZL/WIKIMEDIA COMMONS; RUDMER ZWERVER/SHUTTERSTOCK

evaluation of the MJPO program around a decade ago, but it was never funded (MJPO has since concluded and been superseded by other defragmentation plans). Such studies are often considered prohibitively expensive. It can require decades of tracking population sizes to sort the signal from the noise, explains Silviu Petrovan, a zoologist at the University of Cambridge. Some animals, like amphibians, naturally have population numbers that vary greatly from year to year, he says, meaning totals can zigzag "due to reasons that have nothing to do with your mediation."

One animal that seems to have benefited from Dutch defragmentation policies is the badger. In the 1980s there were fewer than 1,200 of them nationwide. Since the country began building under-road "badger pipes," their numbers have more than tripled. Models by van der Grift's team strongly indicate that the tunnels have a positive effect on population viability. But no robust scientific study has been carried out to prove it, he says. That would entail decades of population monitoring.

The Netherlands is not alone in its limited assessment of the impact of wildlife crossings. "Even when we do enough, we don't do the research for long enough, funded well enough—including a 'before' setting, including control settings—to be able to conclude that we actually reached our objectives," Petrovan says. Many crossing projects don't even reach the point of clearly defining the objectives they set out to achieve, he says.

"We are now at the stage where the data is coming in—it's really coming through."

Jones strikes a more optimistic tone. "We are now at the stage where the data is coming in—it's really coming through," he says. He's particularly encouraged by the ability to do genetic testing: "We've got very profoundly useful and effective ways to assess this stuff."

Historically, in the US, conservation has not been the point of animal crossings. Wildlife bridges have so far been seen almost exclusively as traffic safety tools: two dozen or so overpasses built at hot spots for migrating deer and elk. Threatened smaller species barely register among the diverse victims of the highway. "Amphibians? Reptiles? Please …" says van der Grift, summing up how such concerns are typically laughed away.

Most studies of US crossings have tracked their impact on road collisions and insurance claims. There, they excel: "When sited correctly, with appropriate fencing, to the target species, we know what wildlife crossings work well over 90% of the time," says Nina-Marie Lister, who leads the Ecological Design Lab at Ryerson University in Toronto. "They avoid 90 to 95% of wildlife vehicle collisions. That's an astonishing number in the world of science."

The reduction in property damage and human injury can be significant. In the mid-2010s, for example, a project on State Highway 9 in Grand County, Colorado, added two wildlife bridges, five large arch underpasses, and 10.4 miles of wildlife fencing at a cost of $10 million. The result was an 89% reduction in roadkill. The Center for Large Landscape Conservation, a nonprofit working on ecological connectivity, projected that the crossings would pay for themselves in approximately 22 years, less than a third of the structures' planned 75-year life span.

But if the goal is simply to stop animals from being hit by cars, there is no need for a bridge. "You simply could put a fence and prevent them from going entirely, and your mortality would drop to zero," says Petrovan, who conducts research on wildlife crossings for Conservation Evidence, a database of scientific findings about conservation actions. "It helps us feel better, because we see fewer individuals killed. But for the population, it doesn't actually give any benefits," he says.

Huijser says the US has been less inclined than his native Netherlands—and "almost anywhere else I've worked"—to think about conservation as a goal of crossings. But that is changing. The Infrastructure Investment and Jobs Act, which was signed into law in November and has allocated $350 million for wildlife crossings for the next five years, provides new federal funding for projects and research to reduce wildlife-vehicle collisions as well as connect fragmented areas of habitat. Although that amount is just 0.3% of the bill's $110 billion budget for roads, road ecologists have hailed it as a landmark investment. There is now a publicly funded way to build crossings that target conservation goals, even though collision reduction remains the primary focus, says Rob Ament, senior conservationist at the Center for Large Landscape Conservation. The dedicated funding also means wildlife crossings are no longer competing with potholes for scarce tax dollars. "I think it's actually a huge step forward," Ament says. The bill acknowledges that we need to design infrastructure "with both things in mind: the needs of people—the movement of goods and people—but also the movement of wildlife," he says. "And finally, we're doing that."

But what to build? North America's most influential examples of crossings lie along the Rocky Mountain Front in Canada. The area, which boasts the richest diversity of large mammals on the continent, is bisected by the Trans-Canada Highway. At Banff National Park, a set of 44 wildlife crossings (six overpasses and 38 underpasses) have been built to bridge the gap, creating a linked-up system used by a wide range of species including elk, cougars, and coyotes, as well as rarer animals such as red fox, grizzly bears, wolves, wolverines, snakes, beavers, and lynx.

But Banff's wildlife crossings, like most, suffer from a sort of Horseless Carriage Syndrome, their designs circumscribed by existing infrastructure. Tunnels are often little-adapted culverts, the (usually concrete) tubes that ferry water under roads. And overpasses have generally been borrowed wholesale from roadways—they are built as if they are going to carry the weight of an 18-wheeler and then "top-dressed" with foliage, Lister says.

A scattering of experiments are starting to rethink this model. One is the Wallis Annenberg Wildlife Crossing, the $90 million wildlife bridge under construction north of Los Angeles. Designed by architect Robert Rock, it avoids the humped arch of older bridges in favor of a vast flat expanse that needs just one column to support it between mountains and across a highway traversed each day by an estimated 300,000 cars. It is the "poster child for innovation," says Renee Callahan, executive director of ARC Solutions, a group that researches how to build better wildlife bridges. "It's literally designed for species from mountain lions to mule deer to deer mouse," Callahan says. "They're designing it all the way down—to literally the mycorrhizal layer, in terms of the soil, to make sure that the soil itself has the fungal network that can support the native vegetation."

There are many unknowns as construction starts, not least how different species will react to the sheer volume of vehicles passing beneath. The National Park Service will be monitoring activity on the bridge as well as DNA profiles of animals on either side of the freeway. Many are watching to see what will happen with the area's population of mountain lions. Over time, inbreeding has led to genetic abnormalities, like a telltale kink in local cats' tails. The agency predicted that the population would become extinct within decades without a crossing.

Across the US, the infrastructure bill's $350 million falls far short of what will be needed to address the fragmentation created by the country's 4 million miles of public roads. But there are a handful of innovations that could tip the cost-benefit analysis by allowing crossings to be built at lower cost or in places where it was not feasible before.

Animal bridges are currently built only where there is protected land on both sides of the road, as the typical expense of constructing a concrete bridge would be hard to justify on a site that someone might develop in a few years' time. Lighter, cheaper, modular systems could be used in places whose futures are less secure, explains Huijser: "If the adjacent lands become unsuitable for wildlife, we take it apart and you can move it."

One candidate material for such modular systems is precast concrete. There's also excitement about fiber-reinforced polymer (FRP), a material less dense than concrete that is made from structural fibers set in resin. FRP has been used to build foot and bike bridges in Europe and a quick-and-easy wildlife bridge in Rhenen, just south of the Gooi in the Netherlands. Currently the Federal Highway Administration does not allow it to be used in traffic infrastructure in the US, but there are growing demands for change. "These are barriers that are principally about policy and governance. They're not about science and they're not about technology," says Lister.

"They know that the last thing anybody wants is for a big structure, with a lot of publicity, to get built—and then it doesn't work."

Designers like Lister and innovators like Callahan are vocal proponents of building wildlife bridges across the country. Road ecologists and wildlife scientists, on the other hand, remain more cautious. "They are hypercritical because they know that the last thing anybody wants is for a big structure, with a lot of publicity, to get built—and then it doesn't work. Because everybody will come out of the woodwork and say, 'See! Waste of time! Complete crap!'" Jones says.

But today even cautious types want to see more built. Although we may not have conducted enough research to have all the answers, it would be dangerous to take that as a signal we should stop, Huijser says. He calls such over-cautiousness a "type II error"—a false negative. In this time of mass extinction, it is as if the house is burning down and our solution so far has been to squirt a water pistol at it a few times. To conclude that water isn't the answer would be a mistake.

Despite the challenges in Ede and elsewhere, van der Grift says, the answer is learning while building. We still need to invest in the real work of tagging, installing trail cams, and doing DNA testing and long-term population monitoring, he emphasizes. But we must first build more crossings—and the evidence we have so far says to build big and bold. "You have to realize that you almost cannot do too much," he says. "You do what you think is necessary, study it, and then, nine out of 10 times, you will see, 'Oh, I should have done more.' But there's no point in waiting until you have figured that out." ■

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Local shops are a mainstay of city life in India. Tech firms are coming for them.

The battle

Left: Inside a Dunzo Daily "dark store." Below: N. Sudhakar in his shop in Bangalore.

for India's street corner

By EDD GENT
Photographs by Aparna Nori

From 7 a.m. until well past dusk, seven days a week, N. Sudhakar sits behind the counter of his hole-in-the wall grocery store in the south Indian city of Bangalore. Packed floor to ceiling with everything from 20-kilogram sacks of rice to one-rupee ($.01) shampoo sachets, this one-stop shop supplies most of the daily needs for many in the neighborhood. It's a carbon copy of the roughly 12 million family-run "kiranas" found on almost every street corner in India.

The shop is on a busy street in the Whitefield district, formerly a quiet suburb but now a major hub for the city's booming IT industry. When Sudhakar, who is 49, opened the store 20 years ago, offices had just started going up. Business picked up quickly thanks to an influx of construction workers, followed by IT employees. Now apartment blocks loom behind his shop, housing hundreds of workers employed in the tech parks that dominate the surrounding area.

These days, the same technology industry that helped Sudhakar's business thrive is presenting stores like his with a new challenge. Across the road, a steady stream of delivery drivers line up to grab groceries from a "dark store"—a mini-warehouse located in the heart of the city and built to enable ultra-fast deliveries. It's run by Dunzo, a Bangalore-based startup, and the service is in such wide use it's now a verb unto itself—Bangaloreans who need something ferried across the city will "dunzo it," using the company's app to book an on-demand motorcycle courier.

Dunzo lets users order pickups from nearby shops, but more recently it has pivoted into the rapidly growing market for instant groceries. It's an increasingly crowded space. Borrowing from the playbook of Western companies like Instacart, Gopuff, and Gorillas, which deliver daily essentials right to your door, a slew of local firms are vying for a piece of India's $620 billion grocery market, many of them now promising delivery times of just 10 minutes. Their goal in many cases is explicit: they want to eat into the kiranas' dominant share of "top-up" purchases that customers make in between bigger bulk shopping trips.

They've got a long road ahead. Today, kiranas account for more than 95% of India's grocery market, according to research published in March by the consulting firm Redseer. Modern supermarkets still account for only about 4%, even though they first appeared 30 years ago, and online groceries haven't cracked 1% in a decade. Roughly two-thirds of India's 1.3 billion people live in rural areas largely untouched by these more modern forms of retail.

But in India's megacities, change could come quickly. Years of aggressive marketing, steep discounts from e-commerce players like Amazon and home-grown Flipkart, and a heavy dose of covid lockdowns have gotten the urban middle class hooked on online shopping. These shoppers make up a fraction of the population, but their spending power is considerable, and in more affluent pockets of big cities the battle for India's street corner is well underway.

Sudhakar is dismissive of the hive of activity across the road from his shop and says he doesn't really see Dunzo and its ilk as an immediate threat. But he admits that around half his customers now shop online, and he does worry what this trend could mean for his business and others like it in the future. "It will affect us," he says. "They have more investment. They have more money. They have a better network."

An Indian institution

A kirana isn't any old convenience store, says B.S. Nagesh, founder of the Trust for Retailers and Retail Associates of India (TRRAIN), a charity that supports retail workers. They are tightly integrated into their local communities, normally serving at most a few hundred families. "Many of us have grown up with the kiranas. It is just an extension of our kitchen," he says. "The shopkeeper knows us by name, he knows us by family. He is not only a person who serves us, but tomorrow, if there is a need, he actually helps you out. Kiranas have become an integral part of the society."

This close connection to their neighborhoods allows kiranas to provide a service crucial to many customers: credit. The shopkeeper will note down their purchases in a small notebook called a "bhai khata," and the balance is normally settled on a weekly or monthly basis. Large parts of the Indian economy operate on this kind of informal credit, says Rajat Agarwal, a professor of management studies at the Indian Institute of Technology Roorkee, and cash flow is often a problem.

"It's like doing a service," says Narendra Gupta, who runs a kirana in Kolar, a small city about two hours from Bangalore, with his brother. Gayathri Prasad has been shopping at the Guptas' kirana for 15 years and wouldn't shop anywhere else. "They are just like brothers," she says. When Prasad didn't have any money for about a month, the Guptas let her take what she needed and pay them back when she could. "Kiranas cater to the needs of every class," says Rachana Sharma, a sociologist at Guru Nanak Dev University. That often isn't the case with many modern retail stores, which Sharma says often exclude the less well-off.

The granularity with which these shops understand their shoppers would be the envy of any e-commerce data science team, says Agarwal. In a country with six major religions, 121 languages, and thousands of castes, each with its own habits, diets, and traditions, knowing your customers is essential. The items kiranas stock are finely tuned to the makeup of their surrounding neighborhoods. "Without the use of any kind of data-mining techniques, they are already, in their own crude way, doing analytics to understand their customers," he says.

Despite these unique strengths, a growing number of companies think kiranas are ripe for disruption. India's online grocery industry has grown quickly from a relatively small base, says Abhishek Gupta, a business consultant at Redseer, going from $500 million in 2016 to $5.5 billion by 2021. That growth came mainly from

Above: Apartment blocks loom behind Sudhakar's shop. Opposite: Dunzo Daily delivery workers gear up across the street from his shop.

urban Indians who switched to doing their weekly bulk shopping online. But now some sense an opportunity to eat into the smaller, more frequent top-up purchases that Gupta says make up 60 to 70% of the average kirana's business.

Tapping that market requires an entirely different approach. Typically, goods purchased online are stored in large warehouses on a city's outskirts and take hours or days to ship to customers. Muscling in on kiranas' turf means building networks of smaller "dark stores" embedded deep in the urban environment, making it possible to deliver items faster than a customer can walk to the local shop. "Quick commerce, for the first time, has started disrupting the kirana spend," says Gupta. Redseer estimates that within five years the segment could be worth $5 billion.

The opportunity has set off a feeding frenzy. Zepto, a startup founded by a pair of 19-year-old Stanford dropouts, came out of stealth in November with a promise to deliver groceries in 10 minutes and has since raised a total of $360 million in venture backing. In December, Indian food delivery giant Swiggy said it would invest $700 million in its fledgling grocery business Instamart, and an online grocer called Grofers rebranded as Blinkit and dropped its conventional delivery service for a 10-minute guarantee. Ola, Uber's main rival in India, joined the 10-minute craze in January, announcing plans to expand its network of dark stores to 500 over six months. Dunzo had already launched its Dunzo Daily service last June but announced in March that it would more than double its dark-store count to 200.

While slower to warm to the idea, the country's largest online grocery company, BigBasket, launched a 10-minute delivery option in April. It had dipped its toe into quick commerce three years before with a trial of one-hour deliveries, says Seshu Kumar, head of buying and merchandising, but scrapped the service when it failed to gain traction. Then came the pandemic. "Because kirana stores were closed, because of the lockdown restrictions in many areas, the customers had no option but to try e-commerce," he says.

While most went back to shopping in person as lockdowns waned, for a sizable portion the habit stuck. "Now, people are realizing that these 10-minute delivery startups, instant-gratification startups—they can actually replace the need of a local kirana," says Vaibhav Khandelwal, CTO of Shadowfax, which provides logistics to a who's who of Indian e-commerce companies.

It's a huge logistical undertaking. Khandelwal estimates that each of the major players is operating several hundred dark stores across the country's biggest cities. Even with such a big footprint, ensuring timely deliveries requires streamlined processes for packing groceries, and cutting-edge demand forecasting to get delivery drivers in the right place at the right time. And the location of the dark stores is critical.

"The core of it is network design," says Aadit Palicha, the CEO of Zepto. The goal is to reach as much of their target audience as possible while keeping average delivery distances to just 1.8 kilometers. And while a conventional supermarket might stock tens of thousands of products, quick-commerce firms have learned that most purchases come from a much smaller selection. It's a careful balancing act to ensure you can still meet customers' needs, says Palicha, but his company has found that about 3,000 products is enough to cover almost all of a customer's shopping basket.

Speed and selection aren't the only important criteria, says Dunzo CEO Kabeer Biswas. People pick and stick to a particular shop because they trust the quality of its offerings.

"Most of our time at the organization is spent figuring how we can deliver the best produce," he says. The company uses image recognition to automatically assess the quality of fresh goods. It's also working with startup Qzense Labs, which produces a suite of sensors designed to

The everything store

Collage above: Kirana owner Sharfuddin in his shop in Chamrajpet, a neighborhood in Bangalore. He took over running the shop from his father about 15 years ago.

Credit by hand

Collage below: Jayappa S. runs two kiranas on the border of HSR Layout, an area in the south of Bangalore that's become a startup hub. Jayappa's spouse, Shankaramma, used to work in the garment industry and stitches blouses to supplement income from sales at the shops.

In the bottom two images, Jayappa goes over his bhai khata, the notebook in which he keeps notes of credit he's extended to regular customers.

Kirana tech

Collage above: Dinesh Matahji, who owns a kirana in Chamrajpet, uses apps to help run his shop. Some of the "kirana tech" that's been developed allows shop owners to take online orders and keep track of the credit they extend to customers.

measure things like ripeness, sweetness, and spoilage in fruit.

The long-term goal of these companies is hugely ambitious. In March, posters started popping up around Bangalore featuring a picture of a refrigerator with the text "In loving memory of Sri Fridgesh Coolkarni, 1854–2022." It was a guerrilla marketing campaign from Dunzo suggesting that instant groceries would soon make the fridge obsolete.

"You can decide what to make for dinner 10 minutes before you start cooking," says Palicha. The aim is to fundamentally alter consumer behavior by removing the need to plan purchases, he adds: "When you give somebody a button to get something that they want in 10 minutes, they'll press it a lot more frequently."

For some, it seems to be working. Arshad Ayub, 33, used to shop once a week at a large supermarket and rely on local stores for things like vegetables, milk, and bread in between. But since trying Zepto for the first time in April, he's been converted. "Instead of doing bulk shopping, now whatever is required on a daily basis, we just order and get it in the next 10 minutes," he says. "I never had a situation where I needed something and I had to actually go to a local shop."

Reality check

It's not surprising e-commerce companies are eager to get into groceries, says Arvind Singhal, founder of the India-based consulting firm Technopak, since grocery shopping accounts for two-thirds of the total Indians spend on merchandise each year. But that spending is spread across roughly 8,000 towns and 600,000 villages, the vast majority of which are well beyond the reach of online shopping. "India's food grocery market is attractive in absolute numbers, but it is so fragmented that it's very difficult to consolidate," he says. "Anybody who claims that the kirana is threatened does not understand anything about India."

Quick-commerce companies say they are focused on the affluent upper strata of city dwellers for now, but even then there are questions about the viability of the model. For one thing, India's big supermarket chains make pretax profits of only 5 to 6%, says Redseer's Gupta, even though they have no delivery costs and benefit from favorable supplier deals thanks to the volume of their business. Even if quick-commerce firms manage to reach similar scales, their additional logistics requirements mean they would be looking at margins of just 2 to 3%. And today they're a long way from any kind of profitability. Gupta says that on average, they are losing 15 to 25 rupees on every 100-rupee order they receive.

Cracks are starting to show. Less than four months after announcing its foray into quick commerce, Ola has scaled back its ambitions, reportedly laying off 2,100 dark-store workers in April. And in March, Blinkit found itself so short on cash that it had to take a $150 million loan from food delivery company Zomato, one of its main investors.

It's also not clear what problem they are solving, says Singhal, as most kiranas already take orders via WhatsApp and deliver to customers' doorstep. The only explanation, he says, is a global glut of capital groping around for investment opportunities in an era of low interest rates. "To me, this excitement is on account of this unshackled pressure of money, which is forcing these entrepreneurs to defy economic sense," he says.

There are few signs the money taps will shut off soon, says Anand Ramanathan, a partner at Deloitte India. Investors have been throwing money at Indian startups for at least a decade, scrambling to get a foothold in a nation whose overall consumer markets could be worth $6 trillion by 2030, according to the World Economic Forum. "Do any of these models make money? Is it sustainable? They're not even close," he says. "It's all just a customer acquisition game."

India does have features that may make it a better fit for quick commerce than Western countries. Indians buy groceries more frequently than shoppers in the developed world, says Zepto's Palicha, and its crowded cities make it possible to reach a large number of customers from a single dark store. "This model thrives on density," he says.

There is evidence that in parts of India's biggest cities, kiranas are starting to feel the pinch. In a residential neighborhood on the border of HSR Layout—an up-and-coming suburb in the south of Bangalore that has emerged as a major startup hub—shopkeepers were unanimous that online shopping was cutting into their profits. Ashraf Puncheehar says business at his shop has dropped by 20% in the last six months. "Day by day, new companies are coming online," he says. "You can't compete with them."

Even if it's unlikely that kiranas suffer a widespread die-off anytime soon, localized retrenchments are a possibility. That could lead to a process of what is known as "infrastructural exclusion," says Aaron Shapiro, an anthropologist at the University of North Carolina at Chapel Hill. In the West, the shift from neighborhood stores to larger supermarkets saw companies abandon what they deemed "unviable markets" in poor areas, leading to "food deserts" where residents have limited access to healthy, affordable groceries. In India, the phenomenon could take on a unique flavor. Mohammed Ryaz, a regular customer at a kirana in Chamrajpet, says the shop was a lifeline to less tech-savvy customers during lockdowns. "These are not educated people—they don't know how to place an order [online]," he says.

Another concern is the impact on delivery drivers. More than 80% of India's economy is informal, meaning workers have no official employment contract and aren't protected by employment laws. So for many Indians, gig work isn't markedly different from their alternatives. But the unpredictability of wages due to sporadic work and incentive-based earnings still bothers many gig workers, says Aditi Surie, a sociologist at the Indian Institute for Human Settlements (IIHS). "It actually leaves people feeling this inner sense of precarity," she says. "You have no way of really calculating what is going to happen with your wages next month."

A Dunzo delivery driver, who didn't want to be named, said he doesn't mind the work and regularly pulls 12-hour shifts. But it's only really worth his time if he hits an

Above and opposite: Orders in a Dunzo Daily facility are packed by hand, but machines help, using image recognition to automatically assess the quality of fresh produce.

incentive target of 21 orders a day, which boosts his wages by nearly 50%. "It is a waste if I don't get any incentives," he says. "All my efforts are gone in vain." He typically hits the target eight to 10 days per month.

A helping hand

Why, if India already has a hyperlocal retail network perfectly tuned to the needs of every community, should anyone spend money building a new one? A host of "kirana tech" startups have decided there's no need. Instead, they're building tools to help the shops compete with the behemoths of modern retail. "We see the network of kirana stores in this country as a national infrastructure comparable to probably the power grids or the railroads," says Prem Kumar, CEO of the digital technology company Snapbizz.

His company's products help kiranas track inventory, accept digital payments, and manage credit with customers and suppliers. Basic services can be accessed through a mobile app, but the company also rents out bar-code scanners combined with either a handheld payment terminal or a touch-screen check-out computer. Kiranas can also take orders online via an app, and the company has tie-ins with major brands that run promotions on items stocked by the stores.

A critical factor while designing technology for kiranas is keeping things simple, says Ravish Naresh, CEO of Khatabook, which produces a mobile app that acts as a digital version of the notebooks used to record purchases on credit. The app automatically tallies up debts and sends payment reminders to customers.

Others want to tap into the kirana network to provide financial services to their customers. PayNearby provides kiranas with a mobile app and mini card reader that lets them accept digital payments. It also turns them into neighborhood banks, says CEO Anand Bajaj, allowing customers to withdraw cash, transfer money to relatives, take out insurance, and even book travel tickets for a small commission.

What's had the biggest impact on kiranas, though, is the handful of business-to-business e-commerce apps providing shops with a supply infrastructure to rival the big retail chains. Traditionally, kiranas have sourced products from a many-layered network of distributors and wholesalers who each take a cut, says Sujeet Kumar, cofounder of one such business, Udaan. By aggregating the demand of more than 3.5 million kiranas, the company secures favorable deals with producers, cutting out the middlemen to reduce prices. Nearly every kirana MIT Technology Review spoke to said Udaan, and other B2B apps like Jumbotail and Jiomart, had boosted their business.

Efforts to wrest control of the supply chain that feeds kiranas should raise some alarm bells, though, says IIHS's Surie. The fragmented, informal nature of traditional distribution systems provides a lot of resilience, she says, giving workers a panoply of options for quickly shifting between jobs as their circumstances change. Centralizing these tangled networks into a handful of tech platforms with scant government oversight could give some companies outsize control over the economic lives of millions. "They become the orchestrators of demand and supply and market forces," she says.

Nonetheless, kiranas seem to have some allies in their battle for the street corner. And Snapbizz's Kumar thinks the range of technologies and services now available to them could dramatically reshape these micro-businesses. The kirana of the future will be a "concierge for the household," he says—a one-stop shop providing everything their regular customers could want. He hopes that will help them flourish, and not just for their own sake.

"The network of kirana stores that we have today is the infrastructure for getting essentials to the masses of this country," says Kumar. "As of now, there isn't another viable option." ■

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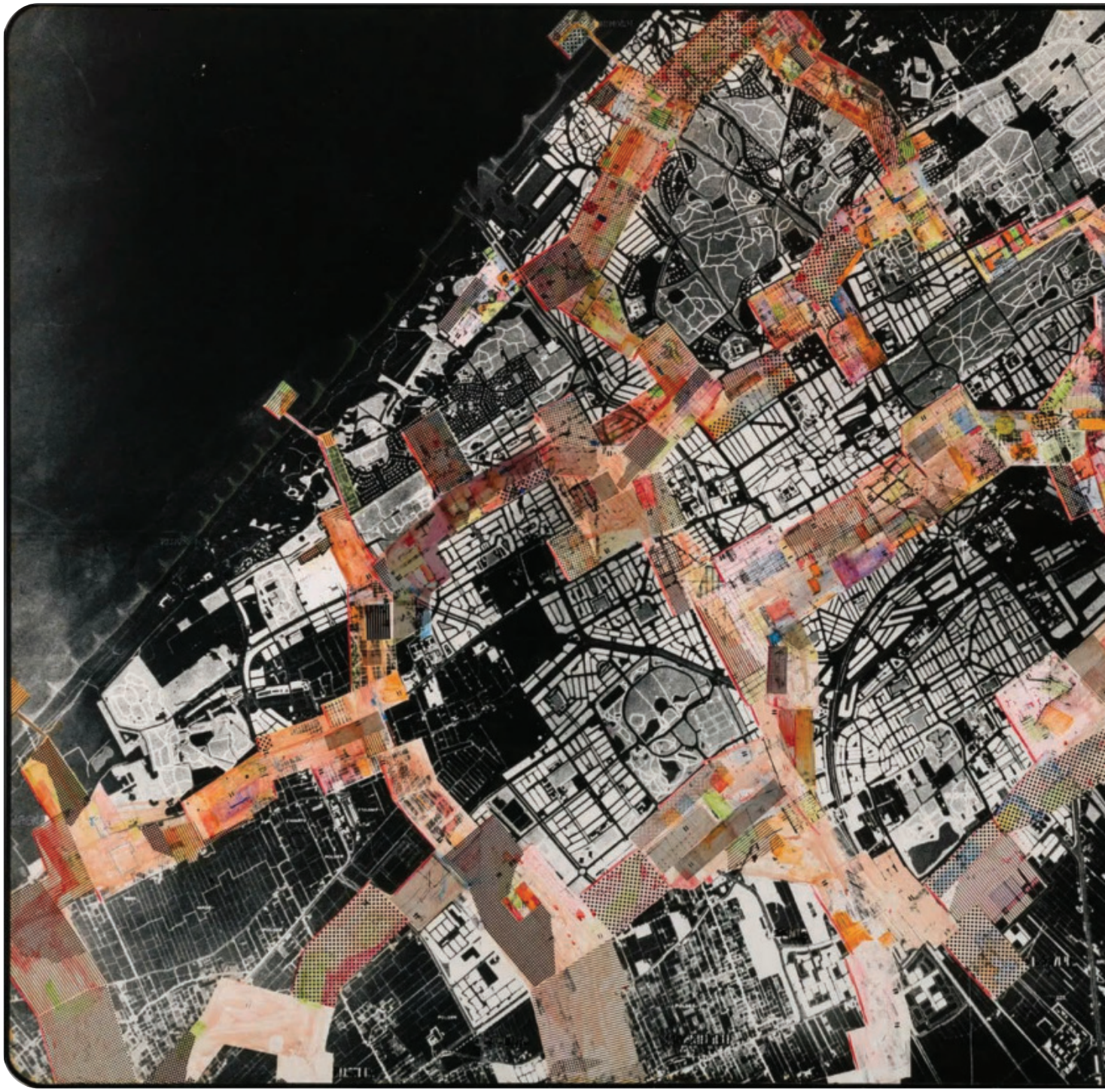

Utopia unresolved

Like nearly every imagined future utopia, New Babylon exists only in architectural drawings, sketches, maps, collages, and experimental films.

Smart city technology was meant to connect, protect, and enhance the lives of citizens. What happened?

By Chris Salter

In 1959, in a short essay called "The Great Game to Come," a little-known Dutch visual artist named Constant Nieuwenhuys described a new utopian city—one that he was soon to dub "New Babylon." "The technical inventions that humanity has at its disposal today," he presciently stated, "will play a major role in the construction of the ambiance-cities of the future."

Like nearly every imagined future utopia, New Babylon was never built. It was manifested only in architectural drawings, sketches, maps, collages, and experimental films. Its creator, generally known as Constant, envisioned his city as a complex network where artificial and natural spaces would be linked together by communication infrastructures; "recourse to a computer" would be necessary to resolve such a complex organizational problem. But New Babylon was to be something even more radical: a place where new technologies would replace the drudgery of labor by automatic processes, enabling the city's inhabitants to experience a "nomadic life of creative play."

Today, Constant's pronouncement seems prophetic. No doubt computers would also have been needed to achieve his visionary concept of an environment in which "each person can at any moment, in any place, alter the ambiance by adjusting the sound volume, the brightness of the light, the olfactive ambiance or the temperature." Above all, electronic technologies would enable complete transformations of sound, light, and the organization of space in New Babylon. These transformations would be accomplished by what Constant called "the most sophisticated behind-the-scenes automation," while electronics themselves "would be part of the visible scenery." Spaces in New Babylon would somehow need to be "aware" of the activities taking place in them so that the environment could know when to change its appearance and behavior.

Constant was soon to achieve international renown as one of founding members of the Situationist International (1957–1972)—a group of artists, writers, and philosophers who aimed to apply Marxism to contemporary urban society. Like many of his SI compatriots, Constant viewed the post-WWII city as a site for both critique and intervention. He and a Situationist collaborator, the cultural critic Guy Debord, declared as much in setting forth a concept they dubbed "Unitary Urbanism," which considered the city not as an agglomeration of faceless architecture and bureaucratic processes but as a set of creative social practices.

New Babylon took shape during the two-year period that Constant was a member of the SI. It was not so much an architectural planning project as it was "a way of thinking, of imagining, of looking on things and on life." Although echoing other technology-charged 1960s utopian city visions such as Archigram's "Walking City" or the performative "Villa Rosa–Pneumatic Living Unit" from the Austrian avant-garde collective Coop Himmelb(l)au, New Babylon began to gel in, of all places, the countryside. In 1959, the artist participated in an experimental-urbanism workshop in the Italian town of Alba at the base of the Piedmont Mountains. Sympathetic to the presence of nomadic Roma camped out by the Tamaro River, he began working on a concept to create a "permanent encampment" for the migrants "where under one roof, with the aid of moveable elements, a shared temporary, constantly remodeled living area is built."

New Babylon would gestate in Constant's mind for two decades. In his vision, land would be collectively owned,

Networks of smart sensors are no match for the brute force of unguided "dumb bombs" like the ones raining down on Ukrainian urban centers.

social systems would be hyper-connected, and automation would create a life of leisure for its citizens. To achieve a new "social organization of the city," Constant imagined a vast hierarchy of local sites (what he called "sectors") connected globally ("networks"). Groupings of interlinked platforms were envisioned as being completely transformable so as to create dynamic relations between inhabitants ("New Babylonians") and their surroundings. With interwoven levels of transport networks and spaces all linked by communications infrastructure, New Babylon defied traditional cartography. Clearly the artist knew, however, that running such a complex, interconnected system would require help from the emerging technologies of computational management and control. Though he had neither the ability to construct New Babylon nor an interest in actually doing so, his concept seemed like an idea whose time would come.

Rise of the smart city

In 1974, the same year that Constant ceased working on New Babylon, a little-known report was published by the Los Angeles Community Analysis Bureau (CAB), titled "The State of the City: A Cluster Analysis of Los Angeles." The report offered the typical stuff of urban research—statistical analysis, demographic data, and housing assessments. But what was not apparent was how the CAB had gathered the data.

While urban theorists somewhat myopically trace the concept of the "smart city" back to the 1990s, when IBM arguably first coined the term, the CAB's research represents one of the earliest large-scale efforts to model the urban environment through "big data." Utilizing a combination of computerized data gathering and storage, statistical cluster analysis techniques, aerial-based color infrared photography (what we today call remote sensing), and direct "on the ground" (i.e., driving around the city) validation of the aerial images, the CAB's analysis was decidedly different from previous attempts. The CAB partitioned the city into clusters representing social-geographic features that sound straight out of today's social media playbook: "LA singles," "the urban poor," "1950s-styled suburbs." What the cluster analysis truly revealed were correlations between socioeconomic forces that could be used as predictors for which neighborhoods were falling into poverty and "urban blight."

Though innovative for the time, the CAB's harnessing of punch cards and computer-based databases was not an isolated endeavor. It was part of a much larger set of postwar experiments focused on reimagining the urban through computational processes. The urban theorist Kevin Lynch's 1960 *Image of the City* spurred years of research into cognitive science on how we map typological elements in urban space (paths, edges, nodes, districts, and landmarks). Cyberneticians such as Jay Forrester at MIT sought to apply complex systems dynamics by way of computer simulations to understand the feedback loops within urban development, involving everything from population and housing to the influence of industry on growth. With Forrester, Lynch, and others, the foundations for smart cities were being laid, just as sensing and computing were entering into the public consciousness.

The contemporary vision of the smart city is by now well known. It is, in the words of IBM, "one of instrumentation, interconnectedness, and intelligence." "Instrumentation" refers to sensor technologies, while "interconnectedness" describes the integration of sensor data into computational platforms "that allow the communication of such information among various city services." A smart city is only as good as the imagined intelligence that it either produces or extracts. The larger question, however, is what role human intelligence has in the network of "complex analytics, modeling, optimization, visualization services, and last but certainly not least, AI" that IBM announced. The company actually trademarked the term "smarter cities" in November 2011, underlining the reality that such cities would no longer fully belong to those who inhabited them.

What is interesting about both early and current visions of urban sensing networks and the use that could be made of the data they produced is how close to and yet how far away they are from Constant's concept of what such technologies would bring about. New Babylon's technological imagery was a vision of a smart city *not* marked, like IBM's, by large-scale data extraction to increase revenue streams through everything from parking and shopping to health care and utility monitoring. New Babylon was unequivocally anticapitalist; it was formed by the belief that pervasive and aware technologies would somehow, someday, release us from the drudgery of labor.

War and sensors

The apocalyptic news broadcast from Mariupol, Kharkiv, Izium, Kherson, and Kyiv since February 2022 seems remote from the smart urbanism of IBM. After all, smart sensors and sophisticated machine-learning algorithms are no match for the brute force of the unguided "dumb bombs" raining down on Ukrainian urban centers. But the horrific images from these smoldering cities should also remind us that historically, these very sensor networks and systems themselves derive from the context of war.

Unbeknownst to Constant, the very "ambient" technologies he imagined to enable the new playful city were actually emerging in the same period his vision was taking shape—from Cold War–fueled research at the US Department of Defense. This work reached its height during the Vietnam War, when in an effort to stop supply chains flowing from north to south along the Ho Chi Minh Trail, the US Army dropped some 20,000 battery-powered wireless acoustic sensors, advancing General William Westmoreland's vision of "near 24-hour real- or near-real-time surveillance of all types." In fact, what the US Defense Advanced Research Projects Agency (DARPA) would later call "network-centric warfare" was the result of multibillion-dollar funding at MIT and Carnegie Mellon, among other elite US universities, to support research into developing distributed wireless sensor networks—the very technologies now powering "greater lethality" for the military's smartest technology.

The visions of the sensor-studded battlefield and the instrumented city both seem to lack a central ingredient: human bodies.

It is well known that technologies originally developed by DARPA, the storied agency responsible for "catalyzing the development of technologies that maintain and advance the capabilities and technical superiority of the US military" (as a congressional report put it), have been successfully repurposed for civilian use. ARPANET eventually became the Internet, while technologies such as Siri, dynamic random-access memory (DRAM), and the micro hard drive are by now features of everyday life. What is less known is that DARPA-funded technologies have also ended up in the smart city: GPS, mesh networks for smart lighting systems and energy grids, and chemical, biological, and radiological sensors, including genetically reengineered plants that can detect threats. This link between smart cities and military research is highly active today. For example, a recent DARPA research program called CASCADE (Complex Adaptive System Composition and Design Environment) explicitly compares "manned and unmanned aircraft," which "share data and resources in real time" thanks to connections over wireless networks, to the "critical infrastructure systems" of smart cities—"water, power, transportation, communications, and cyber." Both, it notes, apply the mathematical techniques of complex dynamic systems. A DARPA tweet puts this link more provocatively: "What do smart cities and air warfare have in common? The need for complex, adaptive networks."

Both these visions—the sensor-studded battlefield and the instrumented, interconnected, intelligent city enabled by the technologies of distributed sensing and massive data mining—seem to lack a central ingredient: human bodies, which are always the first things to be sacrificed, whether on the battlefield or in the data extraction machinery of smart technologies.

Spaces and environments outfitted with sensor networks can now perceive environmental changes—light, temperature, humidity, sound, or motion—that move over and through a space. In this sense the networks are something akin to bodies, because they are aware of the changing environmental conditions around them—measuring, making distinctions, and reacting to these changes. But what of actual people? Is there another role for us in the smart city apart from serving as convenient repositories of data? In his 1980 book *Practice of Everyday Life*, the Jesuit social historian Michel de Certeau suggested that resistance to the "celestial eye" of power from above must be met by the force of "ordinary practitioners of the city" who live "down below."

When we assume that data is more important than the people who created it, we reduce the scope and potential of what diverse human bodies can bring to the "smart city" of the present and future. But the real "smart" city consists not only of commodity flows and information networks generating revenue streams for the likes of Cisco or Amazon. The smartness comes from the diverse human bodies of different genders, cultures, and classes whose rich, complex, and even fragile identities ultimately make the city what it is. ■

Chris Salter is an artist and professor of immersive arts at the Zurich University of the Arts. His newest book, Sensing Machines: How Sensors Shape Our Everyday Life, has just been published by MIT Press.

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Researchers in the growing field of sensory urbanism are developing new ways to understand how a city sounds, smells, and feels.

By Jennifer Hattam

What does your city smell like?

When David Howes thinks of his home city of Montreal, he thinks of the harmonious tones of carillon bells and the smell of bagels being cooked over wood fires. But when he stopped in at his local tourism office to ask where they recommend that visitors go to smell, taste, and listen to the city, he just received blank stares.

"They only know about things to see, not about the city's other sensory attractions, its soundmarks and smellmarks," says Howes, the author of the forthcoming book *The Sensory Studies Manifesto* and director of Concordia University's Centre for Sensory Studies, a hub for the growing field often referred to as "sensory urbanism."

Around the world, researchers like Howes are investigating how nonvisual information defines the character of a city and affects its livability. Using methods ranging from low-tech sound walks and smell maps to data scraping, wearables, and virtual reality, they're fighting what they see as a limiting visual bias in urban planning.

"Just being able to close your eyes for 10 minutes gives you a totally different feeling about a place," says Oğuz Öner, an academic and musician.

Öner has spent years organizing sound walks in Istanbul where blindfolded participants describe what they hear at different spots. His research has identified locations where vegetation could be planted to dampen traffic noise or where a wave organ could be constructed to amplify the soothing sounds of the sea, something he was surprised to realize people could hardly hear, even along the waterfront.

"Just being able to close your eyes for 10 minutes gives you a totally different feeling about a place."

Local officials have expressed interest in his findings, Öner says, but have not yet incorporated them into urban plans. But this kind of individual feedback about the sensory environment is already being put to use in Berlin, where quiet areas identified by citizens using a free mobile app have been included in the city's latest noise action plan. Under EU law, the city is now obligated to protect these spaces against an increase in noise.

"The way quiet areas are identified is usually very top-down, either based on land use or high-level parameters like distance from highways," explains Francesco Aletta, a research associate at University College London. "This is the first example I'm aware of something perception-driven becoming policy."

As a member of the EU-funded Soundscape Indices project, Aletta is helping create prediction models for how people will respond to various acoustic environments by compiling recorded soundscapes, both vibrant and tranquil, into a database and then testing the neural and physiological reactions they elicit. These kinds of tools are what experts say are needed to create a practical framework for ensuring that multisensory elements are included in design criteria and planning processes for cities.

The best way to determine how people react to different sensory environments is a subject of some debate within the field. Howes and his colleagues are taking a more ethnographic approach, using observation and interviews to develop a set of best practices for good sensory design in public spaces. Other researchers are going more high-tech, using wearables to track biometric data like heart-rate variability as a proxy for emotional responses to different sensory experiences. The EU-funded GoGreen Routes project is looking to that

AMRITA MARINO

approach as it studies how nature can be integrated into urban spaces in a way that improves both human and environmental health.

"We're creating a lexicon of elements and how they work in combination to create a complete experience of a space," says Daniele Quercia of Nokia Bell Labs Cambridge, one of the researchers working on the project. Quercia previously helped develop "Chatty Maps" and "Smelly Maps" of city sounds and odors by scraping data from social media. The latter project found strong correlations between people's olfactory perceptions and more conventional air-quality indicators. With GoGreen Routes, he'll be using wearable technologies to assess whether design improvements to new and existing green spaces have the predicted (and desired) impact on people's well-being.

At Deakin University in Australia, architecture professor Beau Beza is aiming for full immersion. His team is adding sounds—and, eventually, smells and textures—to virtual-reality environments that city officials can use to present planning projects to stakeholders. "Static depictions on paper of a streetscape, park, or square are difficult for many people to visualize," says Beza. "Being able to 'walk' through and hear how it sounds increases understanding."

As data collection about people's sensory experiences becomes more widespread, many of these experts caution that concerns about privacy and surveillance need to be taken into account. Issues of equity and inclusion also come into play when determining whose sensory experiences are factored into planning. Underprivileged urban communities have typically borne the brunt of noise and odor pollution from highways and factories, yet they are also often targeted by noise complaints, for example, when their neighborhoods gentrify.

"Sensory perceptions are not neutral, or simply biological; whether we find something pleasant or not has been shaped culturally and socially," says Monica Montserrat Degen, an urban cultural sociologist at Brunel University London. Civic planners in both London and Barcelona are using her research on public-space perceptions and how "sensory hierarchies," as she refers to them, include or exclude different groups of people.

Degen cites the example of a London neighborhood where inexpensive eateries that served as hangouts for local youth were displaced by trendy cafes. "It used to smell like fried chicken," she says, but newer residents found that aroma off-putting rather than welcoming. "Now it smells like cappuccinos." ■

Jennifer Hattam is a freelance journalist based in Istanbul, Turkey.

35 Innovators Under 35

Spoiler alert: Our annual Innovators Under 35 contest isn't actually about what a small group of smart young people have been up to (although that's certainly part of it). It's really about where technology is headed next. As you read about what problems this year's winners have set out to solve, you'll also glimpse the near future of AI, biotech, materials, computing, and the fight against climate change. To connect the dots, we asked five experts—all judges or former winners—to write short essays about where they see the most promise, and the biggest potential roadblocks, in their respective fields. We hope the list inspires you and gives you a sense of what to expect in the years ahead.

Illustrations by Chad Hagen

Climate change

In the next 10 years, the world will need dozens of breakthrough climate technologies to reduce emissions at the gigaton scale.

By Varun Sivaram

We're living in a pivotal decade. By 2030, global emissions must fall by half, mostly through massive deployment of commercial solutions. But emerging climate technologies must come to market during this decade too. The International Energy Agency forecasts that roughly half the reductions needed to cut emissions to nearly zero by 2050 must come from technologies that are not ready for the market today.

Only a handful of clean technologies, such as silicon solar panels, onshore wind turbines, light-emitting diodes (LEDs), and lithium-ion batteries, have graduated from scientific laboratories to mass deployment. And it took decades for them to reach a scale where they could significantly reduce global emissions. Those timelines must be compressed for the world to have a chance of limiting global warming to 1.5 °C above preindustrial levels, which world leaders agreed at last year's Glasgow Climate Conference would offer the best chance of avoiding catastrophic effects.

One way to speed innovation is by promising future customer demand. This gives innovators and investors an incentive to scale up unproven technologies and find ways to rapidly cut costs in the process. The First Movers Coalition, launched by President Joe Biden and John Kerry, the US special presidential envoy for climate (and my boss), along with the World Economic Forum, includes over 50 of the world's largest companies, which have all made commitments to purchase emerging climate technologies by 2030.

Such "advance market commitments" have enabled cutting-edge technologies to swiftly reach commercial markets in other fields, from vaccine development to commercial spaceflight. The same approach could shrink the timeline to scaling up emerging clean technologies and driving down their cost premiums over more carbon-intensive technologies.

On top of swelling demand for clean technologies, investments in their supply are growing. President Biden's Bipartisan Infrastructure Law is investing more than $20 billion in clean-technology demonstration projects, and private venture capital investment set a record in 2021 by topping $40 billion for climate-technology startups.

Venture capital investment slowed in the first half of 2022, and the chilly market climate may affect clean-technology companies in the short term. But investment in the sector still appears more sustainable than the "Clean-tech 1.0" bubble a decade ago, when venture capitalists invested $25 billion from 2006 to 2011 but lost half their money when the dust settled.

In addition to supportive government policies around the world, entrepreneurs today have access to a richer innovation ecosystem. Among the winners on this year's Innovators Under 35 list are some who have incubated their technologies at US national laboratories, secured investment and collaboration from major energy and automotive companies, and made it into the portfolios of so-called "patient capital" investors such as Breakthrough Energy. Particularly for innovators in the United States, this diverse set of capital sources can help a company traverse the so-called "valley of death" and bring a technology from prototype to commercial scale.

Those named to this year's list are seizing this opportunity. Their success is something we can all get behind. ■

Varun Sivaram is senior director for clean energy and innovation for US special presidential envoy for climate John Kerry (and a 35 Innovators winner in 2021 and a judge this year).

Kaichen Dong
University of California, Berkeley

A huge portion of the energy consumption around the world is used to heat and cool buildings. To reduce this consumption and its related emissions, Kaichen Dong, 32, has developed a "smart" coating that can be attached to any roof. The key material is vanadium dioxide, which automatically switches from radiating heat away from a home on a hot day to insulating it in cooler weather. The coating works best in areas where the temperature changes significantly from summer to winter or day to night, and it is not meant to replace heating and cooling systems entirely. Instead, it eases demand on these systems by keeping a building's temperature within a more manageable range.

Chengcheng Fang
Michigan State University

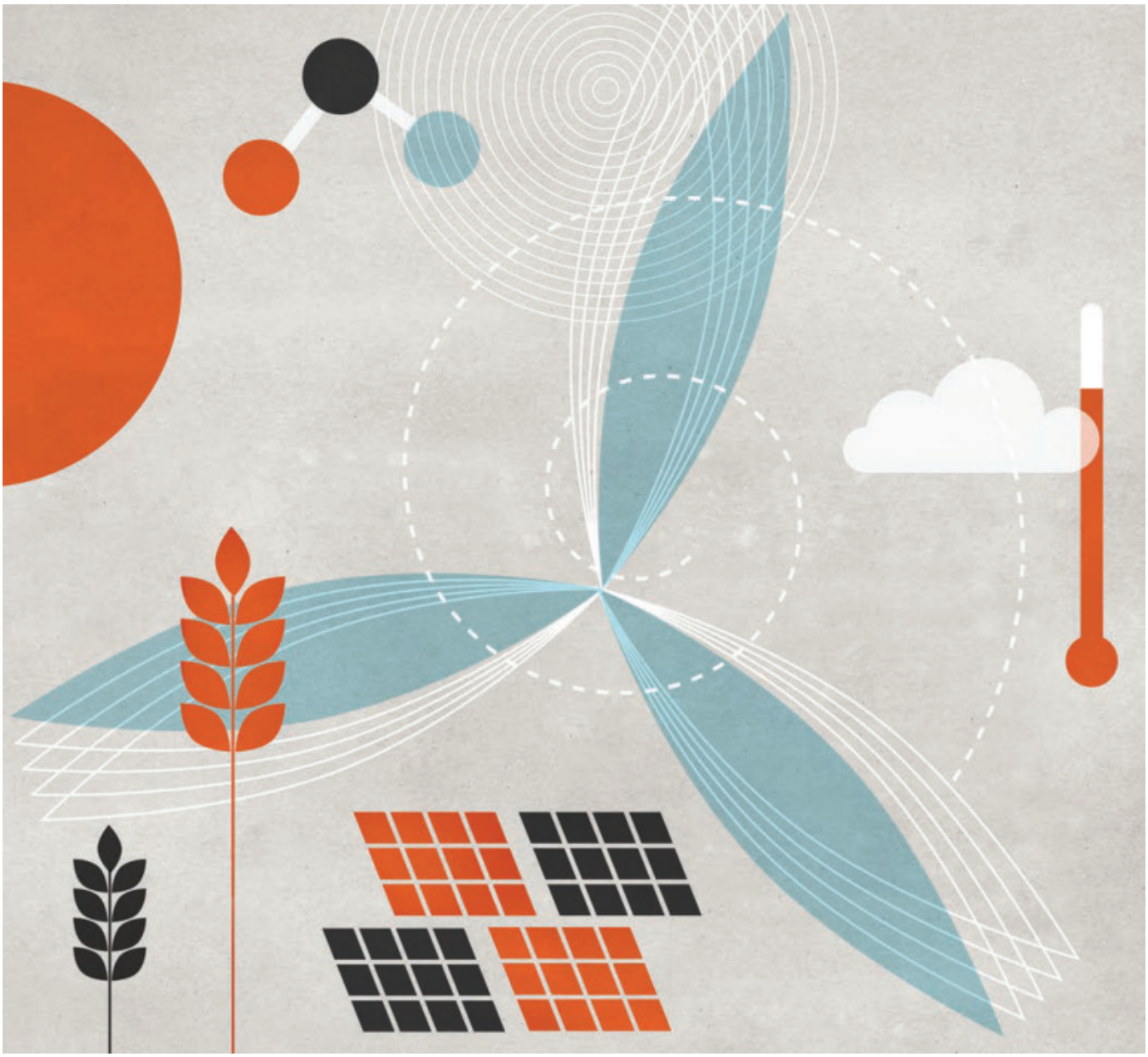
Lithium-metal batteries could offer double the energy density of the lithium-ion batteries typically used in today's EVs, but they have a drawback: it's hard to control the growth of lithium dendrites as the battery is used, which increases the risk of a fire and shortens its life. Chengcheng Fang, 32, says her lithium-metal anode solves those problems. Her technique involves applying pressure to arrange the lithium in a more orderly fashion, which hinders the growth of dendrites, the spiky structures that form as lithium ions build up on the anode. She still needs to find a way to integrate her process into existing manufacturing lines, but her innovation could theoretically allow a car to travel twice as far on a charge as existing electric cars.

Sean Hunt
Solugen

Many chemicals used in households and factories today are manufactured from petroleum. Sean Hunt, 33, cofounded Solugen, which uses enzymes and metal catalysts to turn sugar into industrial chemicals with a much lower carbon footprint. The company's first facility, in Texas, can crank out 10,000 tons per year of chemicals used in water treatment, agriculture, and industrial cleaners, offsetting more than 30,000 tons of carbon dioxide equivalents. It operates on 100% renewable electricity and doesn't generate any emissions or wastewater.

Shannon Nangle
Circe

Shannon Nangle, 33, has built a fermentation technology that converts carbon dioxide and hydrogen into fats for the food industry. "This technology will allow us to produce fats to make meat alternatives juicier and more savory, ice cream and cheese alternatives creamier, and cacao butter for truly guilt-free chocolate," Nangle says. Her main aim is to undermine the need for large-scale animal agriculture, sparing land that would otherwise be used for grazing and growing feed. "We're trying to incentivize regenerative practices to support a revitalized food system," Nangle says. "By being intentional with how we source and produce, we can provide truly delicious, climate-friendly foods."



Magi Richani
Nobell Foods

By now most people know that meat production is a nightmare for the environment, but fewer people focus on the negative ramifications of dairy production. Magi Richani, 33, is working to skip the cows, making dairy products that are less harmful while tasting just as good. “Our technology allows us to make dairy proteins directly from plants without the need for cows,” says Richani. In her view, most plant-based dairy products are missing one key ingredient: a protein called casein, which gives them their creamy texture. Nobell is making cheese using casein from genetically engineered soybeans and aims to have its first products on the market by next year.

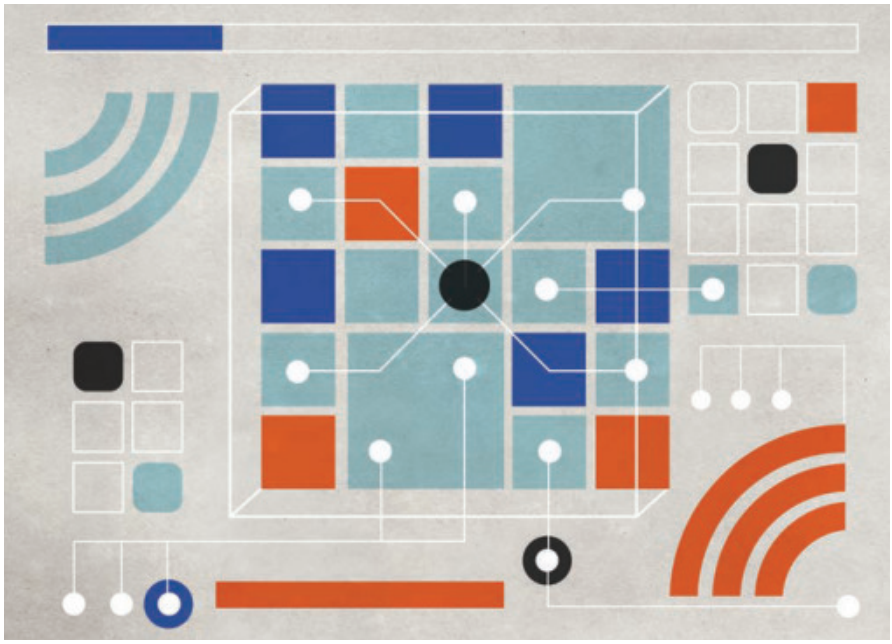
Richard Wang
Cuberg

Lithium-ion batteries are used for electric cars, but they don’t pack enough power for other critical sectors, such as aviation, heavy trucking, and marine transport. Richard Wang, 33, founded Cuberg to address this problem. He’s developed lithium-metal batteries, which have extremely high energy density, with ease of manufacturing in mind. “These advanced batteries are critical for accelerating the electrification and decarbonization of the transportation sector,” he says. Swedish battery maker Northvolt acquired his company in 2021, and Wang says Cuberg is now working toward its first demonstration flight with partners in the electric aviation sector.

While he was drinking coffee, the idea came to him that adding caffeine to perovskites could improve their performance.

Rui Wang
Westlake University

Perovskites have been a major focus of photovoltaic research in recent years because of their intriguing optoelectronic performance, but the poor stability of these synthetic materials has thwarted their commercialization. They quickly fall apart when out in the world. Rui Wang, 29, found that adding caffeine and its derivatives—an idea that occurred to him while drinking coffee—could improve the stability of perovskites “from several hours to almost five years.” His next challenge? Making a perovskite solar cell that will last for decades.



Computing

Alternative materials and approaches will transform computers—maybe sooner than you might expect.

By Prineha Narang

In less than a century, computing has transformed our society and helped spur countless innovations. We now carry in our back pockets computers that we could only have dreamed of a few decades ago. Machine-learning systems can analyze scenes and drive vehicles. And we can craft extraordinarily accurate representations of the real world—models that can be used to design nuclear reactors, simulate myriad greenhouse-gas emission scenarios, and launch a probe on a nine-year trip to study Pluto in an all-too-brief high-speed fly-by.

We fundamentally owe these capabilities to our ability to build progressively better computing devices—the transistors and other components at the heart of computer chips. But the transistor is reaching its limits, along with the traditional von Neumann architecture—the system of separate logic and memory that we use to construct computers. If we want to keep improving computer performance and energy efficiency, it's time for some fresh ideas.

There are, of course, plenty of possibilities at hand: quantum computers, optoelectronic components made from two-dimensional materials, and analog

Hongjie Liu
Reexen Technology

We live in a world of devices that are rarely or never turned off—hearing aids, various types of sensors, augmented-reality devices, smartphones. But batteries don't stay charged forever, so it's critical to minimize devices' power consumption. Hongjie Liu, 34, has created novel ultra-low-power chip designs that can extend battery life more than 10 times by more efficiently processing analog signals and digital data. "My innovation is analog preprocessing combined with mixed-signal in-memory computing, a novel processing architecture that mimics some of the principles of the human brain," he says.

Stefanie Mueller
MIT

It's easy to change the appearance of a digital photo by applying a digital filter. Now imagine the same principle applied to physical objects—clothing that could change its appearance daily or even hourly. Stefanie Mueller, 34, is developing a way to reprogram the appearance of objects using photochromic dyes with fine control over each color channel. "Developing this method required me to leverage knowledge from optics, materials science, hardware engineering, and computational optimization algorithms," she says. Mueller thinks her innovation could be useful in product design. Instead of just buying a shirt, she says, you might buy a subscription that gives that shirt a new look every day.

Uzoma Orchingwa,
Ameelio

People coming out of prison often struggle to put their lives back together, but research has shown that family contact and access to education can dramatically improve their prospects. Uzoma Orchingwa, 31, CEO and cofounder of Ameelio, wants to offer those benefits to prisoners via a free communication and education platform. A big part of the problem, in Orchingwa's view, is the $3 billion prison telecommunication industry, dominated by just two companies. "Families spend up to $500 a month to stay connected with incarcerated loved ones," he says. His goal is to disrupt that industry and, in the process, help prisoners to earn degrees and jobs, thus reducing recidivism and incarceration.

Sara Wahedi
Ehtesab

Sara Wahedi, 27, came up with the idea for Ehtesab following a suicide explosion that occurred near her home in Kabul, Afghanistan. As she searched for information after the tragedy, she wondered why a city like Kabul did not have a verified, monitored platform for emergency information—a situation that has become worse under the Taliban regime. Wahedi's app, called Ehtesab, provides real-time alerts to Kabul residents on everything from electricity outages to explosions and gunfire. The app maps these incidents and updates them; alerts are sent straight to a user's phone after they have been robustly verified.

circuitry are just a few. Many of these approaches have been discussed for years, if not decades.

But some are now reaching promising levels of maturity. In my research and that of 35 Innovators awardee Xu Zhang at Carnegie Mellon University, for example, 2D semiconductors are making their way into optoelectronic devices—the sort used in telecommunication. These devices have started to surpass the performance of conventional switches made with silicon and III-V semiconductors (compounds with elements from columns III and V on the periodic table).

Optical computing, an early approach that was later abandoned in favor of binary electronic circuitry, is also moving forward. I am fascinated by the possibility of building computers that use light as the "working fluid," passing photons around much the way our present chips do electrons.

This is already happening: silicon photonic chips are providing high energy efficiency and are helping overcome the slowdown issues in traditional GPU architectures. They can reduce the time needed to train deep-learning models, enabling the next generation of advanced AI. There are opportunities to integrate photonics with new low-power chip designs like those from TR35 awardee Hongjie Liu at Reexen Technology.

In the long term, such photonic circuits could help us approach or perhaps even surpass widely accepted limits in computing. Theoretical work in photonic information processing suggests that light can be converted to heat and vice versa, which opens up some remarkable opportunities for all-optical energy storage—essentially batteries made out of photons—and alternative computing architectures.

Many of these projects are still happening primarily in the academic realm, but we are slowly moving toward building larger-scale, more fully integrated systems. If we can continue thinking about how these ideas can be integrated into full computing systems, the coming years should see even more progress away from traditional chips and toward an array of different forms of computing. ■

Prineha Narang is the Howard Reiss Chair Professor in Physical Sciences at University of California, Los Angeles (and was a 35 Innovators honoree in 2018).

I am fascinated by the possibility of building computers that use light as the "working fluid."

Xu Zhang
Carnegie Mellon University

Moore's Law, which has powered the drive toward ever-smaller, more powerful computers, has led to the likes of AI, cloud computing, and autonomous driving. But the law is reaching its limits because the billions of devices squeezed onto a silicon chip can only get so small before the laws of physics intervene. Xu Zhang, 34, has approached the problem by developing a kind of two-dimensional semiconductor that's just atoms thick. "By transforming semiconductors from 3D to 2D, it is possible to truly push computing technologies to the ultimate atomic limit and enable a future of ubiquitous computing and ambient intelligence," Zhang says.

"By transforming semiconductors from 3D to 2D, it is possible to truly push computing technologies to the ultimate atomic limit."

Setor Zilevu
Meta and Virginia Tech

Setor Zilevu, 27, is working at the intersection of human-computer interaction and machine learning to create semi-automated, in-home therapy for stroke patients. After his father suffered a stroke, Zilevu wanted to understand how to integrate those two fields in a way that would enable patients at home to get the same type of therapy, including high-quality feedback, that they might get in a hospital. The semi-automated human-computer interaction, which Zilevu calls the "tacit computable empower" method, can be applied to other domains both within and outside health care, he says.

Maayan Ziv
AccessNow

In 2015, Maayan Ziv, now 31, created a mobile app called AccessNow in response to her frustration trying to navigate inaccessible places in her wheelchair. Users can search for, review, and discover locations that meet their needs according to over 25 criteria, including step-free entrances and accessible parking and bathrooms. In 2021, AccessNow filed a patent application regarding its development of technology to detect accessibility features based on patterns "observed" in the built environment and collect and share that information. Using deep learning, AccessNow is training a data model that's designed to deliver increasingly accurate, personalized accessibility information autonomously.

Biotechnology

We're rewriting what we thought was possible in biotech.

By Marzyeh Ghassemi

Have you heard? The tech in biotech is nailing it. Machine learning (ML) and artificial intelligence (AI) can now figure out who has a condition (perhaps better than your doctor can), establish a medical checklist to diagnose you, and help target likely treatments. AI models can help design drugs or find a new purpose for existing ones. At home, just ask your AI assistant—Siri, Alexa, Cortana, or many chatbots—to answer medical questions or talk to you about your day. Those assistants might also have access to information from the smart devices in your home—your scale could work with your Fitbit to check your health.

Are you wondering why that reality doesn't sound like the one you live in? AI has been compared to electricity—the new fuel the world runs on. But as happened with electricity, the deployment of AI in biotech has been uneven. Practical electric power systems were introduced in the 1880s, and most American cities and towns received electricity from utility companies by the 1920s. But 90% of rural America lacked electricity until Congress established the Rural Electrification Administration in 1936. We're seeing a similar unbalanced situation with AI today.

The biggest challenge ML and AI face now is ethics. Models are very powerfully built to do something specific, and not to read between the lines. In other words, the model will do only, and exactly, the thing you told it to do, often by learning in whatever way is fastest, even if the training data is highly problematic. If it turns out that male doctors don't recognize heart attacks in female patients, or if dark-skinned patients' oxygenation levels are misreported, then this is what the AI learns. Models trained this way could underdiagnose women and minorities if deployed.

It's been exciting to see technology that rewrites and improves what we thought was an established health concept—how to evaluate the need for knee surgery, for instance. With the help of technology, we can focus resources on areas of human health that are complex and chronically understudied, or we can move on from simply naming inequity issues to fixing those issues. If AI models can highlight places where our society is failing people, those people could have better options. It's also heartening to see a new focus on reproducibility and benchmarks in AI research.

What ML and AI in biotech broadly need to engage with are the holes that are unique to the study of health. Success stories like neural nets that learned to identify dogs in images were built with the help of high-quality image labeling that people were in a good position to provide. Even attempts to generate or translate human language are easily verified and audited by experts who speak a particular language.

Instead, much of biology, health, and medicine are very much in the stage of fundamental discovery. How do neurodegenerative diseases work? What environmental factors really matter? What role does nutrition play in overall human health? We don't know yet. In health and biotech, machine learning is taking on a different, more challenging, task—one that will require less engineering and more science. ■

Marzyeh Ghassemi is an assistant professor at MIT and a faculty member at the Vector Institute (and a 35 Innovators honoree in 2018).

Alex Abramson
Georgia Tech

Imagine if you could replace a vaccine jab or an insulin shot with a pill. Alex Abramson, 29, is developing a way to make it possible. Until now, pills haven't been capable of delivering drugs based on proteins and nucleic acids, since these molecules are rapidly degraded by the enzymes in the gastrointestinal tract. Further, the biological molecules are too large to pass through the tissue wall of the stomach. Abramson's innovation is a pill that falls to the bottom of the stomach and reorients itself, inserting the medicine directly into the stomach tissue.

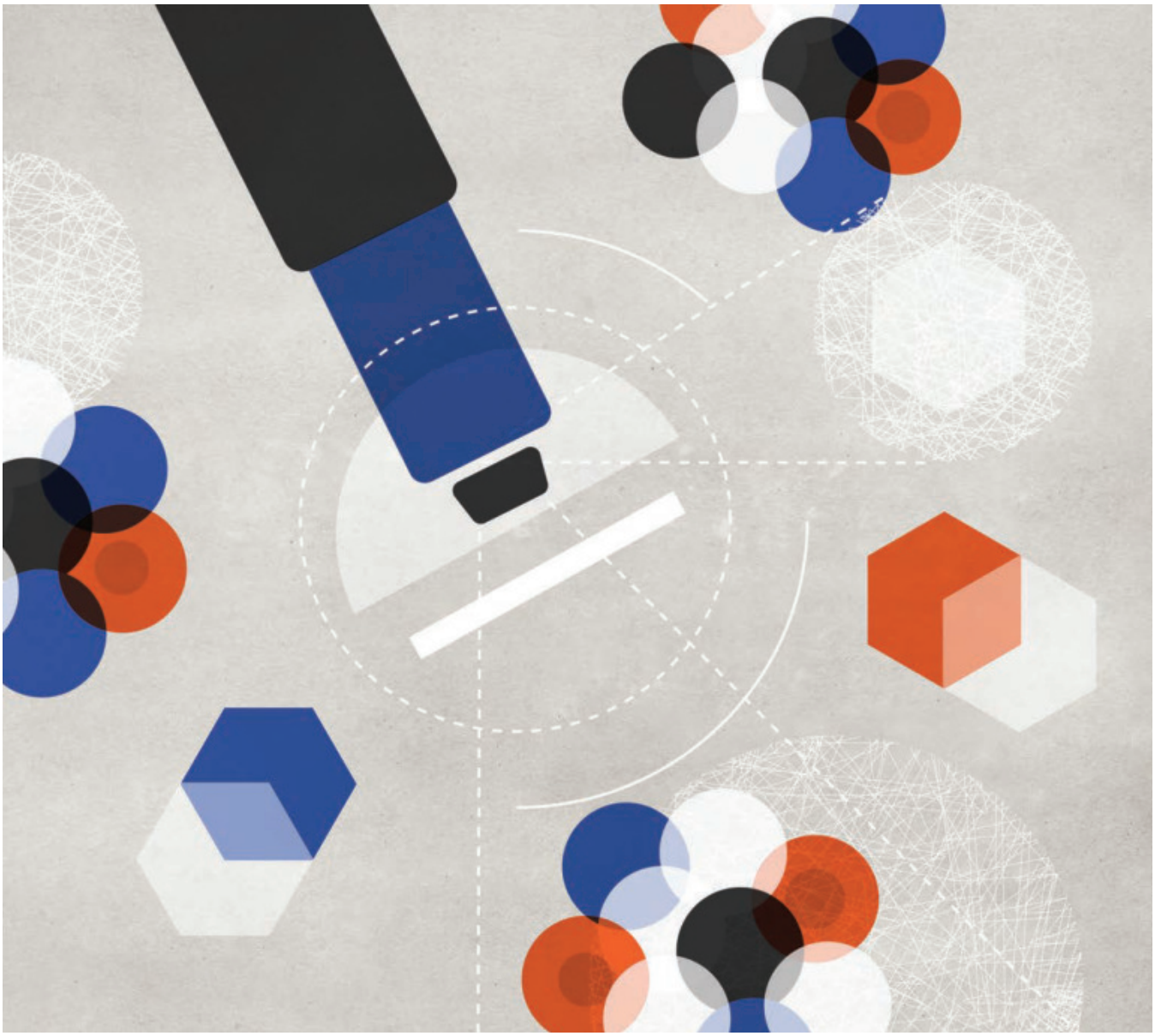
Samagya Banskota
Broad Institute of MIT and Harvard

Gene therapy has the potential to treat a wide range of otherwise intractable diseases by making precise edits to the genome. But the most common method used to deliver gene-editing components involves adeno-associated viruses, which can result in unintended, "off-target" edits. Samagya Banskota, 32, has co-invented a more efficient delivery system using engineered virus-like particles. "We now have a system that can safely and effectively deliver genome editors to multiple tissue and organ types," Banskota says. That should make it easier to develop therapies for a variety of genetic disorders.

Her method allows scientists to examine dozens or hundreds of genes in each experiment, and it works for many different types of organs and cells.

Xin Jin
Scripps Research

Recent advances have identified the genetic risks behind many human diseases, but the next big step is to observe how these genetic variations lead to the illnesses, and how we might modify or even reverse the pathologies. Xin Jin, 34, has invented a method that allows simultaneous analysis of many genes in living organs. "Previously, genetic studies were done by analyzing one gene at a time, and typically one or a few cell types at a time," she says. Her method allows scientists to examine dozens or hundreds of genes in each experiment, and it works for many different types of organs and cells. Jin is using it to better understand how genetic changes affect mental health.



Mijin Kim
Sloan Kettering Institute for Cancer Research

Ovarian cancer kills more than 184,000 women worldwide every year. A better way to detect early-stage cases could greatly lower that number. Mijin Kim, 32, combined machine learning with a special sensor to detect a blood-based "fingerprint" of ovarian cancer. Kim hopes the benefits of her liquid biopsy don't end with one illness. "This method could be rapidly adapted to the detection of many conditions," she says. "The array could be used to train an algorithm to recognize nearly any disease when given enough data from the sensor."

Benjamin Oakes
Scribe Therapeutics

The gene-editing tool CRISPR has revolutionized research, but so far it's been hard to use it to treat disease—it's proved difficult to make the treatments specific enough to be fully safe, and delivering the therapy inside the body has also been complicated. As CEO of Scribe Therapeutics, Benjamin Oakes, 33, is working to optimize novel CRISPR enzymes and ways to package the gene-editing systems to solve those problems. "Our engineered gene editors are more active and create more productive edits, are enhanced to more specifically target any part of the genome, and are more compact," Oakes says. All that makes it possible to target the underpinnings of many more diseases.

Xiao's solution is the first FDA-approved virtual-reality therapeutic for any condition.

Scott Xiao
Luminopia

Amblyopia, the leading cause of vision loss in children, is usually treated by having patients wear a patch over the stronger eye to stimulate the weaker one. Despite how prevalent the condition is, affecting 3% of children, it can be hard to get kids to comply with wearing the eye patch, partly because of social stigma. Scott Xiao, 24, has won FDA approval for an alternative: a digital therapy aimed at retraining the brain to process images from both eyes properly. It involves presenting popular TV shows slightly differently to each eye via a virtual-reality headset—making it the first FDA-approved VR therapeutic for any condition.

AI & robots

The remarkable progress in AI shouldn't be confused with creating human intelligence in machines.

By Oren Etzioni

The term "artificial intelligence" really has two meanings. AI refers both to the fundamental scientific quest to build human intelligence into computers and to the work of modeling massive amounts of data. These two endeavors are very different, both in their ambitions and in the amount of progress they have made in recent years.

Scientific AI, the quest to both construct and understand human-level intelligence, is one of the most profound challenges in all of science; it dates back to the 1950s and is likely to continue for many decades.

Data-centric AI, on the other hand, began in earnest in the 1970s with the invention of methods for automatically constructing "decision trees" and has exploded in popularity over the last decade with the resounding success of neural networks (now dubbed "deep learning"). Data-centric artificial intelligence has also been called "narrow AI" or "weak AI," but the rapid progress over the last decade or so has demonstrated its power.

Deep-learning methods, coupled with massive training data sets plus unprecedented computational power, have delivered success on a broad range of narrow tasks from speech recognition to game playing and more. The artificial-intelligence methods build predictive models that grow increasingly accurate through a compute-intensive iterative process. In previous years, the need for human-labeled data to train the AI models has been a major bottleneck in achieving success. But recently, research and development focus has shifted to ways in which the necessary labels can be created automatically, based on the internal structure of the data.

The GPT-3 language model released by OpenAI in 2020 exemplifies both the potential and the challenges of this approach. GPT-3 was trained on billions of sentences. It automatically generates highly plausible text, and even sensibly answers questions on a broad range of topics, mimicking the same language that a person might use. ▶

The bulk of the rapid progress is in data-centric AI, and the work of this year's 35 Innovators Under 35 winners are no exception.

Laura Blumenschein
Purdue University

Robots aren't generally known for their flexibility, with some exceptions. Laura Blumenschein, 29, co-invented the Vine robot, which moves and grows like a plant. Shaped like a tube, the soft robot uses air pressure to maneuver around and gets longer as material fed through its center comes out the other end. "Think of a flexible blade of grass strong enough to push itself through cracks in concrete sidewalks, but compliant enough to be bent in the wind," she says. Possible applications, says Blumenschein, include flexible intravenous catheters that allow for safer surgeries, shape-changing antennas for avoiding interference, and archaeological tools for exploring tight tunnels and ruins.

Gauri Joshi
Carnegie Mellon University

State-of-the-art machine-learning projects often require massive amounts of data and computational power. As a consequence, only a few groups with these resources control access to many machine-learning models. Gauri Joshi, 34, is working to change that by designing distributed computing algorithms that make it possible for such models to be trained using a network of devices such as cell phones or sensors. "It democratizes machine learning and makes it universally accessible without requiring expensive computing hardware and enormous amounts of training data," Joshi says.

Yoonho Kim
MIT

When treating stroke victims, doctors use a long, thin device called a guide wire to unclog the blocked blood vessels in the brain. But these manually controlled wires provide limited access to difficult-to-reach areas. Yoonho Kim, 33, developed a teleoperated robotic system that can wind its way through the brain's vascular network. "My invention enables robotically assisted procedures for treating stroke and aneurysms with much improved safety and accuracy," Kim says.

Joelle Mbatchou
Regeneron Genetics Center

Large biobanks with medical health records from millions of patients offer a view into how genetic variation can influence people's health. To take advantage of this, Joelle Mbatchou, 32, has developed a machine-learning model called Regenie that makes analyzing the data quicker and cheaper while reducing the amount of computing power required. The method could allow researchers to more easily identify genetic variants associated with specific diseases. "With the increasing number of collaborations being established across large biobanks, many of them involving individuals from diverse populations, Regenie makes it possible to leverage those data and ... potentially make discoveries which can lead to improved clinical care," she says.

Ishan Misra
Meta AI

To be accurate, many AI models need large amounts of human-labeled data. Research from Ishan Misra, 31, shows that it's possible to train these models on visual data alone, skipping the human labels. Misra believes that such self-supervised models will greatly expand the types of problems that AI can solve. "In domains like medical imaging, where labeling is expensive, self-supervised models can play a major role in rapidly developing AI models at a fraction of the cost," he says. "These models can also enable AI models to learn new skills continuously from the stream of data they observe, without human supervision." That could be especially useful for robots operating in environments that constantly change.

Kathryn Tunyasuvunakool
DeepMind

Kathryn Tunyasuvunakool, 32, was part of the team that developed AlphaFold, a machine-learning method for predicting a protein's 3D structure from its amino acid sequence. She also led the team that used AlphaFold to predict and study the structures of all human proteins, data that was made freely available to the scientific community. "If you want to get a detailed understanding of how they work, it's very helpful to know their structure," Tunyasuvunakool says of proteins. "Experimental methods exist for solving protein structures, but they can take a long time and are labor intensive. In many cases, AlphaFold can provide good-quality, actionable structural information within minutes."

Sharon Zhou
Stanford University

Generative AI, which creates entirely new content and images from existing data, is not inherently good or bad, yet many of its applications have been harmful—deepfakes, fake news articles, or chatbots that respond in toxic ways. Sharon Zhou, 29, is working to characterize the problems and advantages by developing new benchmarks with which to evaluate these systems. She notes that generative models are among the most capable AI systems we have, and yet we understand their capabilities the least. She aims to "make it possible to understand how fast our generative models are progressing at the frontier, if at all, and how they're progressing: is it safe, and to what extent can it be deployed?"

Kathleen Siminyu
Mozilla Foundation

Advances in speech and language technologies have led to tools like voice-enabled search, text-to-speech apps, speech recognition, and machine translation, but such tools only work for the languages they've been trained to recognize—typically English, French, or Chinese. For many other languages, including ones spoken by millions of Africans, they remain out of reach. Kathleen Siminyu, 28, wants to change that. She launched a fellowship program through which contributors created nine open-source African-language data sets annotated for a variety of machine-learning tasks. She sees "a possible future where all the information readily available on the internet is equally accessible in African languages as it is in English."

Alain Vaucher
IBM Research Europe

Chemists are always trying to figure out how to make new kinds of molecules. Usually, this requires a lot of research and lab experiments to get it right. Alain Vaucher, 31, made it his goal to simplify the synthesis of novel compounds. He created an AI system that analyzes related compounds to determine the chemical recipe for any molecule you desire. Via an online platform, researchers can draw the skeletal structure of the molecules they want to make. The AI then predicts which ingredients it will need, and under what conditions and in which order they should be mixed. A robot connected to the cloud then executes the instructions.

Generative models are among the most capable AI systems we have, and yet we understand their capabilities the least.

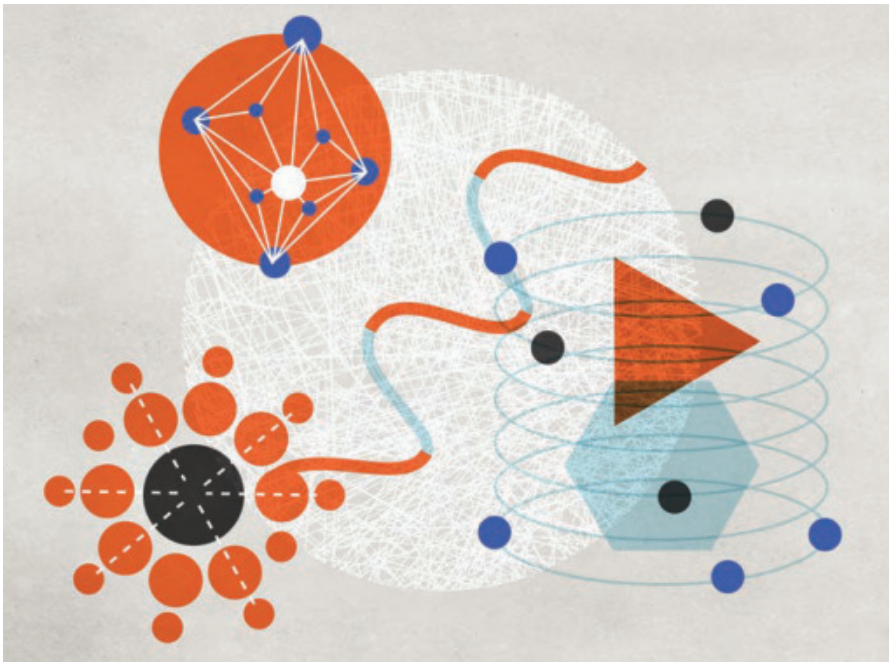
But GPT-3 suffers from several problems that researchers are working to address. It's often inconsistent—you can get contradictory answers to the same question. Second, GPT-3 is prone to "hallucinations": when asked who the president of the United States was in 1492, it will happily conjure up an answer. Third, GPT-3 is an expensive model to train and expensive to run. Fourth, GPT-3 is opaque—it's difficult to understand why it drew a particular conclusion. Finally, since GPT-3 parrots the contents of its training data, which is drawn from the web, it often spews out toxic content, including sexism, racism, xenophobia, and more. In essence, GPT-3 cannot be trusted.

Despite these challenges, researchers are investigating multi-modal versions of GPT-3 (such as DALL-E2), which create realistic images from natural-language requests. AI developers are also considering how to use these insights in robots that interact with the physical world. And AI is increasingly being applied to biology, chemistry, and other scientific disciplines to glean insights from the massive data and complexities in those fields.

The bulk of the rapid progress today is in this data-centric AI, and the work of this year's 35 Innovators Under 35 winners is no exception. While data-centric AI is powerful, it has key limitations: the systems are still designed and framed by humans. A few years ago, I wrote an article for MIT Technology Review called "How to know if artificial intelligence is about to destroy civilization." I argued that successfully formulating problems remains a distinctly human capability. Pablo Picasso famously said, "Computers are useless. They only give you answers."

We continue to anticipate the distant day when AI systems can formulate good questions—and shed more light on the fundamental scientific challenge of understanding and constructing human-level intelligence. ■

Oren Etzioni is CEO of the Allen Institute for AI and a judge for this year's 35 Innovators competition.



Materials

Materials designed and built with nanoscale components will change what's possible in every field of science and engineering.

By Julia R. Greer

In the 24 years I've worked as a materials scientist, I've always been inspired by hierarchical patterns found in nature that repeat all the way down to the molecular level. Such patterns induce remarkable properties—they strengthen our bones without making them heavy, give butterfly wings their color, and make a spiderweb silk both durable and pliant.

What if we could engineer such properties directly into manufactured materials? This could remove the need for complicated manufacturing processes to create devices like stents, microprocessors, and batteries. And eventually, we may even be able to program some degree of intelligence directly into the materials that make up such devices, which could make new features and functionality possible.

In my research group at Caltech, I study new properties of materials that emerge when you take nanoscale building blocks and organize them into 3D structures known as architectures. I predict that architected materials—substances built from the nanoscale up to have useful properties—will eventually replace conventional materials, not only in science and engineering but in many areas of daily life.

Lately, advances in 3D printing and other forms of additive manufacturing have made it possible to organize micro- and nano-size ▶

Beth Esponnette
Unspun

The clothing industry makes roughly 100 billion garments per year, and 30% are never purchased. Beth Esponnette, 34, asked if there was a way to eliminate that waste by making clothes on demand. The resulting company, Unspun, uses existing 3D scanning software as well as software developed in-house to take that scan and create a perfect pattern to weave a garment. Now she's developing what she calls a 3D weaving machine—a 3D printer that uses yarn instead of polymers or metals. Rather than making fabric and then cutting and stitching it, her method goes straight from yarn to the final product. "This innovation makes it possible for the clothing industry to have zero waste," Esponnette says.

Jia Liu
Harvard University

When doctors implant anything into a patient's body, there's a risk that the immune system will reject it. To reduce or even eliminate that risk, Jia Liu, 34, has developed flexible nanoelectronics with physical and chemical properties that mimic biological tissue. One of his designs, a stretchable mesh, could be implanted in the brain to allow scientists to safely track electrical activity from the same neurons for years, Liu says. And there are other possibilities too, he adds: "When integrated with developing tissues such as organoids, it can grow together with the developing tissue, continuously monitoring the tissue-wide activities at single-cell resolution."

Naoji Matsuhisa
University of Tokyo

Wearable devices can help monitor people's health as they go about their day, but existing ones are too rigid to maintain good skin contact. Naoji Matsuhisa, 32, has developed a stretchy diode made of thin rubber sheets that operates at frequencies as high as 13.56 megahertz, a frequency used for electronic wireless communication devices; previous stretchable semiconductor devices maxed out around 100 hertz. Whereas other stretchy circuits often involved embedding brittle electrical components into softer materials, Matsuhisa is making the components themselves flexible.

Carlos Portela
MIT

We think of materials as having certain properties—ceramic is brittle, glass can break, metal is heavy. 3D nanomaterials could flip those assumptions on their head. "Ceramics do not have to be brittle, a material's color could change on demand, and a metallic material could be as light as a feather—all due to engineered 3D nanostructures," says Carlos Portela, 30. Such materials have so far been made only in microscopic amounts in the lab, but Portela has developed a process that allows him to create 3D nanomaterials you can hold in your hand. Such materials could help address a variety of engineering challenges, he says, since they have properties that no existing material could ever attain.

Steve Xu
Northwestern University

Newborns, especially those born prematurely, often need intensive medical monitoring. That usually means sticking electrodes and sensors to the baby and connecting them via long wires to base units fixed to the wall. Steve Xu, 34, has created soft, flexible, skin-safe patches that can monitor a baby's vital signs wirelessly. Not only does Xu's technology reduce skin injuries from the adhesives—which can be life-threatening for newborns—but it removes the wires and enables skin-to-skin contact with the parents. "While this technology is useful across the entire continuum of care from cardiology to remote patient monitoring, we're focused on premature neonates," he says.

Hyunwoo Yuk
SanaHeal

We expect adhesives to work on things like paper and wood and stone, but when something is wet and pliant—like human tissue—suddenly tape and glue don't work so great. Hyunwoo Yuk, 33, has made it his goal to fix that. Taking cues from barnacles, spiderwebs, and other sticky things found in nature, he's developed bioadhesives that allow for near-instant repair of tissues and organs. "We have shown that we can seal severe bleeding and leaks in many organs within 10 seconds without preparation or extra steps, almost resembling the convenience of sealing leaky pipes with duct tape," Yuk says.

building blocks of matter into complex structures with great precision. We can now make new materials from components that range from just a little larger than 100 atoms to several millimeters in size.

This means scientists can decouple properties that have historically been linked together. For example, strong materials are typically heavy, and insulating materials like dinnerware are often brittle. But when ceramics and glass are architected by replacing solid blocks of material with a structure of the same size built of small struts, they can deform and reform like a sponge.

And there's more—architected materials can evolve in space and time in response to a pre-programmed trigger. They can morph into different shapes to respond or adapt to a new environment or a stimulus. They can be made to release objects by relaxing their grip when heated or break apart at designated locations when strained.

Thanks to this built-in responsiveness, future materials could be made with some decision-making capabilities and adaptability. Intelligent materials may be able to automatically release precise amounts of medication, heal themselves when damaged, or perform logical operations when exposed to light. In fact, some architected materials have already incorporated new kinds of logic gates that respond to either mechanical or chemical stimuli.

One area where I see great potential involves using machine learning to predict new architectures for materials that can emulate computationally trained neural networks using light instead of digital input. Eventually, artificial neural networks could be integrated into architected physical materials to make decisions, eliminating the need to first convert the input into digital signals and then process them in computers. This means materials themselves could someday be made to recognize faces or objects, process language, and classify text or numbers.

To realize this vision, we will need new computational models that can accurately capture the mechanics and physics of the additive manufacturing process for an affordable price. Additional models must be able to perform diagnostics, in real time, to determine whether any defects that form will affect performance.

And as if designing, discovering, and demonstrating new material properties weren't hard enough, we'll then have to turn prototypes into technology and manufacture the materials at scale. These tasks represent a major challenge, in part because the models haven't yet been developed.

Knowing there are many talented people working on these problems, I look forward to the day when we can create architected materials and devices imbued with the ability to make decisions on their own. ■

Julia R. Greer is a materials scientist at the California Institute of Technology, and was a 35 Innovators honoree in 2008 and a judge for this year's competition.

Judges

Pieter Abbeel
Professor, UC Berkeley; Cofounder, Covariant; Podcast host, The Robot Brains

Animashree Anandkumar
Bren Professor, Caltech; Director of AI Research, Nvidia

David Berry
CEO, Valo Health; General Partner, Flagship Pioneering

Ed Boyden
Y. Eva Tan Professor in Neurotechnology, MIT/HHMI

Meredith Broussard
Associate Professor, NYU

Yet-Ming Chiang
Kyocera Professor of Materials Science and Engineering, MIT

James Collins
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Cesar de la Fuente
Presidential Assistant Professor, University of Pennsylvania

Oren Etzioni
CEO, Allen Institute for AI; Professor Emeritus, Computer Science, University of Washington

Javier Garcia Martinez
Professor of Inorganic Chemistry, University of Alicante, Spain; President, International Union of Pure and Applied Chemistry

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Qiushi Distinguished Chair, Professor, and Dean of School of Pharmacy, Zhejiang University

Rachel Haurwitz
President and CEO, Caribou Biosciences

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Marc Lajoie
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CEO and Cofounder, Pinscreen; Distinguished Fellow, UC Berkeley

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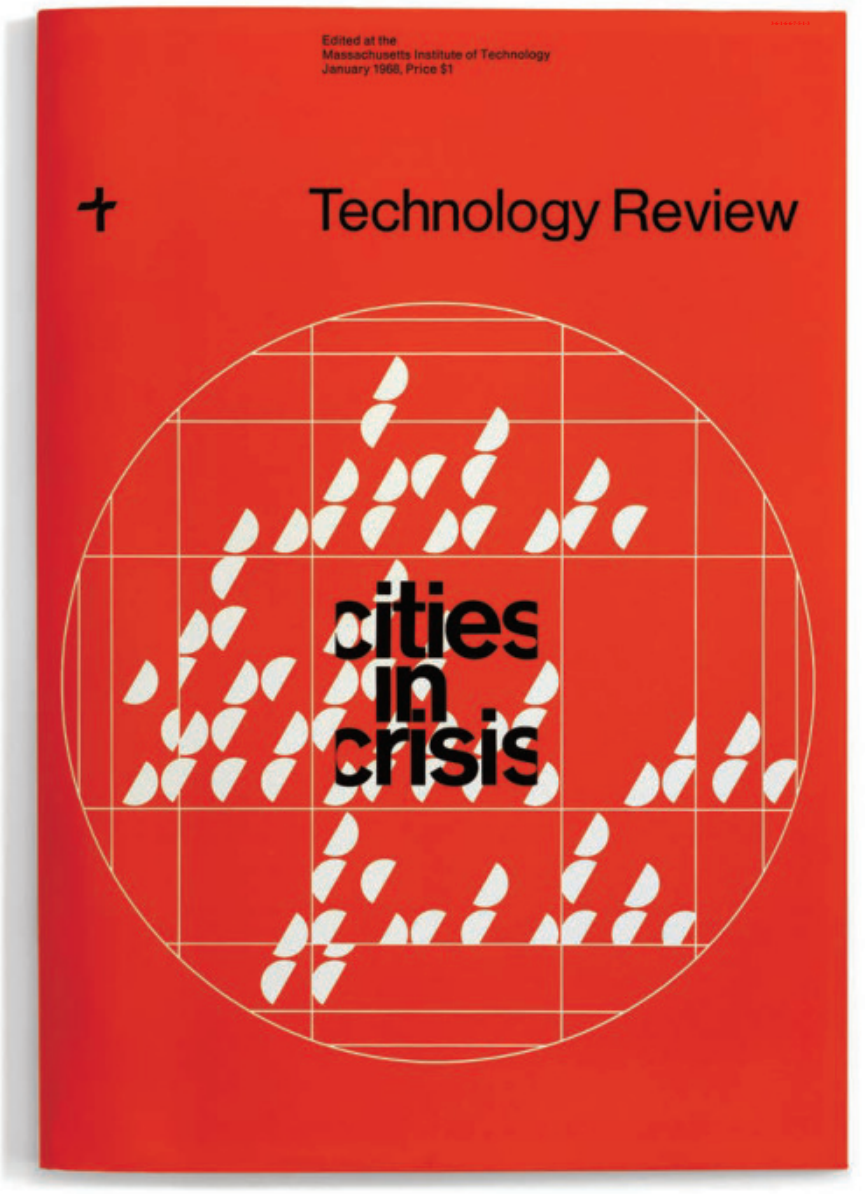
Minmin Yen
CEO and Cofounder, PhagePro

Jackie Y. Ying
Director, NanoBio Lab; A*STAR Senior Fellow

Ben Zhao
Neubauer Professor of Computer Science, University of Chicago

Cities. Still in crisis.

Reading about the challenges our cities faced half a century ago feels frustratingly familiar.



"Our possible city must therefore have certain characteristics: adaptability coupled with a sense of past and future continuity; equalization of opportunity; a diversity of species, habitats, and ways of life. It must be open and responsive, experimental, and engaging. These are crucial qualities for the future. However general, they direct attention to particular possibilities. But these possibilities will not come of themselves. Our cities become more rigid, segregated, and unresponsive. Are there chances to move in an opposite direction?"

—KEVIN LYNCH,
"THE POSSIBLE CITY,"
JANUARY 1968

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