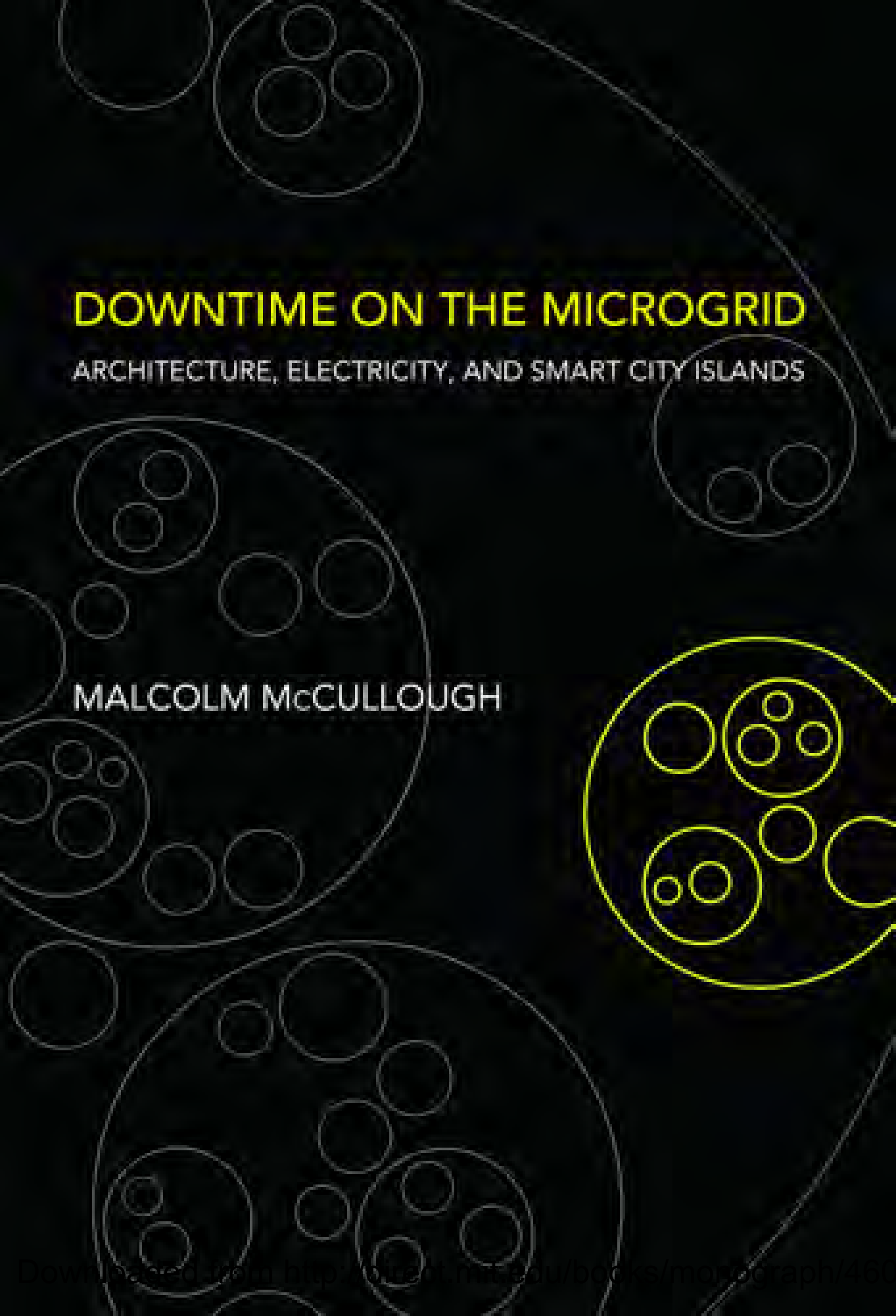
DOWNTIME ON THE MICROGRID

ARCHITECTURE, ELECTRICITY, AND SMART CITY ISLANDS

MALCOLM McCULLOUGH



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For Cal, with excess energy

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PREFACE

If you are looking for a bright spot in dark times, please read on. Personally I find a *new grid awareness* downright delightful. You might discover this too. For me, writing this book has restored some daily gratitude and wonder. I feel better about powering things up each day. I now see the city differently. I happily notice electric substations. I can make a bit more sense of the clean technology news. I see past utopians and doomers. I unplug more often, and worry less about technological dependency the rest of the time. When asked what I think of *the smart city*, as alas I so frequently am in my field, I feel like I have something more humane to say. When faced with a sea of tech-forward white papers, all brimming with solutions, I feel a better chance of not drowning in them. If any of that sounds like you too, please read on.

This work has sought to proceed in *science, technology, and society*, a human-centered approach that takes the long view on technological futurism. In this way, I hope to have assembled a wider synthesis, and in that I hope is a more readable package, than industry professionals ever seem to have time to write. If nothing else, this brings the perspective of the university to a fast-changing field. I remain

confident that the university still cultivates knowledge in ways complementary to the internet.

Please rest assured that having attempted this, I have become all the more aware of all that I do not know. By attempting such work, so outside my usual domain and so easily able to be dismissed as dotage, I am amazed to have gotten this far. Yet the readers and editors have found something here. For my part, I feel that I have learned something important about living in a *world of systems*, while at the same time learning something specific to all that talk of the smart city. Toward the latter, I hope to have sounded something contemporary for that favorite theme in science, technology, and society, and that most foundational system of them all, electricity.

In all this, I hardly feel alone. By now, so many people want to know so much more about anything clean, green, and local or micro that more than just a few of us deserve to go out and investigate as best we can. You are probably neither an engineer nor a policy analyst, and nor am I. Yet we too can seek a better story. Wherever scholars and journalists can begin to make sense of all those white papers out there, that in itself can help. While there are some good overviews of the grid to be found, alas they also seldom bring enough experiential perspective, nor a focus on the built environment, nor the kind of long-term ethnographic wisdom sought through science, technology, and society. On any of these, I found the academic literature surprisingly scant. Thus I have cast the net quite widely. So in reading this book, please be aware that the work has been developed, framed, and I hope balanced with many potential audiences in mind—for example, in architecture, interaction design, cultural studies of infrastructure, social history of technology, and last but not least, perhaps a few amused readers within the vast and changing electric power industry itself. For

when interesting cultural choices lie ahead, sometimes new perspectives can help. However many the narratives from infrastructure builders, policy wonks, doomsday preppers, or green communitarians, still the situation invites new voices. You don't have to second-guess the experts, and this book does not try to do so, to join in this vital new conversation.

Here is how I got to this. After years on the lecture circuit about interactivity in the city, mostly working at the intersection of architecture and interaction design, I do not think I was alone in my dismay. For by the early 2010s, not only had the distant digital overlords taken over and darkened the internet, but also an increasingly stormy world also made it all seem far too fragile. Resilience thus became what to work on, and resilience is mostly local. By now, local means not only food, the arts, and independent small businesses but also clean energy. The 2010s are when local electricity became viable and vital too. The more that the planetary and political climate worsened, the more I found this happy fact impossible to ignore. So when in the year 2016 it appeared that not even a fossil-fuel-sponsored Washington could stop the clean local energy boom, I dared to undertake this study. Perhaps in my own advancing years, I hoped to learn enough to help a local dot org from my public university post. Perhaps somehow I wanted to find a conversation between architects and the big infrastructure builders, who appear more capable than anyone else in this field at the moment. But mostly I just hoped there was yet something good about the smart city.

I began by interviewing dozens of mostly academic counterparts. On this basis, I arranged a month in residence at that epicenter of energy futures sobriety, Lawrence Berkeley National Laboratory. That visit has helped me calibrate much before and since. I continue to read volumes as only a full-time academic has time to do, and with a range quite outside the usual literature. As ever, I seek to write not

as a journalist, nor as an expert, nor as a public intellectual, since I am none of those, but instead just in search of some coherent academic retrospect. I hope this result is just that. I trust that a print book is still the best medium for that.

So if you are looking for a more reflective complement to all the latest feeds, posts, and conferences out there, or even if you are simply looking for some thoughts that might last, there is still nothing quite like a carefully edited book. I hope you will find this one quite carefully assembled, and as a result, more readable than all those ones full of analyses and acronyms. I hope this will feel pleasant, unanticipated, and somehow useful. I hope it will hold up as a thoughtful view of a remarkable time. I know it has been worth my while. I do flip a light switch a little bit differently now, and more to the point, I am altogether happier about being here now in such an activated world.

ACKNOWLEDGMENTS

Any book comes about from the contributions of many, and that is worth saying every time. So with apologies for inevitable omissions, let me give thanks of several kinds.

Without question, the first thanks must be to Katie Helke, editor of the Science, Technology, and Society series at the MIT Press, who saw how to shape this work for the Infrastructures series there. Thanks as well to Infrastructures curators Geoff Bowker and Paul Edwards for taking a chance on that list's first work from the field of architecture and urbanism. Also at the MIT Press, thanks to former senior editor Roger Conover for early strategic advice, Justin Kehoe and Deborah Cantor-Adams for seeing the work through production, and designer Yasuyo Iguchi, without whom I cannot imagine doing a book.

Then in some ways, the deepest thanks are to those who offered encouragement at early formative stages of the work: colleagues Geoff Thun and Kathy Velikov, who are seldom without insights on infrastructures themselves; colleague Robert Fishman, who as acting dean at the time understood where my efforts were going; David Nye, master social historian of electrification, without whose encouragement I would have immediately ceased and desisted; fellow technological

culture writer and design educator William Braham, whose Architecture and Energy conference at Penn in 2012 was an early indicator of expanding cultural prospects; and Paul Edwards, aforementioned, who while still at Michigan heard some of the earliest notions of this project. The Science, Technology, and Society program here, which Paul's many efforts so sustained, is clearly where this project of mine began. Likewise here at the University of Michigan, I am grateful for the openness of expert colleagues in the Energy Institute, particularly Johanna Mathieu and Ian Hiskins, especially for the general-interest workshop they ran in May 2018.

Thanks to Rick Diamond for enabling my short stay (in September 2016) at Lawrence Berkeley National Laboratory, where despite my lack of scientific credentials I met with receptivity at every turn. Thanks there in particular to Steve Selkowitz for interest in the long view, and to Bruce Nordman for sharing the goal of legible work for a wider audience.

For numerous interviews beyond the above, done mostly by Skype when not face-to-face in metro Detroit or Berkeley, mostly in summer 2016 or spring 2017, and with apologies for omissions, my thanks to Gretchen Bakke, Rich Brown, Lucy Bullivant, Carla Diana, Anna Dyson, Gordon Feller, Harrison Fraker, Harry Giles, Ruari Glynn, Gabriel Harp, Philip Haves, Dan Hill, Rusty Klassen, Carol Menassa, Kiel Moe, Stephanie Ohshita, Janie Page, Chris Payne, James Pierce, Jim Saber, Johannes Schwank, Phoebe Sengers, Elizabeth Shove, Linda Simon, Rebecca Slayton, Jennie Stephens, Margaret Taylor, and Hal Wilhite. I would have soon ceased work without these conversations too. But of course even when not so well prepared myself for quite such a range of greatness, I consistently met with openness. It all made wonder why there are only a few times in university life when quite such a series of conversations can occur.

For generously offering use of images, I am distinctly grateful to the artists João Penalva and Stanza. Without these works, the project would have a different tone. I am also grateful to the many others, mentioned throughout the work, who have furnished illustrations. As almost every query quickly met with a favorable reply, this too has been encouraging.

Last but never least, thanks to my lovelies, Kit and Cal, for hearing out the play-by-play, which on any given day went something like, "Can you believe I am doing an old-fashioned print book, on electricity no less, so far into the twenty-first century?" They did believe it, for despite the times, we do have a house that is not only lined but indeed lived with books.

He stepped back. “The telescope’s focused,” he said. “Don’t move it, just look through.” Kirsten looked, but at first she couldn’t comprehend what she was seeing. She stepped back. “It isn’t possible,” she said. “But there it is. Look again.” In the distance, pinpricks of light arranged into a grid. There, plainly visible on the side of a hill some miles distant: a town, or a village, whose streets were lit up with electricity.

—Emily St. John Mandel, *Station Eleven* (2014)

1.1 Restoring some sense of wonder: João Penalva, *Looking Up in Osaka*, Ebisu Higashi cho-me, *Naniiwa-ku* #3 (2005–2006). Courtesy of the artist and Simon Lee Gallery.

1 AT THE EDGE

What would you miss? To live in such a vulnerable world takes some new readiness to let go of *something*.[1]

What would you miss if the power went out? This is not a lament on technological dependency. Those don't get far. This is not a checklist for doomsday preppers, nor a manual for building your own ecovillage, nor a moral guide to greener living. This is not just about installing diesel backup generators. Those spew heavy fumes and soon run out of fuel. This is not a policy analysis, nor a business plan. Despite origins in design disciplines, this is not another vision for a shiny utopian technofuture. Please don't look here for any of those.

If the regional electricity grid went out for a week, what would soon seem most unnatural about that? When did constant electric power start to seem more natural than its absence? How much more of an annoyance would a weeklong outage be to you than it would have been to your grandparents? How much more would there be to miss now than, say, fifty years ago, when as the joke at the time had it, "If it weren't for electricity, we'd all be watching television by candlelight."[2]

Where would you prefer to be in an outage? What kinds of institutions make good meeting points? What kinds of places should plan for resilience? What happens when some have power and some have not? Although critical sites like hospitals, fire stations, or server farms already have their backups, where else should also stay up?

What if your site generates its own? Does making your own electricity foster more thoughtful everyday use? When does at least some monitoring, tuning, and participation feel welcome? Does having it physically present make it more pleasant to keep in mind?

⚡

You might well read this with both pragmatism and wonder. Today almost any individual, organization, or town might generate some of their own electric power, most of the time. Although interconnecting it all gets quite complicated, this simple advantage can no longer be dismissed as naive idealism. Local electricity has quickly become a practical reality. Today a great many players seek a piece of this boom, and millions of owners at least take comfort that it is happening.

So this is about *a new grid awareness*, based in physical surroundings. It is about finding the role of the built environment in the local electricity boom. It is not so much about energy conservation or emergency preparation, which are both necessary but soon tedious topics, as instead about the rediscovery of abundance, expression of cultural change, and participation in local networks. That might seem an unusual invitation for a matter more usually approached through engineering and public policy, but it has become a worthy one. Even just to restore some sense of wonder (figure 1.1), a new grid awareness is worth cultivating.

In particular, this read is an appreciation of inhabitable scale. In an age obsessed with the handheld smartphone and the vast distant network, any scale between those may need rediscovery itself. In the arguments to follow, places and not just individuals frame cultural change. Buildings and districts mediate the scale of local electricity.

This is about innovation and resilience at the edges. As ecologists, for instance, know quite well, more adaptation occurs around the boundaries of different spatial patterns than in their more uniformly consolidated centers. In an unexpected disturbance, a diverse cluster often responds better than a larger monoculture, however well that has been engineered for more expected variations.[3] Today those abstract systemic principles increasingly apply to local clusters of solar panels, battery storage, two-way distributions, network controllers, and local aggregations for trading and balancing. In a world now full of sensate, adaptive systems, even something formerly so uniform as the electric grid may no longer need one size to fit all. Whereas once most grid innovation took place in central power plants, today it has moved out to the nodes—on millions of sites, integrated into other physical structures and systems, with a growing diversity of owners and operators. In a simple name for this complex phenomenon, strategists now call it *grid edge*.[4]

To bring an experiential perspective to these developments, consider *architecture's grid edge*. That is not an expression in everyday use. While unlikely to go viral, it does provide a convenient name for renewed appreciation of surroundings. After all, most electricity gets used in buildings. Always-on power has disappeared into normalcy. Thus to speak of architecture's grid edge invites new design expressions of living with increasingly local, knowable, and better-appreciated electricity. It reflects the many grid edge elements now becoming components of physical surroundings. There it

implies cultural value change. It emphasizes that inhabitation matters: most meaningful social change gets framed by familiar material circumstances. After all, the word "architecture," in its larger sense, means any spatial configuration that people are going to have to live with.

In taking this position, it can help to think of architecture as an accumulation of systems. In that, it can help to think of systems as sets of workable material circumstances. For in a material system, the spatial configuration matters as much as the features of any individual components. The desired performance emerges from tuning this system in the context of other systems. For in the built environment, each new technology layers into the surroundings, and somehow remakes them in the process. Electrification did so a century ago, with profound cultural impact, and likewise information technology does so today. The latter is not just new smartphone apps. Far more technology gets built into surroundings than gets carried about in your bag. Not all of that is in smart homes: in buildings, far more diverse layerings of these technologies occur in larger commercial, institutional, industrial, and transportation settings than in so many millions of similar individual dwellings.

This is an invitation to rethink major categories like "the" grid, or what back in the twentieth century they called "the system." To imagine each of these as one total thing has done little good, especially if it ever seems out of control. Instead, you probably sense a growing need to adapt amid a *world of systems*. Within this ever-changing world, some of the largest systems seem admittedly vulnerable, but also more variable, and increasingly able to be interconnected, and intermittent.[5]

So if you encounter hype on *the smart city*, or wonder what, if anything, that means to your work, you might start by thinking of it as many and not one. You might ask

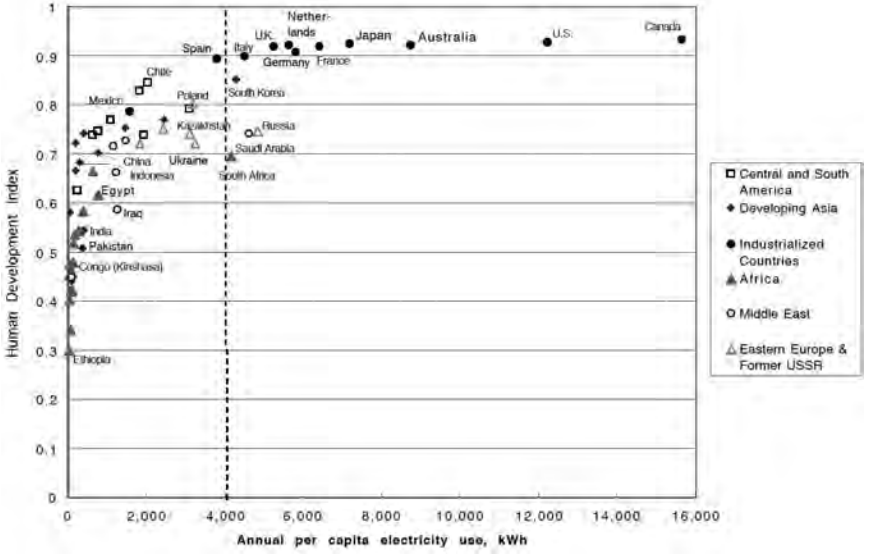
when, where, and for whom. If you hear talk of a *smartgrid*, you might look for its innovations at its edges, among the millions of devices now clustering there. To find something real and positive amid so much smart city futurism, consider the physically embedded context of its power systems. There at architecture's grid edge, today anyone might face new priorities. In those, you might expect that the worthwhile opportunities are local, or at least the worthwhile questions are so. If so, read on.

⚡

Opportunities in local electricity futures seem most relevant for the billion people who never had much electricity in the first place. Just as mobile phones have especially transformed places that lacked any previous landline service, likewise local electricity makes all the more difference in places without a reliable electric grid. Now as more local arrangements become viable, development can often bypass the difficulties of getting onto a grid. Although the results seldom match the very real advantages of a larger regional service, particularly at balancing diverse sources and schedules, alas much of humanity never had such a service.

That is not just a technical challenge. Anthropologists who study this social process assert how electric power gets "advocated, contested, ignored, . . . negotiated and selected" differently in one culture than another.[6] As ever, the success of externally imposed infrastructures depends on how well they fit with social practices on the ground. More local programs can have many social and economic advantages, and more attractive political arrangements. Many more protagonists gain the opportunity to build local prosperity without becoming the bottom of someone else's economic pyramid.

Whatever the circumstances, little else provides such a direct benefit. A famous graph (figure 1.2) using United Nations data shows a high correlation between electric power usage (per capita) and Human Development Index, which is still one of the better measures of a better life.[7] At least that is so throughout the middle range of electrical usage, between extremes of deprivation at one end and waste at the other. To do some good today, assist a solar village project someplace where phone minutes are the currency, where charging stations are the new well (the casual everyday meeting place), and where fuel for cooking would otherwise be foraged wood.



1.2 The famous graph of correlation between electricity consumption and the Human Development Index. Alan Pasternak, Lawrence Livermore National Laboratory, 2000.

However positive and important that faraway story now grows, in its countless instances, meanwhile change comes closer to home. To the billion people in places that have had electricity longest, and among whom the gentle readers here surely reside, new challenges arise. Existing conventions can hardly continue. Likewise here in North America, which is the locus of this writing, interesting choices lie ahead.

The United States' twentieth-century electric power grid has been called the greatest invention ever. In a retrospect written just after the millennium, the National Academy of Engineering formally declared it number 1 on its list of "20 Greatest [American] Engineering Achievements of the 20th Century." The grid delivers power everywhere, reliably, amid ever-changing circumstances, almost entirely without storage, to be produced and consumed in the same instant. Today, though, this most fundamental technological marvel of modern life is changing more rapidly than it has for a lifetime.

In doing so it becomes a story for anyone. Having long since disappeared into daily life, with its operations invisibly left to engineers and policy analysts, now electricity comes back into the open again and back into more widespread cultural debate. There it invites new forms of appreciation, expression, ownership, and participation. If nobody can agree quite how, almost everyone can agree that major, epochal change has begun. For instance, in 2017, chief executive Anna Pramaggiore of Chicago's Commonwealth Edison observed, "In effect we are turning our own foundation upside down. . . . And this is a revolution. They don't come around often but we are in the midst of one right now."[8]

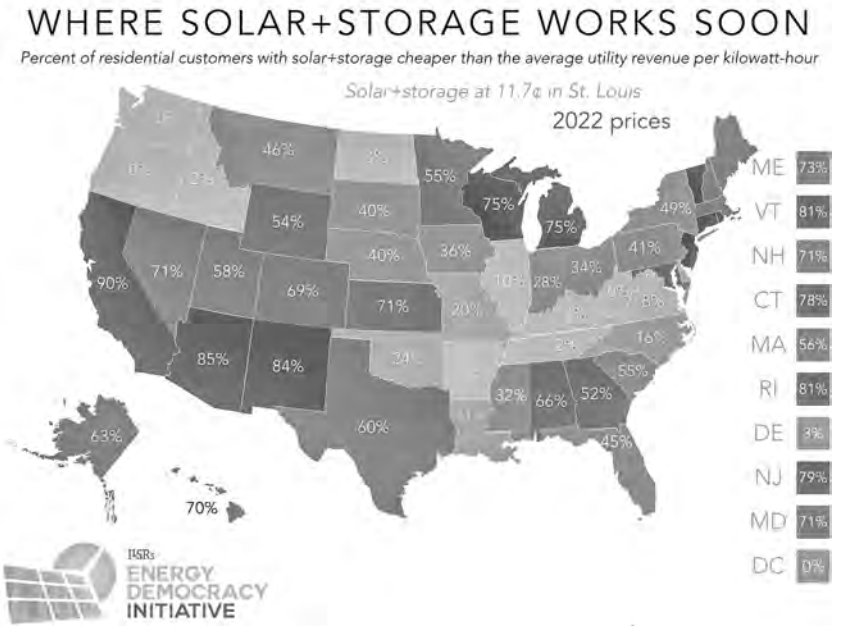
Now as some historians would be quick to point out, Commonwealth Edison is the very company through which,

little more than a century ago, the pioneering tycoon Samuel Insull first built the centralized model of natural monopoly that has prevailed to this day. There began the model that public utility companies still work to defend. So it is noteworthy for such a company to admit upheaval from inside. As this anecdote illustrates from the source, it appears that the question of who gets to play has been cast open.

The aspiring players are many. Whether with voices of economics, environmentalism, urbanism, policy, technology, democracy, or philosophy, many more fields seek new grid awareness. Now as these diverse voices join the conversation, some disclaimer seems necessary. To join this broad agenda does not mean ignorance of long-established expertise. As each discipline explains the scene to itself, it does so with a right to find out, not with better answers. To speak in everyday language does not mean disrespect for the latest complexities in policy. While perhaps no one field can claim highest new insights, many more fields must now seek and express their own, and any one might gain indirect insights from another.

Here in one such grasp of the scene, note four trends, obvious to all, now turning the formerly invisible world of electricity upside down. For brevity, call them energy decentralization, decarbonization, Internet of Things, and external threats.

First, decentralization inherently widens interests. Anyone can now participate in grid reform. As strategists like to put it, "The world is ready to move from energy generated centrally to energy generated everywhere."[9] The cost of wind and solar generation has become competitive with conventional means in many regions (figure 1.3). Local network operations by owners have improved. Storage, the most vital new component, is now advancing more rapidly, under aggressive speculations. Thus the public generally



1.3 Electricity generated everywhere: a forecast map of the percent of households by state where power from solar plus storage will cost no more than grid electricity. Institute for Local Self-Reliance.

wants renewable energy and is unimpressed when utility companies say that it cannot yet work.[10] Alas, this bright green democratic future brings dark times for existing utility operators. You don't have to be a policy analyst to see how defectors to locally owned generation leave everyone else with higher per capita rates, which induce still more defectors. And you don't have to be an engineer to see that the variability of wind and solar power, and especially the two-way flow of power, make the challenge of scheduling and balancing it all only worse. In that, the need for long-distance infrastructure does not disappear. Since the greatest diversity of sources provides the best means of balancing

ever-changing supplies and demands, the best practices of power quality remain grid-wide. Almost everything about that technology, alas, has been designed for one-way power flow, and much about policy seeks to perpetuate that. Hence these issues have become everyday fare in green journalism.

Second, for larger reasons of climate justice and carbon reduction, many more systems must move to cleaner energy. The cleaner that electricity becomes, the more things should use it instead of using fossil fuels. So long as fuels are being burned, it remains physically more efficient to use the heat and pressure directly, rather than first convert it and then transmit it as electricity. Yet it may not be cleaner. When measured against emissions as opposed to physical efficiency, an equivalent amount of work done with remote electric power can be cleaner than done with so many millions of smaller sites of combustion. A gigawatt hour from a large thermal power plant is much cleaner than twenty years ago, thanks to recent shifts from burning coal to two-cycle natural gas. For the moment, and despite its external problems, that conversion has been North America's largest recent means of decarbonization. Thus while no electric vehicle should claim to be zero emissions until charged from sources that are zero too, already a fleet of them might be cleaner than an equivalent number powered by their own internal combustion engines. Then as generation increasingly comes from emission-free sources, many other uses go electric as well. If ever all sources of electricity were clean, then everything should be electric.[11] Whether such an increase in demand for electricity could drive better grid reform is a more delicate question, however.

Third, and as the main basis for the smart city, digital devices infuse all of this. A culture of information technology that has creatively disrupted resource flows in so many other walks of life now also reshapes the electric power industry. The result is almost always called *smartgrid*. By now that can

mean just about anything. But in short, it most usually describes the versatile, real-time, two-way coupling of distributed supply and variable demand. It means new markets, practices, and platforms. As usual for the Internet of Things, it embraces more monitoring, tracing, and tuning. While it has always been important for energy-intensive users like factories, the Internet of Things also now becomes an attractive distinction in commercial designs and a lifestyle element for always-online inhabitants. On the whole, embedded intelligence does tend to increase the viable range of variations. Thus in a 2015 report on the "energy revolution," the business magazine *Forbes* summarized it: "In effect, energy is the last domino of the information age. . . . Clean energy is one of the most dynamic sectors in the world—hot start-ups, technological whizbangery, cutthroat competition, billions in venture-capital investments, a race against the climate clock."[12]

Last but hardly least among these four main driving trends, ever more unpredictable threats arise. For many people this is enough in itself to create grid awareness. Alas, to recite too much of this quickly makes for gloomy reading, but in short, as has become all too evident in the daily news cycle, an aging infrastructure faces increasing disruptions.

Aging makes even its smallest everyday faults more troublesome. In an unequaled tour for the general reader, anthropologist Gretchen Bakke observes how badly the grid has been "fraying."[13] In an annual review for the year 2017, at this writing, the American Society of Civil Engineers gave the entire energy infrastructure a barely passing grade of D+.[14] While most everyday faults come from the usual small sources like a tree falling, the grid's overall age often compounds the effects.

Then the big disasters hit. If nothing else prompts grid reform sooner, it happens right after superstorms. Storms are disasters that anyone might understand. By contrast,

although the different external threat of cyberattack is real, it has not yet not been dramatically realized in North America. A successful attack on a large enough substation could bring down a region for weeks, and the cybersecurity to prevent that adds yet another layer of central infrastructure costs. So far the realized threats come from unprecedentedly heavy weather.

Where more than distribution has failed, the outages are not just overnight (figure 1.4). Here already are new haves and have-nots; repairs do not seem to occur equitably. For instance, at this writing, Florida had been impressively restored after Hurricane Irma, but much of Puerto Rico faced months without electric service after Hurricane Maria. As a consequence of its humanitarian crisis, the case of Puerto Rico became newsworthy as a forefront in debates on energy democracy.

1.4 Outages are not just overnight when major equipment fails: a RecX "spare tire" recovery transformer arrives at a substation. Courtesy of ABB.

Who gets to play? Why would anyone who is not an economist, engineer, or policy analyst care to read (or write) about grid edge developments? To the rest of us, it does seem like one of the more positive trends of the times. Throughout the decade of the 2010s in North America, the field has rapidly diversified. Grid reform has been accelerating, and no amount of denial from Washington has been able to stop it. Developments in *clean green local micro* energy have become community causes, legislative debates, investor crazes, and mainstream news.

Of course the investor-owned public utility companies say they have got this. Only they have the means to interconnect, maintain, and operationally balance so much large, dangerous infrastructure. Much of this is indeed an engineering consideration; what happens to stabilize such giant voltage waveforms in the first few seconds and minutes after a disruption involves some impressive physics, and is best done across a large, diverse network. Yet the situation is inevitably also political. The utilities have every incentive to maintain consensus that their monopolies are natural. Yet today they are no longer the only ones providing power. They are no longer necessarily the most innovative builders of energy infrastructure, especially its new layers of information infrastructure. They no longer have the only legitimate positions in energy policy debate.

In a prominent case of what sociologist Michel Callon has described as a *hybrid forum*, today a heterogeneous mix of voices counters the utilities' aging monoculture (figure 1.5).[15] Neighborhoods, governments, dot orgs, industries, commercial real estate developers, individual homeowners, and corporate server farms all weigh in. These many counterparts in this debate do not lack expertise. Major infrastructure builders like Siemens or Schneider Electric propose innovative technological solutions. Online

1.5 Joining the hybrid forum.

organizations like the Clean Coalition, Smart Electric Power Alliance, or Institute for Local Self-Reliance counter with civic and egalitarian concerns as well as policy advocacy and innovation. Major environmentalist networks like 350.org expose entrenched opposition. Economists debate how to value resilience and not just price efficiency. Urban planners advocate local energy governance, whether for municipal ownership as in Boulder, Colorado, community choice as in California and now Illinois, or design initiatives as in New York's much-watched Reforming Energy Vision. Thus the politics has urban geography. Energy democracy debates arise not only because so few cities control their own power but also since neighborhood- and district-scale developments are such an important locus of cultural identity.

When expertise itself diffuses, however, and as plurality inevitably redistributes trust, not all may go so well. Alas, the internet hardly guarantees a democratic forum. Debate soon fills not only with disinformation from entrenched controlling interests but also with wild misconceptions from the fringes. Advocates with no real background weigh in on complex matters of engineering and policy. The more utopian or dystopian their scenarios, the more quickly those spread.

Lest this writing be too easily misread as another small drop in that flood, do take a moment to understand what is warranted. This writing has no self-interested agenda to promote, nor any firsthand experience at building new infrastructure, nor any claim to refute better-informed expertise. It just asks how so many different players can claim to have separate, proprietary answers on those. It asks the hybrid forum to find fresh perspective on the built environment. In doing so, it points out that inhabitable scale is often both the locus and the subject matter of hybrid forums. Any expertise is in the continuing relevance of surroundings amid the increasing prevalence of interactivity. From that perspective, any proprietary, always-on technological future needs questioning. From many perspectives, locality needs attention. The idea that one place can be different from another has vitality in many fields. So does the idea that infrastructures and localities remake one another. The disciplines of architecture and urbanism somehow understand this. Indeed buildings and cities have been been radically remade by electrification before. Seen in historic perspective, that aspect of locality has useful analogies today, when pervasive information technologies increasingly become a matter of context. As architecture and urbanism know well, there is much more to context than geocoded position. Habitual activities and institutions shape local differences not only in space but also sensibility. The local

material context is where social and technical change couple most tightly, and where they interplay as cause and effect. Without such embodiment in habitual contexts, externally conceived programs don't get far.

In the spirit of hybrid forum, consider what follows as work in *science, technology, and society*. Although the name of that field is often abbreviated as STS, too many acronyms soon make a text unreadable. Most works on electricity are loaded with acronyms. So by contrast, let this writing avoid acronyms altogether. To begin from a single representative word instead, this diverse scholarly field frequently unites on the cultural study of *systems*. Although that work mostly arises from social historians of technology, sociologists of science, or analysts of technology policy, it often takes an interest in the built environment. There it takes an interest in the material circumstances of living with technological systems. There it emphasizes how systems have become so intrinsic to modern life that not everyone senses their history, paradigms, or unintended consequences.

A *system* is a set of processes and things brought together, and operated for the advantages it provides for stability, scale, and dynamic control.[16] Its advantages are mostly internal. Its structure of accumulations, flows, and feedback loops is of greater interest than any one device it contains. This structure makes it behave differently in a given set of circumstances than some other arrangement would do. At least within the conditions for which it has been engineered, a system adapts. According to the consensual definition on Wikipedia, *adaptation* is "the tendency of a system to make internal changes needed to protect itself and keep fulfilling its purpose."[17] Choosing "places to intervene in a system,"

as the ecologist Donella Meadows famously put it, matters especially for more resilient design. Since "systems surprise us," as Meadows advised, it is better to adapt along with them than to expect command and control in advance.[18]

In a much-admired recent history of such ideas, literary scholar and Re:Enlightenment project founder Clifford Siskin explains how system became a fundamental, especially viable way of shaping knowledge and working in the world. "Even in our best efforts to connect system to history, system has been strangely sublimated into an intellectual issue: an idea that carries and accumulates meanings rather than as an object that works in the world—or doesn't—to produce them." To Siskin, phenomena of use shape a system, more so than an idea, law, or formulation can do. Form, situation, habit, and grasp tend to matter; "we need to engage system as not just an abstract concept or idea but as something materially in the world."[19] Beyond thinking of the world itself as a system, as Isaac Newton so influentially did, today this means operating in a world full of systems.

Of course multiple systems might influence one another. A system maintains itself not only through the interdependency of its own parts but also in reaction to externalities, whether random disturbances or recurrent exchanges with other systems. More remarkable systems exhibit not only internal stability but adaptive response to context too. Self-reorganization occurs more easily in clusters. Many emergent advantages cannot easily be formulated, simulated, owned, or governed. Complexity instead invites discovery, tuning, and adaptation.

Such a situational perspective on systems helps explain so much outside interest in the likes of electric power networks. The externalities are not all technical or environmental. Organizational, social, and political context can create disturbances too. Technological systems, especially the largest

ones, not only create but also are created by shifting sociopolitical outlooks. They are not culturally value neutral.

As eminent works in science, technology, and society have often emphasized, electric power grids are cultural systems. Perhaps because the internet has become the main disruptor, too little such critique has addressed the built environment. Back when it was being called "cyberspace," the internet was imagined to negate geometry and place. Today's soaring city rents increasingly suggest otherwise. Today the internet layers onto the city and purportedly makes it smart. On this, science, technology, and society work has frequently admired the role of architecture and the city, but has too seldom come from architects and urban designers themselves. Of course, the built environment embodies and alters attitudes; new infrastructures more often layer onto than outright replace older ones; and together, social and technological change play out amid the contexts of everyday life.

Otherwise, because infrastructure builders too easily assume all is technology driven, and because the distant digital overlords increasingly own it all from their cloud, the latest futurism tends toward the macro scale. As the media critic Ian Bogost has put it, "Everyone is already living inside one big computer."[20] There the prevailing narrative too easily assumes convergence, efficiency, omnivision, monetization, technoutopia, and much else wrapped up in the businesslike language of *the smart city*.

So the time is right for new chapters in the social history of electrical technology, written from the edges, amid changing values, enacted in the built environment and implemented at local scale. Consider this work as one of what must become many diverse voices in that movement.

Today there is a sticky new word to help frame such conversations: *microgrids*! Whatever it may or may not portend, the word has caught on and propagated. Relative to more cumbersome policy jargon (and acronyms) of the energy industry, this one is viral enough to be considered a meme. When a word catches on, and fresh media feeds take it all over the place, all that a long print read such as this one can do is to offer some retrospect. At this writing, across the years 2016 to 2018, microgrid implementations have been few (around two thousand in America, according to one respected tracker), but the forecasts and discussions have been many.[21] The number of newsletter stories has steadily increased.[22] From many of the larger perspectives just described, these are the years in which the microgrid became a significant cultural theme. On a practical level, it has gained traction from great opportunities in "solar plus storage"—a way to overcome the limitation that the sun goes down each night. It has also become a regular feature of energy futures conferences. More abstractly, it eventually implies much else about local resilience.

In short, *microgrid* means a local energy network that can intermittently run independently of the larger interconnecting grid. To do so, it needs not only local generation but local control too. With a good mix of energy sources, adequate technologies of switching, monitoring, and voltage regulation, plus preferably some battery storage, a microgrid might run independently for any amount of time, in what is called *island* mode. So then its capacity to go in and out of that mode matters most. Thus to emphasize the importance of this dynamic, the noun has been verbed: *to island*. Microgrids can island.

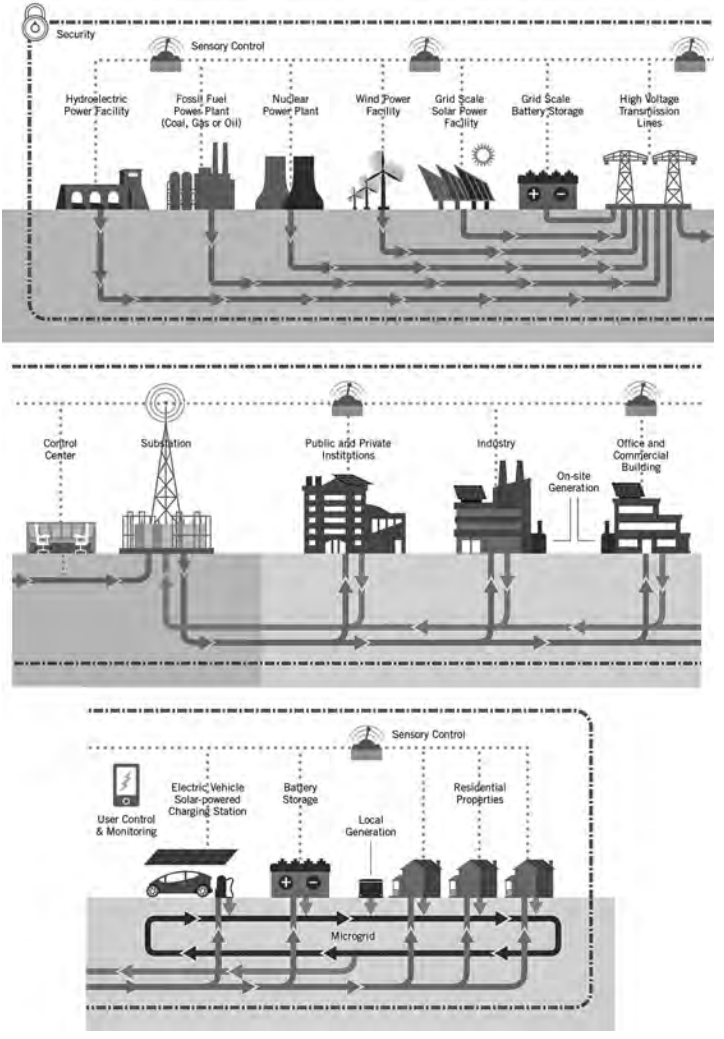
To build a microgrid adds new layers of costs, responsibilities, physical wiring, and technical challenges to a resource that one could formerly take for granted. For

this simple reason not many microgrids exist. Since it also adds new layers of resilience, ownership, and appreciation, however, many more are in the works. Those are not to be underestimated amid such precarious times, nor amid the rise of clean local energy. Hence despite the additional cost overhead, and with energy independence in mind, microgrid prototypes now get debated, funded, and built. The idea has certainly become a part of any larger grid reform visions (figure 1.6).

When a period of open *interpretative flexibility* supplants closed old technological certainties, new concepts invite unconventional investigations. So if the idea of a microgrid has a cool factor that exceeds its immediate advantages, it is well warranted at the moment. The word does appear to appeal to the hybrid forum; at some point strategists, utopians, doomers, engineers, economists, policy wonks, citizens, political lobbyists, and community activists each have used it. When so many separate perspectives simultaneously perceive one same phenomenon, and especially when many distinct disciplines each find themselves at work on one same challenge, often a new sensibility arises.[23] It is time for some cultural research into what this meme means.[24]

For instance, even the US Department of Energy acknowledges this development, even when otherwise politically forbidden to mention much else about life beyond fossil fuels. In a set of public education pages about technology development, the department explains, "Because they are able to operate while the main grid is down, microgrids can strengthen grid resilience and help mitigate grid disturbances as well as function as a grid resource for faster system response and recovery."[25]

Microgrid is not a new idea: the century-old district steam plant that predates the mainstream grid is a microgrid of a sort. Microgrid is not a yet a major market trend:



1.6 Microgrid (highlighted here in the bottom panel) in the context of "The Power Industry of the Future," as illustrated for New York's widely watched Reforming Energy Vision (2015). Courtesy of New York Power Authority.

growth is high but volumes are as yet insignificant. So far, microgrids are costly and few. It is not yet a major economic shift the way wind and solar generation have become, although local control of solar plus storage would certainly kick that boom to a much-higher, incontestably advantageous level. A microgrid is not necessarily even green: many run on dirty diesel backup generators. Nevertheless, it has become a provocative way to assert the comfort of grid awareness and the value of resilience. It provides a useful local counterpoint to all those all-connecting, all-seeing, imaginaries of *the smart city*.

Despite the use of the definite article, "the" grid has always been an aggregate; it has always had many distinct regions and pools. Back before they all interconnected, and especially back when each application (streetcars, for instance) had its own power systems, islands of service were the norm. Using them as a part of a larger system had no need for a trendy verb. Today that aggregate quality gets rediscovered. When enough small pieces can intermittently connect or disconnect as necessary, then in the aggregate they can conceivably improve, not worsen, the stability and agility of the larger grid that loosely joins them. Clusters thus can increase resilience.

Ultimately, if such an archipelago becomes indistinguishable from any larger, more centralized entity, it may no longer make sense to speak of "the" grid with the definite article in the singular. It also may no longer make sense to plan so many grids from the top, nor to expect any one technological layer to feed all of them. Thus it was at a microgrid conference in 2017 where Commonwealth Edison's chief executive gave the remarks cited earlier on a "revolution," now "turning the industry upside down," in which microgrids "will emerge as a defining infrastructure."[26]

As the disciplines of architecture and urban design understand best, a city is an aggregate and not a continuum. In the long read to follow, let the narrative slowly arc toward that prospect. When faced with more totalizing visions of *the smart city*, architecture and urbanism could do more to emphasize this reality. To put it in systems thinking, the aggregate city provides a vital balance between autonomy and connectivity, where specialized zones develop in clusters. Or to put it as a city council might do, sets of premium infrastructure districts have become urban economic generators.

In a foremost principle of urban design, persistent aggregations of built form provide good social infrastructure. Rents soar highest in city centers that would be impossible to imagine without their architecture. Great halls, courtyards, town houses, towers, canal frontages, plazas, and landmarks persist, even as their uses change. Their enduring affordances for good city life surpass the sameness of suburban sprawl or the privations of small town life. Their effectiveness depends on how their boundaries and networks get clustered and nested. There the passage of persons, goods, resource flows, and data is carefully filtered, often intermittently. Then when conditions change, so do those boundaries and flows. Despite the usual use of the definite article, "the" smart city is never one all-connecting system.

At the moment, a search on "smart city islands" brings up a few infrastructure plans for geographic islands (land surrounded by water, such as Chongming's Dongtan Eco-City in Shanghai), and not for islands within infrastructure itself. There is less to be found about capacity for intermittency surrounded by requirements for connectivity. Turn the phase around, however, and the search results are null at this writing. Despite all the millions of posts about all things conceivably being smart at any conceivable scale, at this writing there is not a one with the phrase "islands in the smart city."

This is surprising because so many prototypes of the smart city have been built in specially planned development districts quite separate from the complexities of the metropolitan core. Like Google/Alphabet's oft-cited Toronto waterfront experiment by Sidewalk Labs, the autonomous vehicle campus in Michigan, or Korea's larger, earlier, oft-criticized experiment at New Songdo, prototypes of the smart city prefer to work from the ground up in their quest for whole systems integration at district scale. In a pattern consistent with the largest urban commercial development projects like Canary Wharf, Hudson Yards, or any number of phases of Shenzhen, these developments do create islands. While their flows of information and capital may be continuous, their engagement with the surrounding city is not. This tempts architects and urbanists to consider the inverse: What would it take for a district to remain very much part of the city, yet be somehow occasionally self-sufficient?

To island one resource temporarily does not mean to disconnect from all others at once. A neighborhood temporarily on an electrical microgrid probably does not suspend water or internet connections as well. To island a resource formerly considered so uniform and universal as electricity raises political tensions too. It creates a new kind of haves and have-nots. Nevertheless, to island responsibly, intermittently, and as a part of a diverse cluster can bring advantages to all.

Thus for islands, in the plural, as a noun, instead the better word has been *archipelago*. It describes not just a plurality but also a meaningful set. Islands in an archipelago frequently share some economic, political, or cultural identity. This implies sufficient density among necessarily separate entities. It implies emergence, but without the possibility of a continuum. In its most usual, geographic use, the word describes an island chain. In architecture and the city,

however, it depicts the necessity of contrasts, distinctions, and boundaries within the cluster. Yet almost no version of the smart city mentions archipelagos. You don't have to fear the totalitarian potentials of perpetual connectivity to see, just from that simple omission, that there is something quite wrong with those always-on futures.

Islands interconnect intermittently. Often, in the relations of more loosely clustered small systems with more tightly engineered larger systems, the more interesting opportunities are out at the edges.

With grid edge in mind, this is the shape of the argument to follow. To declare such a road map in advance may help in examining a complex field of increasingly general interest. Toward that aim, several keywords have been introduced here in advance (figure 1.7). Then in the respective chapters ahead, and in the spirit of new grid awareness, begin with a longer historic perspective on electrification. Given the existing abundance of stories on origins with Thomas Edison and Nikola Tesla, let this one instead focus on situations in architecture and the city. Next consider the overall contemporary challenge of local electricity, as so quickly outlined above, in a bit more detail. Do so with the belief that many more voices now belong in a hybrid forum. When everyone knows things must change, but nobody knows quite how, much more widespread grid awareness seems wise. Then to take the local perspective, take a look at the fast-moving microgrid meme. Do so in an integrative way with hindsight, which is what long-form print does best. From that, consider architecture's grid edge, and approach it more as a manifestation of local electricity than by the more usual agendas of smart green building. Next, given that nothing

Grid Edge	*Millions of on-site, mostly owner-operated elements that now dominate electric power innovations.*
Architecture's Grid Edge	*Grid edge elements experienced as a part of physical surroundings, and performing as components of smart green building.*
World of Systems	*The circumstances of living adaptively amid many systems, not just subject to command and control by "the system."*
Hybrid Forum	*The social and political context for debates on policy change, urban design, and heterogeneous engineering.*
The Smart City	*A techo-utopian quest, whose cultural image always lies just beyond actual developments in informatics for city services.*
Smartgrid	*The project, mostly by infrastructure builders, to create an end-to-end, realtime, two-way, transaction network for electricity.*
Archipelago	*A dense, diverse set of islands with intermittent connections, emergent effects and collective identity.*
Downtime	*Here, not just involuntary outages, but also occasional voluntary intermittency, as well as naturally passive operations.*

1.7 A few key terms in the narrative.

should be called smart without appropriate opportunities for participation, note the importance of interactivity. Microgrids run on a new layer of local digital systems. Together, let this series of investigations begin to inform that larger question of archipelagos.

Since so much writing on grid reform is laden with pitches and acronyms, at least something written for a wider readership might try to tell it otherwise. Here, let this narrative seek a long view and some alternative storylines. Let its language be rich but readable, and do not let its lack of practical acronyms imply disregard for specialists in technology and policy. Let it provide a retrospective portrait of a moment (the years 2016–2018) more than any sort of prediction or plan. More specifically, understand this project as a cultural look at how the microgrid meme has catalyzed not only a new grid awareness but perhaps also the beginnings of a major cultural shift away from taking electricity for granted.

"What would you miss" need not anticipate crisis, however. It can also describe everyday islands. The point is that connecting everything always everywhere may not sustain. Since each island in an archipelago might make different choices, with different local resources, and different physical context, and none would have always everything, this too becomes a fair meaning of the question. It also recasts the issue, however, from a question of technological dependency to a question technological appropriateness. Where is intermittency appropriate? Under the right conditions, might more kinds of natural, passive, and unconditioned operations feel right? This is asked amid a rise in digital temperance. As in recent cultural corrections against internet overconsumption, so with electrical use: might a new awareness welcome momentary, daily, and seasonal patterns of voluntary intermittency? What does it mean to consider that prospect

in the context of architecture, where for instance traditional or newly net-zero systems need no additional power, and where, don't forget, at least some physical advantages of the built environment still function passably in power outages. So that becomes a third meaning of the question.

With all that in mind, consider one last keyword: *downtime*. Let that mean more besides outages. Let it hold three different meanings to the question, "What would you miss?" Within the context of electricity, consider downtime as outright emergencies, downtime as temporary islands from larger infrastructures, and downtime as natural operations without need for external power. The word obviously has other meanings too, whether in measuring the high reliability of networks or expressing the high sensitivity of participation. In that sense, people themselves need some downtime. From that, take a physiological metaphor for the limits of always-on systems—one worth repeating in some arguments to follow: a heart must always beat, but a brain needs some rest.

Downtime on the microgrid invokes a rich range of perspectives on a matter too often taken as distantly objective engineering and policy. It implies something about where you are. It asks how acceptably that place might disconnect. In perhaps its most obvious interpretation, downtime on the microgrid describes your island staying up while the larger grid is down. After all, resilience is almost always local.

Here then begins a long read on the microgrid meme, from the perspective of the built environment, with an emphasis on longer shifts in sensibility. Although this writing must seem academic in character, nevertheless it invites the general reader. Although it comes from a design domain, nevertheless it may be best read across disciplinary boundaries, even by full-time participants in the building of

a brighter, greener future, even in the electric power industry. Even for them, and now too for the rest of us, local electricity now invites transdisciplinary inquiries, increasingly hybrid forums, and at least a few more kinds of guides.

NOTES

1 At the Edge

1. "What would you miss?," the first line here, likewise appears as the leader in the press endleaves for the paperback edition of novelist Emily St. John Mandel's *Station Eleven* (New York: Alfred A. Knopf, 2014). Yet it is too inclusive a question to credit to any one source. Meanwhile, "the vulnerable world of the Anthropocene" is best summarized in Roy Scranton's terse, remarkably readable *Learning to Die in the Anthropocene: Reflections on the End of a Civilization* (San Francisco: City Lights Books, 2015). Then that's it for the dystopian keynote! *Downtime on the Microgrid* is not a work of dystopian doom and gloom, nor conversely is it technoutopian. In an era and nation ever less prepared for ambiguity and intermittency, this book seeks both of those, and thus a middle ground.

2. "Watching television by candlelight" is attributed to the stand-up comedian George Gobel, in a televised tribute to Thomas Edison, by the prominent producer David O. Selznick, in 1954.

3. See Andrew Zolli and Anne Marie Healy, *Resilience: Why Things Bounce Back* (New York: Simon and Schuster, 2012), 93–117.

4. The term "grid edge" was coined by Greentech Media in 2013. See Mike Munsell, "Greentech Media Defines the Future of the Electricity System, and It's Called Grid Edge," Greentech Media, October 7, 2013, https://www.greentechmedia.com/articles/read/greentech-media-defines-the-future-of-the-electricity-system-and-its-called#gs.40x4an.

5. Clifford Siskin, *System: The Shaping of Modern Knowledge* (Cambridge, MA: MIT Press, 2016), 3–21.

6. Tanja Winther, *The Impact of Electricity: Development, Desires and Dilemmas* (New York: Berghan, 2008), 217.

7. Alan D. Pasternak, "The United Nations' Human Development Index and Electricity Use, 60 Countries, 1997," in *Global Energy Futures and Human Development: A Framework for Analysis* (Livermore, CA: Lawrence Livermore National Laboratory, October 2000).

8. Elisa Wood, "Microgrid 2017: ComEd CEO Sees Microgrids Emerging as 'Defining Infrastructure,'" Microgrid Knowledge, November 10, 2017, https://microgridknowledge.com/microgrid-2017-com-ed.

9. Paul Hawken, *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming* (New York: Penguin, 2017).

10. David Roberts, "Utilities Have a Problem: The Public Wants 100% Renewable Energy, and Quick," Vox, September 14, 2018, https://www.vox.com/energy-and-environment/2018/9/14/17853884/utilities-renewable-energy-100-percent-public-opinion.

11. David Roberts, "The Key to Tackling Climate Change: Electrify Everything," Vox, September 19, 2016, https://www.vox.com/2016/9/19/12938086/electrify-everything.

12. Greg Satell, "How the Energy Revolution Will Transform How We Live and Work," *Forbes*, February 8, 2015, www.forbes.com/sites/gregsatell/2015/02/08/how-the-energy-revolution-will-transform-how-we-live-and-work/.

13. Gretchen Bakke, *The Grid: The Fraying Wires between Americans and Our Energy Future* (New York: Bloomsbury, 2016). Bakke's best seller was on Bill Gates's book picks list for 2016.

14. "2017 Infrastructure Report Card," American Society of Civil Engineers, 2017, https://www.infrastructurereportcard.org.

15. Michel Callon, Pierre Lascoumes, and Yannick Barthe, *Acting in an Uncertain World: An Essay on Technical Democracy* (Cambridge, MA: MIT Press, 2009).

16. Siskin, *System*.

17. Wikipedia, "Adaptation," Fall 2017. Alas, this definition around self-adapting systems seems self-referential.

18. Donella Meadows, *Thinking in Systems* (White River Junction, VT: Chelsea Green, 2008), 145–165, 86.

19. Siskin, *System*, 30, 3.

20. Ian Bogost, "You Are Already Living Inside a Computer," *Atlantic*, September 14, 2017, https://www.theatlantic.com/technology/archive/2017/09/you-are-already-living-inside-a-computer/539193.

21. "U.S. Microgrids 2017: Market Drivers, Analysis and Forecast," Wood Mackenzie, November 2017, https://www.greentechmedia.com/research/report/us-microgrids-2017.

22. Across this period of writing, 2016–2018, I have steadily monitored feeds from Greentech Media, *Microgrid Knowledge*, Navigant Research, Rocky Mountain Institute, Smart Electric Power Alliance, and more.

23. Ian Hacking, *Historical Ontology* (Cambridge, MA: Harvard University Press, 2002).

24. For reliable standard definitions and measures in microgrids, without a stake in building the results, this project relies on the work of the Lawrence Berkeley National Laboratory, which I visited for a month in fall 2016, while on academic leave and researching this book.

25. Office of Electricity, "The Role of Microgrids in Helping to Advance the Nation's Energy System," US Department of Energy, 2017, https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/role-microgrids-helping.

26. Wood, "Microgrid 2017."

2 Electrification's Eras

1. Richard Pence, ed., *The Next Greatest Thing* (Washington, DC: National Rural Electric Cooperative Association, 1984), 1.

2. Morris Cooke, "Plan for a Nation-Wide Development of Rural Electrification," in *The Next Greatest Thing*, ed. Richard Pence (Washington, DC: National Rural Electric Cooperative Association, 1984), 61–62.

3. David Cushman Coyle, ed., *Electric Power on the Farm* (Washington, DC: US Rural Electrification Administration, 1936).

4. Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983), 17, 7, 6.

5. Vijay Vaitheesswaran, *Power to the People: How the Coming Energy Revolution Will Transform an Industry, Change Our Lives, and Maybe Even Save the Planet* (New York: Farrar, Straus and Giroux, 2003), 32.

6. Walt Patterson, *Transforming Electricity: The Coming Generation of Change* (London: Earthscan 1999), 1, 12–13.

7. Gretchen Bakke, *The Grid: The Fraying Wires between Americans and Our Energy Future* (New York: Bloomsbury, 2016).

8. David E. Nye, *America's Assembly Line* (Cambridge, MA: MIT Press. 2013).

9. Tyler Hamilton, *Mad Like Tesla: Underdog Inventors and the Relentless Pursuit of Clean Energy* (Toronto: ECW Press, 2011).

10. Bakke, *The Grid*.

11. Of the many histories on the Columbian Exposition, see Harold Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880–1930* (Chicago: University of Chicago Press, 1991).

12. David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880–1940* (Cambridge, MA: MIT Press, 1990), 37–41.

13. "Jeremiah D. Lambert, *The Power Brokers: The Struggle to Shape and Control the Electric Power Industry* (Cambridge, MA: MIT Press, 2015), 10.

14. Bakke has sketched this origin well: "The hydroelectric plant at Niagara Falls was the closing bell on the effervescent, chaotic immensely creative and inventive activity of the previous seventeen years. 1879, the first arc light grid in San Francisco; 1882, the first low-voltage, direct current grid in New York; 1887, the first alternating current grid; 1891, proven long-distance high voltage transmission. And in 1896, the completion of the first large-scale generating station at Niagara Falls, together with the first long-distance transmission wires in constant use, the total adoption of parallel circuits, incandescent lighting, and the equal near total adoption of alternating current. America had her grid." Bakke, *The Grid*, 54.

15. E. T. Whitaker, *A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century* (London: Longmans, Green, and Co., 1910), 1.

16. Linda Simon, *Dark Light: Electricity and Anxiety from the Telegraph to the X-ray* (Boston: Houghton Mifflin Harcourt, 2004), 3.

17. Simon, *Dark Light*, 4.

18. Simon, *Dark Light*, 169.

19. Nye, *Electrifying America*, 156, 138–184.

20. Nye, *Electrifying America*, 156.

21. Thomas P. Hughes, "How to Think about Technology and Culture," in *Human-Built World: How to Think about Technology and Culture* (Chicago: University of Chicago Press, 2005), 111–132.

22. Nye, *Electrifying America*, 138.

23. Joel Tarr and Gabriel Dupuy, eds., *Technology and the Rise of the Networked City in Europe and America* (Philadelphia: Temple University Press, 1988).

24. Ithiel de Sola Pool, ed., *The Social Impact of the Telephone* (Cambridge, MA: MIT Press, 1977).

25. Lewis Mumford, *Sticks and Stones: A Study of American Architecture and Civilization* (New York: Boni, 1924), 163, 164.

26. To me, as a resident of metro Detroit, these are local legends. On all this as an effect of electrification, Nye has researched and told it well in *America's Assembly Line*.

27. Reyner Banham, *Theory and Design in the First Machine Age* (Cambridge, MA: MIT Press, 1960), 10.

28. Filippo Tomasso Marinetti, cited in Banham, *Theory and Design in the First Machine Age*, 125.

29. Talbot Faulkner Hamlin, *The American Spirit in Architecture* (New Haven, CT: Yale University Press, 1926), 258.

30. Banham, *Theory and Design in the First Machine Age*, 11.

31. Elizabeth Shove, *Comfort, Cleanliness, Convenience: The Social Organization of Normality* (Oxford: Berg, 2003), 117–158.

32. Ronald Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1996), 155–166.

33. "The New Deal shifted the majority of American families to an asset strategy for economic security through state-enframed home ownership of electrically modern dwellings." Tobey, *Technology as Freedom*, 209.

34. Tobey, *Technology as Freedom*, 69–71. Aside from lights, and the flat iron, which 80 percent of electrified and 60 percent of all homes owned, no other electrical appliance was held by a majority, with the vacuum cleaner, second most, owned by just 20 percent of all homes, and the clothes washer by 10 percent.

35. Platt, *The Electric City*, 269.

36. David E. Nye, *When the Lights Went Out: A History of Blackouts in America* (Cambridge, MA: MIT Press, 2010), 144.

37. Lambert, *The Power Brokers*, 19, citing Samuel Insull, *Central Station Electric Service*, ed. William Eugene Kiely (Chicago, private printing, 1915), 116–117.

38. Bakke, *The Grid*, 66.

39. Lambert, *The Power Brokers*, 15

40. Lambert, *The Power Brokers*, 49.

41. Lambert, *The Power Brokers*, 49, citing Platt, *The Electric City*, 276.

42. Institute for Energy Research, July 2014, https://www.instituteforenergyresearch.org.

43. Gifford Pinchot, cited in Morris Cooke, "Plan for a Nation-Wide Development of Rural Electrification," cited in Pence, *The Next Greatest Thing*, 61–62.

44. Hughes (*Networks of Power*, 370) provides an oft-cited summary:

1. Economies of scale, in steam turbine generation
2. Locating these giant power plants near population centers
3. High-voltage transmission to load centers
4. Cultivating mass consumption especially via rate differentials
5. Interconnecting power plants to optimize their different characteristics
6. Interconnection of loads to aid diversification and balancing
7. Centralizing control
8. Forecasting loads
9. Lowering peak capacity and scheduling maintenance via interconnection
10. Accepting government regulation to establish natural monopoly
11. Achieving consistent return on investment so as to obtain affordable capital

45. Hughes, *Networks of Power*, 1.

46. Bakke, *The Grid*, xviii.

3 Smart Green Blues

1. Lester Brown, *The Great Transition: Shifting from Fossil Fuels to Solar and Wind Energy* (New York: W. W. Norton, 2015), 17, 150. Here he continues, "Our relation with the natural world will change from one where we are in conflict with nature to one where we are in sync with it."

2. Brown, *The Great Transition*, 141.

3. Gretchen Bakke, *The Grid: The Fraying Wires between Americans and Our Energy Future* (New York: Bloomsbury, 2016).

4. Brown, *The Great Transition*, 76.

5. Trevor Pinch and Wiebe Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Help Each Other," in *The Social Construction of Technological Systems*, ed. Wiebe Bijker, Trevor Pinch, and Thomas P. Hughes (Cambridge, MA: MIT Press, 2012), 11–44. "By this we mean that there is not only flexibility in how people think of or interpret artifacts but also that there is flexibility in how artifacts are designed. There is not just one possible way or one best way of designing an artifact." Pinch and Bijker, "The Social Construction of Facts and Artifacts," 34.

6. Pinch and Bijker, "The Social Construction of Facts and Artifacts," 20–21.

7. Pinch and Bijker, "The Social Construction of Facts and Artifacts," 20–21.

8. Richard Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System* (Cambridge, MA: MIT Press, 1999), 11–31, 2, 68.

9. Jeremiah D. Lambert, *The Power Brokers: The Struggle to Shape and Control the Electric Power Industry* (Cambridge, MA: MIT Press 2015), 100–130.

10. Lambert, *The Power Brokers*, 262.

11. Paul Joskow and Richard Schmalensee, *Markets for Power: An Analysis of Electric Utility Deregulation* (Cambridge, MA: MIT Press, 1983).

12. Joskow and Schmalensee, *Markets for Power*.

13. The histories of Enron are many. See, for example, Lambert, *The Power Brokers*; Vijay Vaitheesswaran, *Power to the People: How the Coming Energy Revolution Will Transform an Industry, Change Our Lives, and Maybe Even Save the Planet* (New York: Farrar, Straus and Giroux, 2003).

14. David E. Nye, *When the Lights Went Out: A History of Blackouts in America* (Cambridge, MA: MIT Press, 2010), 33.

15. Mark Chediak, "U.S. Power Demand Flatlined Years Ago, and It's Hurting Utilities," Bloomberg, April 25, 2017, https://www.bloomberg.com/news/articles/2017-04-25/u-s-power-demand-flatlined-years-ago-and-it-s-hurting-utilities.

16. Amory Lovins, *Reinventing Fire: Bold Business Solutions for the New Energy Era* (White River Junction, VT: Chelsea Green, 2011).

17. Mason Wilrich, *Modernizing America's Electricity Infrastructure* (Cambridge, MA: MIT Press, 2017).

18. Peter Fox-Penner, *Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities* (Washington, DC: Island Press, 2014), xiii.

19. Jennie Stephens, Elizabeth Wilson, and Tarla Rai Peterson, *Smart Grid (R)Evolution: Electric Power Struggles* (New York: Cambridge University Press, 2015).

20. Author interview with Gretchen Bakke, July 2017.

21. Comment from an anonymous reader of this book's manuscript.

22. John Farrell, "Reverse Power Flow: How Solar+Batteries Shift Electric Grid Decision Making from Utilities to Consumers," Institute for Local Self-Reliance, July 2018, https://ilsr.org/solar-plus-storage.

23. Stephens, Wilson, and Peterson, *Smart Grid (R)evolution*, 7–8, 186.

24. Rebecca Slayton, "Efficient, Secure Green: Digital Utopianism and the Challenge of Making the Electrical Grid 'Smart,'" *Information and Culture* 48, no. 4 (2013): 450.

25. Electric Power Research Institute, 2017, http://smartgrid.epri.com.

26. John Doerr, "Salvation (and Profit) in Greentech," TED, 2007, https://www.ted.com/talks/john_doerr_sees_salvation_and_profit_in_greentech.

27. Venkat Pothamsetty and Saadat Malik, "Smart Grid Leveraging Intelligent Communications to Transform the Power Infrastructure," Cisco white paper, February 2009, 1, 4, 9, 11.

28. Cisco, "Digital Utilities" (2018), https://www.cisco.com/c/en/us/solutions/industries/energy/external-utilities-smart-grid.html.

29. Mike Munsell, "GTM's Grid Edge Executive Council Now Counts 100 Member Companies," GTM, January 28, 2016, https://www.greentechmedia.com/articles/read/gtms-grid-edge-executive-council-now-counts-100-member-companies.

30. Nick Srnicek, *Platform Capitalism* (Cambridge, UK: Polity Press, 2016).

31. Stuart Bennett, *A History of Control Engineering, 1930–1955* (Washington, DC: Institution of Engineering and Technology, 1993).

32. Stuart Bennett, *A History of Control Engineering, 1800–1930* (Washington, DC: Institution of Engineering and Technology, 1979).

33. Gene Smith, "Power Industry Adds Computers," *New York Times*, October 8, 1964), 63. The *New York Times* ran several articles by Smith on power automation.

34. Slayton, "Efficient, Secure Green," 458.

35. Fox-Penner, *Smart Power*, 25–29.

36. Adam Greenfield, *Against the Smart City* (London: Verso, 2013), kindle segments 4 and 5 respectively.

37. Carolyn Marvin, *When Old Technologies Were New: Thinking about Electric Communication in the Late Nineteenth Century* (New York: Oxford University Press, 1988), 4.

38. Elizabeth Shove, "Infrastructures and Practices: Networks beyond the City," in *Beyond the Networked City*, ed. Olivier Coutard and Jonathan Rutherford (London: Routledge, 2016), 242–257.

39. Evgeni Morozev, *To Save Everything, Click Here* (New York: Public Affairs, 2013).

40. This refers to a literature search of Social History of Technology and the Society for the Social Studies of Science papers, 2007–2015, conducted in fall 2016.

41. Author interview with Rebecca Slayton, May 2016.

42. Author interview with Phoebe Sengers, July 2016.

43. A Google search for "green grid blues" yielded zero results in spring 2017; likewise for "smart green blues" in fall 2017.

4 Microgrid Institutions

1. Elisa Wood, "How 2017 Made the Argument for Microgrids," Microgrid Knowledge, January 2, 2018, https://microgridknowledge.com/microgrids-2017.

2. Umair Irfan, "Puerto Rico's Blackout, the Largest in American History, Explained," Vox, May 8, 2018, https://www.vox.com/2018/2/8/16986408/puerto-rico-blackout-power-hurricane.

3. Naomi Klein, "The Battle for Paradise," Intercept, March 20, 2018, https://theintercept.com/2018/03/20/puerto-rico-hurricane-maria-recovery.

4. Deborah Acosta and Frances Robles, "Puerto Ricans Ask: When Will the Lights Come Back On?," *New York Times*, October 19, 2017, https://www.nytimes.com/2017/10/19/us/puerto-rico-electricity-power.html.

5. Peter Fox-Penner, "Why Solar 'Microgrids' Are Not a Cure-all for Puerto Rico's Power Woes," Conversation, November 8, 2017, https://theconversation.com/why-solar-microgrids-are-not-a-cure-all-for-puerto-ricos-power-woes-86437.

6. Fox-Penner, "Why Solar 'Microgrids' Are Not a Cure-all."

7. Resilient Power Puerto Rico, "Our Mission," 2017, https://resilientpowerpr.org/about-us.

8. Mike Scott, "Microgrids Hold the Key to Providing Power for All," *Forbes*, July 19, 2018, https://www.forbes.com/sites/mikescott/2018/07/19/microgrids-hold-the-key-to-providing-power-for-all/#59bf8c2d6472.

9. Julia Pyper, "Large Corporations Are Driving America's Renewable Energy Boom. And They're Just Getting Started," Greentech Media, January 10, 2017, https://www.greentechmedia.com/articles/read/large-corporations-are-driving-americas-renewable-energy-boom.

10. Peter Asmus, "Here Come the 'Locavolts!,'" Renewable Energy Resilience, July 20, 2008, www.peterasmus.com/journal/2008/7/20/here-come-the-locavolts.html. See also Jennie Stephens, Elizabeth Wilson, and Tarla Rai Peterson, *Smart Grid (R)Evolution: Electric Power Struggles* (New York: Cambridge University Press, 2015), 147.

11. Denise Fairchild and Al Weinrub, *Energy Democracy: Advancing Equity in Clean Energy Solutions* (Washington, DC: Island Press, 2017), 1–20.

12. Dan T. Ton and Merrill A. Smith, "The U.S. Department of Energy's Microgrid Initiative," *Electricity Journal* 25, no. 8 (October 2012): 84.

13. Matt Grimley and John Farrell, "Mighty Microgrids," Institute for Local Self-Reliance, March 3, 2016, https://ilsr.org/report-mighty-microgrids.

14. Robert H. Lasseter, Abbas Akhil, Chris Marnay, John Stephens, Jeff Dagle, Ross Guttromson, A. Sakis Meliopoulous, Robert Yinger, and Joe Eto, "The CERTS MicroGrid Concept," Transmission Reliability Program, US Department of Energy, April 2002, 30.

15. LexisNexis word search of "microgrid," by decade, from 1950 to 2000.

16. See, for instance, Robert H. Lasseter and Paolo Piagi, "Microgrid: A Conceptual Solution," *IEEE Annual Power Electronics Specialists Conference* 6 (July 2004): 4285–4290.

17. Anya Kamenetz, "Why the Microgrid Could Be the Answer to Our Energy Crisis," *Fast Company*, July 1, 2009, https://www.fastcompany.com/1297936/why-microgrid-could-be-answer-our-energy-crisis.

18. Elisa Wood, ed., "Think Microgrid: A Discussion Guide for Policymakers, Regulators and End Users," International District Energy Association, May 2014, https://blog.se.com/wp-content/uploads/2014/06/Think-Microgrid-Special-Report.pdf.

19. *Economist*, "Grid Unlocked: American Utilities Mimic the Tech Industry to Make Systems More Resilient," October 17, 2014, http://www.economist.com/news/business/21625885-american-utilities-mimic-tech-industry-make-systems-more-resilient-grid-unlocked.

20. "Community Microgrid Initiative," Clean Coalition, 2019, https://clean-coalition.org/community-microgrid-initiative.

21. Grimley and Farrell, "Mighty Microgrids," 2.

22. Navigant Research, "Market Data: Microgrids," Summer 2014, https://www.navigantresearch.com/research/market-data-microgrids.

23. Peter Asmus, "Microgrids: Pie-in-the-Sky Dreams versus On-the-Ground Realities," Navigant Research, March 4, 2016, https://www.navigantresearch.com/news-and-views/microgrids-pie-in-the-sky-dreams-versus-on-the-ground-realities.

24. Navigant Research, "Market Data: Energy Storage for Microgrids," Fall 2017, https://www.navigantresearch.com/reports/market-data-energy-storage-for-microgrids; Navigant Research, "Building-to-Grid Integration," Fall 2017, https://www.navigantresearch.com/reports/building-to-grid-integration; Navigant Research, "Navigant Research Leaderboard: Smart City Suppliers," Fall 2017, https://www.navigantresearch.com/reports/navigant-research-leaderboard-smart-city-suppliers.

25. Author interview with Bruce Nordman, June 2016.

26. Bruce Nordman and Ken Christensen, "DC Local Power Distribution with Microgrids and Nanogrids," n.d., https://eta-intranet.lbl.gov/sites/default/files/icdcm2015nordmanLPD.pdf.

27. Chris Marnay, Bruce Nordman, and Judy Lai, "Future Roles of Milli-, Micro-, and Nano-Grids," Microgrids at Berkeley Lab, 2011, https://building-microgrid.lbl.gov/publications/future-roles-milli-micro-and-nano.

28. Elisa Wood, "Solar Is Good. Solar Microgrids Are Better," Microgrid Knowledge, August 8, 2106, https://microgridknowledge.com/solar-microgrids-are-better.

29. Gretchen Bakke, *The Grid: The Fraying Wires between Americans and Our Energy Future* (New York: Bloomsbury, 2016), 219–254.

30. Author interview with Jim Saber, May 2017.

31. That is just what this project has done, alongside its many other methods, including library research, long-term historic reading, mostly academic interviews, and a short residence at the Berkeley Lab. Hence the many journalistic items in these endnotes.

32. David Roberts and Alvin Chang, "Meet the Microgrid, the Technology Poised to Transform Electricity," Vox, May 24, 2018, https://www.vox.com/energy-and-environment/2017/12/15/16714146/greener-more-reliable-more-resilient-grid-microgrids.

33. David Roberts, "The Key to Tackling Climate Change: Electrify Everything," Vox, September 19, 2016, https://www.vox.com/2016/9/19/12938086/electrify-everything.

34. "Microgrid Knowledge Survey 2016," Microgrid Knowledge, http://microgridknowledge.com/white-paper/microgrid-knowledge-survey-2016.

35. Kevin Normandeau, "Microgrid 2018 Opens with the Message: Microgrids for the Greater Good," Microgrid Knowledge, May 7, 2018, https://microgridknowledge.com/microgrids-greater-good.

36. Christopher Villarreal, David Erickson, and Marzia Zafar, "Microgrids: A Regulatory Perspective," California Public Utility Commission, April 14, 2014, 25, 3.

37. "Hudson Yards: Sustainability and Resiliency," Hudson Yards, 2016, http://www.hudsonyardsoffices.com/office/10-hudson-yards/availabilities/building/sustainability-and-resiliency.

38. Jeffrey Spivak, "A Developing Front in Resilience: Electricity Microgrids," Urban Land, February 17, 2015, https://urbanland.uli.org/sustainability/developing-front-resilience-electricity-microgrids.

39. Diane Cardwell, "Solar Experiment Lets Neighbors Trade Energy among Themselves," *New York Times*, March 13, 2017, https://www.nytimes.com/2017/03/13/business/energy-environment/brooklyn-solar-grid-energy-trading.html.

40. "The Future of Energy Is Local," Brooklyn Microgrid, http://brooklynmicrogrid.com.

41. "Powering a New Generation of Community Energy," New York State Energy Research and Development Authority, https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize.

42. Pecan Street, www.pecanstreet.org.

43. Stephens, Wilson, and Peterson, *Smart Grid (R)Evolution*, 28–31.

44. Stephens, Wilson, and Peterson, *Smart Grid (R)Evolution,* 150.

45. Author interview with Jennie Stephens, June 2016.

46. Mags Harries and Lajos Heder, SunFlowers installation, 2009, http://muellersunflowers.powerdash.com/aboutus.

47. United Nations Environmental Programme, "District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy," 2014, 28.

48. Morgan Kelly, "Two Years after Hurricane Sandy, Recognition of Princeton's Microgrid Still Surges," Princeton University, October 23, 2014, https://www.princeton.edu/main/news/archive/S41/40/10C78/index.xml?section=featured.

49. Edward Borer, "Resilient Community Microgrids: Concepts, Operations and Maintenance," International District Energy Association,February 2015, http://www.microgridresources.com /HigherLogic/System/D ownloadDocumentFile.ashx?DocumentFileKey=38b01592-a6a4-5446-218d-73b998943030.

50. Daniel Kammen, "The Ecoblock Project," Renewable and Appropriate Energy Laboratory, University of California at Berkeley. https://rael.berkeley.edu/project/the-eco-block-project. See also "Sustainable Design of Communities," *Scientific American*, June 26, 2017, https://rael.berkeley.edu/2017/06/sustainable-design-of-communities-in-scientific-american.

51. Elisa Wood, "Pittsburgh Plans Grid of Microgrids; Wins Smart City Money," Microgrid Knowledge, October 17, 2016, https://microgridknowledge.com/grid-of-microgrids-pittsburgh.

52. John Farrell, "Energy Democracy in the 51st State," Institute for Local Self-Reliance, February 2015.

53. Mary Douglas, *How Institutions Think* (Syracuse, NY: Syracuse University Press, 1986), 55.

54. Kevin Lynch, *The Image of the City* (Cambridge, MA: MIT Press, 1960), 49–52.

55. Lynch, *The Image of the City*, 46–90.

56. Lucy Bullivant, ed., *4D Hyperlocal: A Cultural Toolkit for the Open-Source City* (Hoboken, NJ: Wiley, 2017).

5 Architecture's Grid Edge

1. This generalization about buildings comprises residential, commercial, information-technological, and industrial uses, which are quite distinct in their usage issues and patterns. This project research included a visit to the Lawrence Berkeley National Laboratory, which measures such patterns at a vast societal scale, and whose data reports (for instance, the famous Sankey diagrams of large-scale energy flow) are the most widely cited of their kind.

2. Word counts on Google searches, March 2017.

3. Digital fabrication, design for assembly, and material systems have become the most prominent research focus of my own institution, Taubman College of Architecture and Urban Planning at the University of Michigan, and this focus provides at least some basis for investigating architecture's grid edge as a material system design opportunity.

4. Bruce Nordman, "Beyond the Smart Grid: Building Networks," Lawrence Berkeley National Laboratory, 2010, https://eta-intranet.lbl.gov/sites/default/files/beyond.pdf. Nordman's many clear writings and presentations are an especially prominent resource from Lawrence Berkeley National Laboratory.

5. On building energy, I am grateful for guidance from several kind experts in this aspect of my home discipline. See my acknowledgments. To me the most useful spot-check has been the Architecture and Energy conference held at Penn in 2012, and published as William Braham, and Daniel Willis, eds, *Architecture and Energy: Performance and Style* (New York: Routledge, 2013).

6. This has been the emphasis of my previous writings, the most enduring of which has been Malcolm McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing* (Cambridge, MA: MIT Press, 2005).

7. For a representative sample of contemporary technologies and agendas, see the working papers at BuildingIQ, https://buildingiq.com/resources.

8. Kevin Lucas, "So What Exactly Is This 'Grid Edge' Thing, Anyway?," Alliance to Save Energy, June 20, 2016, https://www.ase.org/blog/so-what-exactly-grid-edge-thing-anyway. "Grid Edge hardware is the physical material you can touch: solar panels, advanced metering infrastructure, smart inverters, energy storage systems, smart thermostats, smart appliances and building controls."

9. "Why Are Buildings Behaving Badly?" Grid Edge Limited, 2017, http://www.gridedge.co.uk/buildings-behaving-badly-1.

10. "World Green Building Trends 2018: SmartMarket Report," World Green Building Council, November 13, 2018, 18–19.

11. Tom Madden, "The Greenest Building in the World: The Edge," Living Map, August 3, 2017, https://www.livingmap.com/smart-building/the-edge.

12. "The Edge: Amsterdam, The Netherlands," PLP Architecture, 2016, http://www.plparchitecture.com/the-edge.html.

13. Tom Randall, "The Smartest Building in the World: Inside the Connected Future of Architecture," Bloomberg, September 23, 2015, https://www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building.

14. Jane Wakefield, "Will Tomorrow's Smart Office Be a Saviour or a Spy?," BBC News, April 6, 2016, http://www.bbc.com/news/technology-35696521.

15. "Elon Musk Explains Why the Tesla-SolarCity Merger Is All about Microgrids," Microgrid Media, June 27, 2016, http://microgridmedia.com/elon-musk-explains-why-the-tesla-solarcity-merger-is-all-about-microgrids.

16. See Association for Computer Aided Design in Architecture, acadia.org.

17. William Mitchell, *Me++: The Cyborg Self and the Networked City* (Cambridge, MA: MIT Press, 2003), 7–17.

18. Mitchell, *Me++*, 7, 10

19. Mitchell, *Me++*, 10.

20. William Mitchell, *Placing Words: Symbols, Space, and the City* (Cambridge, MA: MIT Press, 2005), 9.

21. As this gross generalization has been unpacked in some of my previous work, please excuse such a short summary here. See, for instance, Malcolm McCullough, *Ambient Commons: Attention in the Age of Embodied Information* (Cambridge, MA: MIT Press, 2013), 91–108.

22. Mitchell, *Placing Words*, 4.

23. Most first citations of the extended mind are to the body of work by Andy Clark, including a later book by that very name. For the standard citation, see Andy Clark and David J. Chalmers, "The Extended Mind," *Analysis* 58, no. 1 (January 1998): 7–19.

24. Ian Bogost, *Alien Phenomenology, or, What It's Like to Be a Thing* (Minneapolis: University of Minnesota Press, 2012).

25. Elizabeth Shove, "Infrastructures and Practices: Networks beyond the City," in *Beyond the Networked City*, ed. Olivier Coutard and Jonathan Rutherford (London: Routledge, 2016), 246.

26. "H-E-B at Mueller," American Institute of Architects, 2016, http://www.aiatopten.org/node/489.

27. Lake/Flato, 2016, http://www.lakeflato.com/urban-development/h-e-b-mueller.

28. Author interview with Stephen Selkowitz, Lawrence Berkeley National Laboratory, September 2016.

29. "A Day in the Light," *Metropolis*, May 2004, http://www.metropolismag.com/uncategorized/a-day-in-the-light.

30. "Daylighting the New York Times Building," Lawrence Berkeley National Laboratory, https://facades.lbl.gov/newyorktimes/nyt_arch-approach.html.

31. Author interview with Stephen Selkowitz, Lawrence Berkeley National Laboratory, September 2016.

6 Situated Interactions

1. Howard Gardner and Katie Davis, *The App Generation: How Today's Youth Navigate Identity, Intimacy, and Imagination in a Digital World* (New Haven, CT: Yale University Press, 2013).

2. Rebecca Solnit, "Diary: In the Day of the Postman," *London Review of Books* 35, no. 16 (August 29, 2013): 32–33.

3. Clifford Siskin, *System: The Shaping of Modern Knowledge* (Cambridge, MA: MIT Press, 2016).

4. At this writing, the annual ACM Tangible and Embedded Interaction conference, now in its twelfth year, has adopted the currently popular theme of "postdigital."

5. Author interview with Hal Wilhite, September 2016.

6. Author interview with Harry Giles, May 2016.

7. Grégoire Wallenborn and Harold Wilhite, "Rethinking Embodied Knowledge and Household Consumption," *Energy Research and Social Science* 1 (2014): 56–64.

8. Douglas Rushkoff, *Present Shock: When Everything Happens Now* (New York: Penguin, 2013).

9. In 2007, *Wired* magazine editors Gary Wolf and Kevin Kelly started a "life-logging" movement. Today, many resources link to Wolf's blog, *Quantified Self*. http://quantifiedself.com.

10. Gardner and Davis, *The App Generation*.

11. Thomas Tierney, *The Value of Convenience* (Albany: SUNY Press, 1993), 39–40.

12. Lewis Mumford, *Technics and Civilization* (New York: Harcourt, Brace, 1936).

13. See especially Tim Wu, *The Attention Merchants: The Epic Scramble to Get Inside Our Heads* (New York: Alfred A. Knopf, 2016).

14. Elizabeth Shove, *Comfort, Cleanliness, Convenience: The Social Organization of Normalcy* (Oxford, UK: Berg, 2003), 184, 171–183, 196.

15. Jennie Stephens, Elizabeth Wilson, and Tarla Rai Peterson, *Smart Grid (R)Evolution: Electric Power Struggles* (New York: Cambridge University Press, 2015), 186.

16. Dietmar Offenhuber, "Indexical Visualization: Traces, Symptoms, Evidence" (working paper, spring 2018).

17. Author interview with Rick Diamond, June 2016.

18. For the classic argument that comfort is best understood as a pursuit and not a state, see Lisa Heschong, *Thermal Delight in Architecture* (Cambridge, MA: MIT Press, 1978).

19. Author interview with Chris Payne, September 2016.

20. Richard Coyne, *The Tuning of Place: Sociable Spaces and Pervasive Digital Media* (Cambridge, MA: MIT Press, 2010), 19, xxvii.

21. Yolande Strengers, *Smart Energy Technologies in Everyday Life: Smart Utopia?* (London: Palgrave Macmillan, 2013), 2–10.

22. Strengers, *Smart Energy Technologies in Everyday Life*, 8, 135, 151–152.

23. James Pierce and Eric Paulos, "Materializing Energy," in *Proceedings of the 8th ACM Conference on Designing Interactive System* (New York: ACM, 2010), 113–122.

24. Although this project began from past work in ambient interface, it has alas witnessed a deceleration of tangibly interactive arts and installations. Built space has often become more responsive, but seldom with nonscreen engagement.

25. Wallenborn and Wilhite, "Rethinking Embodied Knowledge and Household Consumption," 56.

26. Matt Crawford, *The World beyond Your Head: On Becoming an Individual in an Age of Distraction* (New York: Farrar, Straus and Giroux, 2015).

27. At least among my own previous works, there is a common thread on presence and practice through flowing engagement with situated technologies. This is not the higher meaning of the perennial philosophy per Aldous Huxley, but just a persistence about craft.

28. Shove, *Comfort, Cleanliness, Convenience*, 196.

29. This has been a theme on attention in my previous book; see Malcolm McCullough, *Ambient Commons: Attention in the Age of Embodied Information* (Cambridge, MA: MIT Press, 2013). See also Brian Bruya, *Effortless Attention: A New Perspective in the Cognitive Science of Attention and Action* (Cambridge, MA: MIT Press, 2010), 3–29.

7 To Island

1. Rebecca Solnit, *A Paradise Built in Hell*: *The Extraordinary Communities That Arise in Disaster* (New York: Penguin, 2009).

2. UN Office for Disaster Risk Reduction, "How to Make Cities More Resilient: A Handbook for Local Government Leaders" (Geneva: United Nations, 2012), 63.

3. "Definitions of Community Resilience: An Analysis," Community and Regional Resilience Institute, 2013, http://www.resilientus.org/wp-content/uploads/2013/08/definitions-of-community-resilience.pdf.

4. "Developing Urban Resilience," Urban Land Institute, 2017, https://developingresilience.uli.org.

5. Daniel Lerch, "Six Foundations for Building Community Resilience," Post Carbon Institute, November 18, 2015, 4.

6. "Definitions of Community Resilience: An Analysis."

7. Kresge Foundation, "Bounce Forward: Urban Resilience in the Era of Climate Change" (Washington, DC: Island Press, 2015).

8. "Community Microgrid Initiaitive," Clean Coalition, 2019, https://clean-coalition.org/community-microgrid-initiative.

9. Lerch, "Six Foundations for Building Community Resilience," 15.

10. Author interview with Bruce Nordman, September 2016.

11. Andrew Zolli and Anne Marie Healy, *Resilience: Why Things Bounce Back* (New York: Simon and Schuster, 2012), 25–28, 115, 92–100.

12. Lance H. Gunderson and C. .S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington, DC: Island Press, 2002).

13. Clifford Siskin, *System: The Shaping of Modern Knowledge* (Cambridge, MA: MIT Press, 2016), 3–21.

14. Daniel Daou and Pablo Pérez-Ramos, eds., *New Geographies, 8: Island* (Cambridge, MA: Harvard Graduate School of Design, 2016), 7. The existence of this intriguing volume, which is devoted more to poetics, has helped me recast some larger argument about clusters here into metaphors of the archipelago, which help explain the resonance of the microgrid meme.

15. Immanuel Kant, *Critique of Pure Reason* (1781), trans. Norman Kemp Smith (London: Macmillan 1964), 257, cited in Robin Mackay, "Philosophers' Islands," in *New Geographies, 8: Island*, ed. Daniel Daou and Pablo Pérez-Ramos (Cambridge, MA: Harvard Graduate School of Design, 2016), 61.

16. Marc Shell, *Islandology: Geography, Rhetoric, Politics* (Stanford, CA: Stanford University Press, 2014), 13.

17. Sonia Glavaski, "Controlling the Grid Edge," ARPA-E, September 2018, https://arpa-e.energy.gov/sites/default/files/Glavaski_FastPitch.pdf.

18. David Roberts, "Clean Energy Technologies Threaten to Overwhelm the Grid: Here's How It Can Adapt," Vox, December 3, 2018, https://www.vox.com/energy-and-environment/2018/11/30/17868620/renewable-energy-power-grid-architecture.

19. Gretchen Bakke, *The Grid: The Fraying Wires between Americans and Our Energy Future* (New York: Bloomsbury, 2016), xviii.

20. E. R. Morgan, S. Valentine, C. A. Blomberg, E. R. Limpaecher, and E. V. Dydek, "Boston Community Energy Study: Zonal Analysis for Urban Microgrids," MIT Lincoln Laboratory, March 2016, https://apps.dtic.mil/dtic/tr/fulltext/u2/1033735.pdf.

21. Goncalo Cardoso, "Distributed Energy Resources: Customer Adoption Model (DER-CAM)," Lawrence Berkeley National Laboratory, May 12, 2016, https://building-microgrid.lbl.gov/projects/der-cam.

22. Adam Greenfield, *Against the Smart City* (London: Verso, 2013).

23. Oswald Matias Ungers, Rem Koolhaas, Peter Riemann, Hans Kollhoff, and Arthur Ovaska, "The City in the City—Berlin: A Green Archipelago," *Lotus* 19 (1978): 82–97.

24. Oswald Matias Ungers, Rem Koolhaas, Peter Riemann, Hans Kollhoff, and Arthur Ovaska, *The City in the City—Berlin: a Green Archipelago*, ed. Florian Hertweck and Sébastien Marot (Baden, Ger.: Lars Mueller Publishers, 2013).

25. Pier Vittorio Aureli, *The Possibility of an Absolute Architecture* (Cambridge, MA: MIT Press, 2011), 18, 9.

26. Aureli, *The Possibility of an Absolute Architecture*, 46.

27. Aureli, *The Possibility of an Absolute Architecture*, 46.

28. "Navigant Research Leaderboard: Smart City Suppliers," Navigant Research, Fall 2017, https://www.navigantresearch.com/reports/navigant-research-leaderboard-smart-city-suppliers.

29. Drew Hemment and Anthony Townsend, eds., *Smart Citizens* (Manchester, UK: Future Everything, 2013), 5, 9.

30. Christopher Alexander, "A City Is Not a Tree," *Architectural Forum* 122, no. 1 (April 1965): 58–62; Shannon Mattern, "A City Is Not a Computer," *Places Journal* (February 2017), https://placesjournal.org/article/a-city-is-not-a-computer.

31. Mattern, "A City Is Not a Computer."

32. Bruce Sterling, "Stop Saying 'Smart Cities': Digital Stardust Won't Magically Make Future Cities More Affordable or Resilient," *Atlantic*, February 12, 2018, https://www.theatlantic.com/technology/archive/2018/02/stupid-cities/553052.

33. Since in many ways intermittency is where the project began, I was glad to hear a highly respected sociologist raise this too. Author interview with Elizabeth Shove, July 2017.

34. Antoine Picon, "The Limits of Intelligence on the Challenges Faced by Smart Cities," in *New Geographies, 7: Geographies of Information*, ed. Ali Fard and Taraneh Meshkani (Cambridge, MA: Harvard Graduate School of Design, 2015), 77–83.

35. Emily St. John Mandel, *Station Eleven* (New York: Alfred A. Knopf, 2014), 311.