

Green Gadgets?

The Smart Cities Movement and Urban Environmental Policy

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Abstract

The world's population is now primarily city-dwellers, and there are more mobile, wireless computers than desktops. In an age of urbanization and technological ubiquity, how is the social compact around environmental degradation, science and policy and planning shifting? What new challenges and what new tools are emerging? This paper examines three interrelated developments in the smart cities movement through an environmental policy lens. First, it considers the rapid growth in investment in smart infrastructure designed to improve efficiency, and the impetus provided by global carbon emission reduction efforts. Second, it looks at shifts in transportation and mobility and potential structural changes in metropolitan land use patterns that may have significant impacts on regional ecosystems. Finally, it examines the implications of distributed sensing for citizen science and debates around urban environmental justice.

Urbanization and Ubiquity

In the lifetimes of our children, the urbanization project will be completed. We will have built the system of cities that their descendants will live with forever.

Paul Romer, economist

Planet of Cities

It is well understood that we are amidst the greatest period of citybuilding humanity may ever know. "[T]he world population will reach a landmark in 2008," United Nations demographers declared in 2007, "for the first time in history the urban population will equal the rural population of the world."¹ Since then - every conference, perhaps every single paper on the future of urbanization begins with this rote observation. (Truth be told, the UN was a little over-zealous, and there's some evidence that the pace of urbanization has slowed, particularly in sub-Saharan Africa, and the 50 percent threshold was not actually crossed until early 2009).² Still, Romer's observation hits the mark. And we are well on our way to complete urbanization of the world's population. By 2050, nearly 70 percent of humanity will live in cities.³ A speculative estimate suggests as many as 90 percent of the world's projected future population of 11 billion will be city dwellers in 2100.⁴ The network of built-up areas and connecting infrastructure that supports them will shape the next several centuries of development, if not longer — much as we still live with the geopolitical consequences of the Silk Road, the ports of the Age of Exploration, the railroads of the British Empire, and the U.S. Interstate Highway System.

Yet even as we make sweeping generalizations about the urban destiny of our civilization, we must recognize the great diversity in the nature of city development across the globe. Dispersal of existing metropolitan populations continues in the United States - which alone among rich countries will add an estimated 90 million new metropolitan inhabitants by 2050 - despite counter-currents of urban revitalization (which is happening at vastly lower densities than historically).⁵ Already largely urbanized, Brazil will spend the 21st century rebuilding its vast squatter cities, the favelas. In sub-Saharan Africa,

where 62 percent of citydwellers live in slums, the urban population is projected to double in population in the next decade alone (though as noted above, this rate is increasingly the subject of debate). Asian cities, reflecting the tremendous diversity of the largest and most populous continent, are charting a vast range of new forms - from the *desakota* urban-rural sprawl of Indonesia, to Singapore's hyper-managed artificial paradise, to India and China's tandem campaigns to build one-hundred 'smart cities' in the coming decade.

Connected People

At the precise moment that the world became mostly urban, the spread of information and communications technologies (ICTs) passed its own crucial threshold - in 2008, also for the first time, the number of mobile broadband internet subscribers surpassed the number of fixed lines. The internet became mostly 'untethered' - to borrow a term employed by the U.S. Army in the 1990s as it contemplated the dawning era of telecommunications-enabled mobile urban warfare (and reflecting the reality that 'mobile' isn't accurate - most of us are stationary most of the time when we use our portable devices!).⁶

Mobile networks challenge urban planners' intuition about how telecommunications influences travel behavior and land uses. Often, we simplistically assume that by freeing us from wired terminals, mobile phones will allow firms and workers to permanently relocate to rural areas en masse. Yet most evidence points to the opposite. In developing countries, mobile phones have been a powerful enabler of seasonal rural-urban migration (which, not surprisingly, can best be tracked through mobile phone movements recorded by mobile phone companies).⁷ Mobiles also reinforce the value of large gathering sites — the essential purpose of cities, after all. For instance, the most robust cellular networks are those that blanket meeting spaces like stadiums and conference centers. Refugees from the Syrian conflict have spread out across Europe with little more than their precious smart phones in hand.⁸ In that sense, mobiles can be seen as a catalyst for density. They get you to the meeting, and help you find your friends when you get there.

But there are counter-currents, of course. Mobile networks are also a substrate for sprawl, eliminating the social isolation and opportunity cost of travel by automobile. Not

surprisingly, the capital invested in the 285,000 towers that makeup the U.S. cellular grid (About \$500 billion, growing at \$30-40 billion annually) now rivals that of the U.S Interstate Highway System (about \$500 billion in current dollars), whose economic value and working lifetime it so clearly extends and amplifies.^{9,10}

Connected Things

Talking on the go is hardly a new idea—the first mobile phone call was placed in the United States in the 1920s, from the back seat of a specially-outfitted automobile in the Philadelphia suburb of Elkins Park. But also in 2008, even as we untethered ourselves from the grid, people become a minority on the internet. Today, there are at least two additional things connected to the Internet for every personal device. But forecasts are that by 2020 some 50 billion networked objects will outnumber humans ten to one.

Today, the “internet of things”, as these connected objects are collectively known encompasses a growing range of wearable and portable devices designed for health and fitness applications, as well as a growing array of networked automotive systems. But increasingly, as new and retrofitted buildings and urban infrastructure come online, they too will be fitted with embedded sensors and controls. These systems will have tremendous impacts for how cities are managed and planned as businesses, governments and even citizens tap the pool of observations they create to understand the world, react, and even predict. This ‘big data’ will be an immanent force that pervades and sustains our urban world, and its volume and velocity of production will drown out the entire human web. Consider that one proposed smart city for 200,000 people would produce over 150 times the amount of data contained in all of the 10 billion photos archived on Facebook as of 2013 (about 300 petabytes per year versus Facebook’s 1.5 petabyte photo archive).¹¹ This middling smart city would even put the world’s most prolific scientific instrument, the Large Hadron Collider, to shame — that atom-smasher only musters a data flow of about 20 petabytes annually.¹²

A New Symbiosis

No invention has been more timely than the telephone. It arrived at the exact period when it was needed for the organization of great cities and the unification of nations.
Herbert Casson, *The History of the Telephone* (1910)

Throughout urban history, the capabilities of ICTs and the size and complexity of cities have advanced hand-in-hand. City growth drives innovation in information processing tools, and the resulting governance innovations unlock further rounds of urban expansion. In the ancient world, writing supported cities' role as specialized hubs for government, commerce and religion. In the industrial cities of the 19th century the telegraph, telephone, and mechanical tabulators powered a "control revolution" that coordinated human activity on a previously unimaginable scale.¹³ Today, the Internet and cellular networks make both urban sprawl and global cities of previously unthinkable size possible- five, ten or even twenty million people. Without these key technologies, cities would have collapsed under the weight of their own expansion.

As we confront unprecedented urbanization then, in the context of a new revolution in information processing technology, this is the fundamental question — can we employ these tools to manage another round of urban scaling - to megaregions of forty, fifty, seventy-five, or one hundred million people - while simultaneously delivering a higher standard of living in a more environmentally sustainable and resilient manner?

This is, at its core, what the smart cities movement is all about.

The Smart Cities Movement

This is the final phase of industrialization. Everything in your society has to be modernized. Everything has to be smart.

Fareed Zakaria, Newsweek¹⁴

“Smart city” pilot projects are proliferating around the world, bringing together technology companies and cities and towns in public-private partnerships to promote sustainability, conserve energy, reduce costs and meet the needs of citizens who are demanding a reasonable price.

World Economic Forum, 2012¹⁵

The term “smart” has entered the global urbanization discourse in the last few years, with little consensus on what it means, what it can contribute to a broader discussion about strategies for improving the urban condition, and its rhetorical limitations. As seen in the epigraphs preceding this section, it is widely employed by bombastic proponents of corporate-engineered “solutions” to complex urban problems - with a sense of inevitability borrowed from the ICT industry’s own mythology.

How “smart” won out over other terms is unclear - it is merely the latest in a lineage dating to the 1970s coined to describe the convergence of cities and ICTs - “wired city”, “intelligent city”, and “information city” and so on. William Mitchell, former dean of MIT’s School of Architecture and Planning and an prolific author on the topic, chose the name “Smart Cities” for the research group he set up at the MIT Media Lab in 2003. Adapted by IBM for a multi-million dollar marketing initiative in 2008 as “Smarter Cities”, the term seems to have stuck.

Nailing down a precise definition has been a bit trickier, and scholars have proposed several. A useful one put forth by a major EU-funded effort (the oddly named *FIREBALL* project) weaves technological transformation together with broader goals of citizen empowerment:

A useful definition to start with is to call a city “smart” when “investments in human and social capital and traditional (transportation) and modern (ICT-based) infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government” [Caragliu et al 2009]. To this, the no-

tion of empowerment of citizens and “democratizing innovation” should be added [Von Hippel 2005]).¹⁶

Furthermore, the authors tack on to this definition a placemaking element, arguing:

The smart city provides the conditions and resources for change. In this sense, the smart city is an urban laboratory, an urban innovation ecosystem, a living lab, an agent of change.¹⁷

In this view, a smart city is defined by the convergence of these four elements - human capital development, digital enhancement of infrastructure, citizen engagement through open innovation processes, and a distinct and critical place-based element.

Smart cities, then, are seen as a pragmatic frameworks for urban management and planning, highly focused on problem-solving. Their broad historic context comes from urbanization and ubiquity. But their immediate context is an economic crisis and the breakdown of global governance. Where old institutions are seen as failing in the face of global challenges, new technologies and insurgent local efforts are seen as viable progressive alternatives. As the FIREBALL authors put it, “the smart city is the engine of transformation, a generator of solutions for wicked problems.”¹⁸

The Role of the Financial Crisis

‘Black swans’ matter.¹⁹ By accident, the 2008 financial crisis was an crucial catalyst for the smart cities movement, fusing together the three trends that came to a boil that year — global urbanization, the mobile internet, and connected things.

While the market was moving in the general direction of smart cities, the financial crisis provoked a sharp and severe cutback in ICT spending by Fortune 500 and multinational corporations - the bread and butter customers of technology vendors such as IBM, Cisco and Oracle. Aside from travel, ICT capital spending was one of the easiest places to trim and stockpile cash for what looked at the time to be a very volatile and extended (and potentially catastrophic) period of economic and financial uncertainty.

At the same time, however, government stimulus spending began to ramp up in the United States, Europe and East Asia. Urban infrastructure represented the most promis-

ing opportunity for technology vendors to capture post-crisis stimulus spending. One widely circulated forecast, published in 2007 by consultancy Booz Allen Hamilton, claimed that global infrastructure needs would top \$1.5 trillion annually for the next 25 years - just shy of 3 percent of global GDP. According to the Urban Land Institute, a real estate industry think tank, the United States alone needed to spend \$2 trillion to repair and rebuild its decaying infrastructure.²⁰

The bulk of infrastructure spending - 97 percent - will be on conventional materials like asphalt and steel. But as much as 3 percent could go to ICT or “smart city” components, services, and support. This figure is remarkably constant — either looking at the global scale (say by comparing market forecasts for smart infrastructure to total infrastructure) or a large development project (for instance Songdo City in South Korea, whose ICT business strategist reports a 2.9 percent figure), or a single building (which can be gleaned from a variety of trade publications).

Smart city ICT comes in three layers, according engineering consultancy Arup - “instrumentation” that collects data throughout the city, “urban informatics” systems that process the signals, and an “urban information architecture” or set of management practices and business processes to put the results to use. Andrew Comer, a partner at construction engineering firm Buro Happold explains the cocktail math:

If you project that figure into the future, multiply it by a fairly conservative estimate of the construction costs involved, and take a relatively small percentage of that for high-technology infrastructure, it's trillions of dollars. If these hi-tech companies can capture parts of this market, they have a twenty to thirty year period of insatiable growth.

Thus, smart cities promise to be a cash cow for the technology industry, chalking up some \$100 billion in potential revenues over the next decade. And that’s even before the management consulting fees - for, as Arup argued in a 2010 white paper, “the smart city is so different in essence to the 20th century city that the governance models and organisational frameworks themselves must evolve.”²¹

The Market Matures

This is a huge, huge opportunity.

Peter Löscher, CEO, Siemens (2011)

By 2011, even conglomerates like Siemens and GE had turned their attention to the smart cities market, sensing even greater potential than the ICT niche that IBM and Cisco had unearthed. Yet, in the years since 2008, despite thousands of conferences, pilot projects and other campaigns the ambitions of these firms have largely been unrealized. As *The Economist* reported in autumn 2013:

Many cities lack the necessary resources for the more ambitious dreams of city planners. Companies such as Cisco, IBM and Siemens are all eager to sell them systems. “None has met its revenue targets,” says a smart-city expert at a big consultancy. A new “infrastructure and cities” division at Siemens has the lowest profit margin of all of Siemens’s big businesses.²²

The reasons for inflated expectations are many, but largely have to do with misperceptions about the decision-making processes of local governments, a lack of easily repurposable business models, and a poor job selling the value of investments to actual ‘end users’ — the citizens themselves. But despite the setbacks of these old-line tech giants, the smart cities market has continued to expand, mature and evolve in a number of ways that suggest its long-term viability.

This is most clearly seen in the exponentially expanding size and scope of the smart cities market forecasts. One widely noted study, published in 2011 by Boulder, Colo.-based Pike Research (now a part of Navigant) pegged the total market at \$100 billion in annual sales globally by 2020.²³ But soon after, at the behest of the UK government, Arup produced a new forecast which expanded the range of services, more than quadrupling the market to \$408 billion per year by 2020.²⁴ Just over 12 months later, consultancy Frost & Sullivan, in its own estimate again quadrupled the pie to \$1.56 trillion.²⁵

What is the significance of these ballooning forecasts? Partly, it reflects the growing expectations among an expanding array of stakeholders - it isn't just IBM that is banking on the smart city market to expand, but the UK government as part of its export-led economic growth policy. Also, definitions of the sector are expanding (notably from the Pike to Arup forecast) to include a larger range of value-added services riding on top of smart infrastructure, recognizing where the true nexus of innovation lies. Finally, there is a growing sense of the massive "dark matter" cloud of startups and SMEs moving into the market and developing new niches with considerable potential - as seen in networks like Urban.Us and CityMart which are trying to challenge traditional geographic obstacles to city-vendor procurement and startup-investor relationships and help fledging firms expand globally beyond their initial launch cities.

But perhaps far more significantly, these forecasts are beginning to reflect the arrival of the big consumer-facing ICT companies in the smart city market - Google, Apple, Intel, and Microsoft - all of which are now forming groups, developing strategy, making acquisitions and launching initiatives in this space. (Full disclosure: I am a consultant to Sidewalk Labs, of which Google is a major investor, and have previously consulted for Intel). Given that IBM and Cisco may have failed to capture citizens' imagination because they lacked experience with consumers, this could signal a crucial development.

The Political Economy of Smart Cities

For indeed any city, however small, is in fact divided into two, one the city of the poor, the other of the rich; these are at war with one another.

Plato, *The Republic*

So far, we have largely looked at the corporate agenda for smart cities, yet as Plato reminds us, the city is and has always been a contested social and economic space. For every potential productivity or efficiency gain, smart technologies present a redistributive risk. Considerable serious debate is now underway, for instance, about the possibility of mass unemployment as intelligent systems are widely deployed in the coming decades, and the potential for catastrophic impacts on income and wealth distribution.²⁶ Several

efforts to map the political economy of smart cities have been widely circulated, including the author's.²⁷ These seek to shift the locus of attention from the “what” of smart systems - the technologies and their applications - to the “why” and “how”. The more successful ones, such as Elie Cosgrave's doctoral thesis on Bristol, England's smart city policy framework, succeed by dissecting competing interests around specific projects in communities.

But even as global technology companies have dominated discussions about smart cities over the last decade, a parallel grassroots movement has coalesced. To use a computing metaphor: if industry has produced a mainframe vision of a smart city, the alternative is something akin to the personal computer: inexpensive and decentralized. Three big shifts in technology are enabling this shift. First, as mentioned previously, computing has moved off the desktop. By 2011, sales of personal computers were flat, while smart phones and tablets sold in record numbers. These devices not only decentralize computing power from large organizations into the hands of everyday people, they also embed it in everyday urban spaces, spurring new ideas about potential uses. Second, the shift from fixed to untethered communications is pushing information technology into every crevice of the city. Third, cloud computing has decoupled information processing from place, enabling supercomputing power to be accessed from any device, anytime, anywhere - including our pockets. These raw materials provide a vastly expanded array of basic components for entrepreneurs, tinkerers, and media artists to develop novel responses to urban challenges - giving rise to services as varied as Uber (for e-hailing taxis), SeeClickFix (for 311), and HandUp (for donating to homeless individuals). Hal Varian, Google's chief economist, has likened the situation to the early industrial era, when standardized machine parts spurred a global frenzy of ‘combinatorial innovation’.²⁸ Where the corporate smart city primarily seeks to control, optimize and make efficient, the bottom-up version also aspires to enhance access, sociability, transparency, and entertainment.

What of city government then? What is its role in this? As I wrote in 2013, it seemed a battle was brewing over the soul of the smart city:

Everywhere that industry attempts to impose its vision of clean, computed, centrally managed order, [civic hackers] propose messy, decentralized, and democratic alternatives. It's only a matter of time before they come to blows.²⁹

While they have rebuffed the most audacious visions of industry, city governments have not yet really embraced a fully citizen-powered vision of the smart city either. For now, they seem to be trying to balance interests, and identify sustainable strategies for innovation over the long term.

They are doing this through two primary means - creating new leadership positions and developing “digital master plans”. New leadership positions such as Chief Innovation Officers, Chief Technology Officers, Chief Data Officers and Chief Digital Officers, have given cities the ability to coordinate and elevate technology policy and planning within city government, and leverage external resources in the private sector, universities and the philanthropic community. Digital master plans represent a new comprehensive, long-range urban planning activity, seeking to develop a vision and road map for investments in ICTs that align with citywide policy.³⁰

The political economy of the smart city is still in flux, and alliances and alignments of course vary from place to place — the relationship between industry and city government runs from hot to cold, and the same for civic hacker groups as well. Meanwhile, universities are moving en masse to position themselves a key players as well through the establishment of urban science and urban informatics centers and ‘living labs’ for smart city engineering.³¹

Smart Cities & the Environment: Three Emerging Intersections

During the Progressive Era, widespread recognition of the threats to public health presented by overcrowding and poor sanitation in American cities led to the launch of numerous reform programs. These efforts improved sanitary conditions through improvements in water and sewer infrastructure and housing stocks. At the same time, conservationists succeeded in establishing a consensus around the need to prevent further damage and depletion of natural resources from human settlement and industrial activity.

As the environmental movement matured in the post-war period. New scientific evidence gave rise to a loose compact of interests, which played an increasing role in spurring nations and regions to address the effects and roots causes of environmental degradation. Previously, externalities from industrial production could be ignored, as those costs could be off-loaded to surrounding neighborhoods, downstream residents, or down-wind lakes. But as suburban sprawl brought city and countryside into more direct contact, these distinctions began to break down.

Increasingly, this compact (especially at its scientific roots in the case of climate change) is being attacked, but is it unraveling? As they provide new tools for monitoring, regulating and managing urban environments, to what extent does the smart cities movement reinvigorate the public debate over the social compact on environmental sustainability and the protection of the larger society?

This paper has broadly summarized and characterized the key trends and developments giving rise to the smart cities movement and the political economy shaping its ongoing evolution. The remainder of the text will examine at three themes where the smart cities movement is directly engaging structural underpinnings of the urban environmental compact, and pose a number of questions for further discussion and research. These

themes are: infrastructural complexity and efficiency, transportation innovation, and citizen science.

1. Infrastructural Complexity and Efficiency

One of the key engineering challenges of future cities is infrastructural complexity. Delivering responsive, high-quality urban services requires careful integration of many different networked resources in a carefully synchronized fashion. For instance, mass deployment of electric vehicles will require new approaches to balancing the flow of vehicles on road networks as well as the flow of energy on power grids, and the interactions between the two dynamic systems. As social demands for reliability and resilience increase, increasingly distributed points of generation and distribution will further complicate matters. Meanwhile, the liberating impacts of ICTs on individuals and organizations - breaking down traditional schedules and travel routes - is creating more differentiated infrastructure usage patterns, further complicating the picture.

Coping with the complexity of infrastructure itself, and the rapidly changing and increasingly dynamic patterns of use will require new approaches from operators. Three possibilities present themselves.

First, even as complexity is a challenge, it can also be a tool. By engineering entire systems, new synergies can be exploited (such as co-generation, which uses waste heat from industrial processes to produce electricity). This is a well-established approach that is being developed in many efforts, but is largely incremental in the gains it presents.

Second, new sensory capabilities of smart cities, when linked to predictive computer models can allow for infrastructure to be managed in a far more optimized fashion than before. For instance, renewable energy sources such as solar present a particularly difficult problem given their fickle nature and the high cost of building storage for cloudy days. But as researchers at the National Center for Atmospheric Research and Xcel Energy in Boulder, Colorado have shown, hyper-accurate solar forecasts can be used to balance supply and demand in real-time over a wide area. In one experiment, the group briefly supplied 60 percent of the state's power needs exclusively from solar.³² This is an example

of what we might call a *super-intelligent city*, where machine intelligence performs analytical and allocation functions largely beyond the scope of possible human understanding (but with human oversight, at least for now). It is, essentially, a fly-by-wire city. Take away the computers, and it falls apart. For a sneak preview of this in practice, we need only look at some of the more recent innovations in active structural control, which operate in much the same way.

An alternative approach, which addresses the lack of transparency inherent in the previous example (assuming that the model uses machine learning, it is probably illegible) is what is called *human task-routing*. Here the idea is to assemble a large group of human beings online to disaggregate portions of a large, complex task into smaller, discrete tasks that can be more easily completed and re-assemble the completed work into a finished product. We might imagine this being used to analyze data about energy flows in a city, analyze signals intelligence for counter-terrorism efforts, or look for signs of socioeconomic distress in data collected at city schools. Such approaches are currently employed in a number of crowd-sourced online work platforms such as ODesk, Mobileworks and Amara for tasks like market research, writing documents, transcription and translation.³³

A third approach to infrastructural complexity and efficiency is simply behavior change - trying to 'nudge' people (to use Thaler and Sunstein's 2008 term) to reduce burdens on infrastructure. This raises some of the most intriguing possibilities because we start to enter a world where market-based innovations that we have seen in telecommunications get unleashed on the consumer energy sector. In the 1980s, when digitization of the phone system allowed more calls to be squeezed onto the same trunk lines, it also put intelligence in the network. Creating new services like call waiting, voice mail, and caller ID was then simply a matter of writing new switching software.³⁴ Proponents of smart power grids expect a similar wave of innovation in energy services. Start-up firms could audit and manage our home's electricity use in return for a small cut of the savings off our energy bill. In a world where Siemens forecasts that electricity prices could change as often as every fifteen minutes, we'll be relieved to have a piece of tracking software automate the process.³⁵ Smart grids could also map our social networks to the production, dis-

tribution, and consumption of electricity. Eric Paulos of the University of California, Berkeley, proposes using sensors to document how, where, and by whom energy is generated and making this information available during transactions. Such metadata could enable markets for power around any number of causes, interests, or goals. Today, power suppliers largely compete on price and carbon footprint. A smart grid could allow the data about electricity to become as valuable as the power itself, which holds the potential to enable better decisions about how we use electricity.³⁶

Smart city innovations in efficiency, and the infrastructure complexity they will manage and require be put in place to achieve them, raise many questions about the environmental compact:

- How will the public perceive the complex cause and effect relationships within these systems and the environmental outcomes they produce?
- How will the role of software and algorithms be made more transparent? How can the assumptions of model-builders be scrutinized, and their implications examined?
- What is the role of human oversight in the automation of urban infrastructure systems?
- What are the ethical issues involved when choosing between automating efficient behaviors and seeking to induce behavior change?

2. Transportation Innovation

The second area where the smart cities movement is having a more direct impact on the public debate around the social compact on environmental sustainability, is in transportation innovation.

While enormous changes have occurred in urban America's business, government and society in the last 25 years, little has changed in transportation. One could make the case that the way we get around - from the technology, to the business models, to the regulatory schemes - hasn't changed in 75 years (for surface transportation) to 125 years or more (for rail and ferry transit).

Yet in the last several years we have seen the introduction of innovation after innovation, almost exclusively privately-initiated, that are dramatically changing transportation business models, challenging existing regulatory schemes head-on, and most importantly, threatening substantial long-term shifts in travel patterns and land use in our inner cities and larger metropolitan areas in coming years - shifts that could have both profound positive and negative impacts on regional ecosystems. Thousands of new digital technologies and services have come to market in recent years that are turning transportation from a bricks-and-mortar business into an information-based and informatics-based activity.

Disruption is happening throughout the value chain. Some examples include:

- Infrastructure networks: adaptive traffic signaling, electronic road pricing
- Vehicles: autonomous vehicles, programmable vehicle performance
- Business models: car sharing, ride sharing
- Interfaces: crowdsourced traffic reporting, multi-model integration

The result of all this investment and innovation is that city dwellers are increasingly dependent upon an array of digital services and technologies to make and manage travel choices, and often to actually take the trip. These services are having real impacts on travel behavior - changing why, when, where and how people take journeys to work, home

and other locations and activities. They are changing both the supply and the demand side of the travel equation.

Ironically, while transportation planners are mostly unaware of the interactions between new ICTs and travel behavior, and their implications for future land use needs, some of the startups are tackling this head on as part of their core offering. For instance, carpooling services like Zimride, launched at the University of California, Berkeley but later deployed for two large music festivals (Coachella and Bonaroo), is a platform for large venue and facility operators to coordinate and incentivize carpooling. Over the long run, services like Zimride could allow large amounts of parking to be freed up for development - potentially creating a virtuous circle of densification that could create greater demand for transit.

Transportation planning is only slowly waking up to these developments. Internal debates in the field remain focused on infrastructure and urban form rather than the direct behavioral impacts of these new technologies. As a result, these high-value, high-impact innovations in transportation are coming from the private sector with little coordination or planning. And their collective impact, and potential unintended consequences are not being adequately explored.

Take, for instance, the conflicts between Uber and local regulators. It is clear that the conflicts between innovators and regulators that we are seeing now is just an early indicator of much larger challenges to come. These are just the initial skirmishes in much bigger conflicts that will arise over how transportation systems work in 21st century cities, and the roles and relationships between public and private sector providers. The rapidly, private-sector innovation-driven shift in transportation — which I call ‘re-programming mobility’ — has profound consequences for the environmental compact in the United States, as it ties together the two most significant environmental choices most American households make: their choice of residence and their mode of commuting. Some questions include:

- How can transportation planners understand, forecast and explain alternative transportation futures to communities?

- What kinds of narratives can create compelling linkages between individual transportation choice architectures and community goals and visions and global environmental impacts?
- What are the actual trade-offs among the three ‘assets’ of land use, transportation, and ICTs? What substitutes and what complements? What kinds of new more sustainable designs and forms are possible (e.g. ‘televillages’, or whatever is the next version of them - such as the Washington, D.C. developer who got a zoning change to eliminate a required parking deck by giving every resident a bike share membership).

3. Citizen Science

Computers are mostly used against people instead of for people; used to control people instead of to free them...

People’s Computer Company Newsletter #1 (1972)

When Steve Jobs and Steve Wozniak demonstrated the Apple I prototype at the Homebrew Computer Club in Palo Alto, Calif., just down the road from Menlo Park (where the more radical People’s Computer Computer, another user group, gathered), the electronics community in Northern California was abuzz with the potential of democratized computing power. Today, the same urges that set off that revolution can be felt within the networks of inventors, entrepreneurs, tinkerers and researchers exploring the potential of connected objects, environments, buildings and cities. And as the ability to cheaply and quickly deploy sensors in the city meets up with the long-established traditions of citizen science developed in fields as varied as astronomy and ornithology, the smart cities movement is poised to breathe new energy into the urban environmental justice movement.

In recent years, the Internet has allowed scientists to engage ever-larger groups of amateurs in collecting and analyzing data, in much the same way that meteorologists have long collected weather and climate data from a distributed network of volunteer-main-

tained instruments and stations. Amateurs have made important discoveries in many areas of science, such as astronomy, by analyzing large sets of data. They have also played a major role in formulating research questions as well, such as the growing interest in rare diseases, which were ignored until victims could find each other, share information and organize online.

But citizens aren't waiting for universities to launch their own research. Urban environmental sensing is a particularly intense area of citizen-driven scientific data collection. In Paris, for instance, the internet think tank FING developed a wristwatch for measuring street-level ozone. In a demonstration involving 100 bicyclists riding in a single neighborhood, volunteers were able to create a finely detailed air pollution map that dramatically surpassed the government's sparse network of just ten stations across the entire city. At MIT's SENSEable City Laboratory, researchers took some rudimentary GPS-enabled phones, glued them to various pieces of rubbish and threw them away. Within days, they had generated a map of the 'removal chain', illuminating the secret journeys of our waste. In New York, a group calling itself Public Laboratory builds inexpensive sensors that alert citizens to situations during thunderstorms when the city's stormwater drains overflow into its sewage system, causing coastal discharge of human waste. The intent is that ambient displays in homes would spur people to refrain from flushing toilets during these events, thus reducing the flow of raw sewage into waterways.

As mentioned previously, universities are seizing the chance to stake out new territory in smart cities. In the last 12-24 months a vast array of new academic and non-profit institutions have been established to develop and exploit these new data streams to advance human understanding and improve the management of cities. From New York University's Center for Urban Science and Progress to the University of Chicago's Urban Center for Computation and Data to the Intel Collaborative Research Institute for Sustainable and Connected Cities in London, it has become clear that this is going to be a major global research theme, one with considerable potential impact across a huge range of policy arenas.

Not surprisingly, many of the new urban science labs – including MIT’s SENSEable City Lab and NYU’s Center for Urban Science and Progress – are directly engaging with these kinds of citizen urban science efforts. This makes sense, since the nature and scale of the subject of interest (cities) almost demands a strategy of leveraging citizens as extensions of the university’s capacities.

More importantly, however, is that by including citizens in research it is potentially more likely that they will welcome the results of the research as valid and accept their use in the design of new interventions. Engaging citizen science may represent a strategy for making this wave of urban science, and its application in the public sector, significantly less technocratic than what we have seen in the past, and make the research itself into an act of civic engagement. Open data will play a crucial catalyzing role in those collaborations.

Citizen urban science raises a bewildering number of questions about the environmental compact. A representative handful include:

- Will citizen urban science focus mostly on augmenting professional data gathering, filling in gaps, or creating alternative narratives that challenge official data?
- What is the role that open data platforms in facilitating collaborations between citizens, universities and city governments in urban research?

Implications for Planning Research

This survey has described the rise of the smart cities movement and its emerging intersections with urban environmental policy in three areas: infrastructural complexity, transportation innovation, and citizen science. In conclusion, further elaboration on the potential for citizen science to inform planning research is warranted, and a cautionary tale about the overall prospects of the smart city movement to achieve meaningful long-term environmental results.

Citizen Urban Science: Nodes of Future Collaboration

The nature of urban research appears to be changing rapidly. Universities around the world are bringing online a massive new infrastructure for data-driven urban research in the coming decades — an investment which could surpass \$2.5 billion by 2030. But the ‘new urban science’, as many are calling this movement, has not yet defined how it intends to engage or empower non-professionals in the research process — a glaring omission in an age where new digital platforms are unleashing the power of mass participation in so many other areas of the economy, governance, and intellectual and political life.³⁷ While there is much talk of the importance of citizens in these efforts as beneficiaries of research effort, their envisioned role in the research process is much less clear. Predominantly, these efforts envision future urban research as a tripartite collaboration of university, city government and private sector firms. But will this new intellectual venture be an inclusive endeavor? What role is there for the growing ranks of increasingly well-equipped and well-informed citizen volunteers and amateur investigators to work alongside professional scientists? How are researchers, activists and city governments exploring that potential today? Finally, what can be done to encourage and accelerate experimentation?³⁸

Citizen science has thrived in recent years as these changes have unfolded. While amateurs have long played important roles in many fields, from astronomy to meteorology, the web has lowered the cost and expanded the range of collaborative activities with professional scientists. For instance, amateurs now routinely participate not only in the analysis of large data sets, but in so doing help train computer software to perform the same tasks. There is so much citizen science happening now, that the practice itself is becoming a field of academic inquiry itself - in early 2015 the prestigious journal *Bioscience* called for the recognition of “research on citizen science as a distinct discipline”.

Urban research is changing quickly — but its relationship with citizen science will inevitably become deeply complex and multi-faceted, and controversial. That’s because not only is citizen science a necessary key to improving the science of cities, it is a tool for making the case that the results of such research are to be trusted when applied in urban governance. Citizen science can provide the ground truth necessary to trust the synoptic urban sensing tools being used in urban science. Our operating hypothesis then is that citizen urban science will become an increasingly important strategy within the urban science movement

- For doing better science – by creating larger and more detailed data sets;
- For making the pursuit of science less technocratic – by giving citizens a stake in data gathering, analysis, application of results, and even setting parts of the research agenda;
- For applying new knowledge in the real world – by creating sustained engagement between researchers and partners in local governments for tech transfer.

The way that citizen urban science evolves will both shape and be shaped by the legacy of the environmental justice movement over the last half-century, which demonstrated how citizen urban science can have major lasting impacts on urban policy and planning, and the lives of people and groups in urban communities. Environmental justice itself grew directly out of the civil rights struggle — in 1968 Martin Luther King, Jr. fought on behalf of black sanitation workers in Memphis.³⁹ The environmental justice

movement coalesced in the 1970s and 1980s through activist efforts, which focused attention on the systematic biases and shortcomings of environmental risk assessment practices in the United States — especially around urban air pollution impacts of siting decisions for highly noxious public facilities such as incinerators, trash transfer stations and waste treatment plants.

In the 1990s, the movement began to trigger reforms on urban environmental policy at the federal level. Robert Bullard's landmark report *Dumping in Dixie: Race, Class, and Environmental Quality* (1990) led directly to the Clinton administration's 1994 executive order (Executive Order 12898) mandating environmental justice reviews in the conduct of federal government operations.⁴⁰ But despite its origins in a movement based on its appeal of human rights, ethics and fairness, data and quantitative evidence has been critical to building support and a record of victories for the movement. Citizen- and activist-collected data have been used to win cases on the behalf of communities unfairly targeted as hosts for threats to public health such as nuclear waste disposal and industrial facilities.⁴¹ Such data were used to contest the federal government's own assessment tools, which had become so institutionalized that their weaknesses were called an "open secret".⁴²

While previously environmental justice had a contentious relationship with professional science — generally the movement viewed traditional science as cold and detached, and unwilling or unable to incorporate social factors into environmental hazard assessment, whereas the scientists saw environmental justice advocates as unorganized and emotional — the movement still wielded scientific data and methods to serve its own ends with great prowess and effectiveness. Evidence-based campaigns have been effective in policy circles at the federal level- bringing change to the ways the EPA conducts environmental assessments as well as leading to the creation of the Office of Environmental Justice, these efforts still face adversity. Despite the massive amount of citizen-collected data the movement has produced, very little has been utilized in formal scientific research where it is still often viewed with extreme skepticism.⁴³

Today's efforts to link environmental concerns with citizen cover a broad spectrum of models for bringing together citizens, academic researchers, and government agencies to do urban research. A recent paper looks at three case studies:

- Chicago's **Array of Things** - a large-scale urban environmental sensor network blanketing the downtown Loop, established to provide a testbed for university research and citizen engagement.
- Amsterdam's **Smart Citizens Lab** - a training and prototyping facility in Amsterdam that seeks to develop a corps of citizen scientists to deploy and maintain sensors throughout the city.
- New York City's **Trees Count!** - a crowdsourced effort to conduct a decennial census of street trees to support ongoing planning and operations, and potential future research.

These early efforts to mobilize citizens to advance the collection, analysis and application of urban data in cities highlight both the promise and the nascent nature of citizen urban science today. While citizen science has spread broadly around the globe and garnered attention from national policymakers, this movement is only slowly gaining traction at the city level.⁴⁴ As these projects and others like them progress, the utility of citizen generated data is substantial. Yet further efforts are necessary to organize and direct the trajectory of citizen urban science for it to have the transformative impact demonstrated by the environmental justice movement.

Three emerging nodes of collaboration that should be targeted for further research and support in the immediate future - shared sensing infrastructure, open data, and networked social capital.

1. *Shared Sensing Infrastructure* - Each of these efforts began with research and development of a new instrument for data collection - the Array of Things sensor pod, the Smart Citizen Kit, and the app and tablets used by Trees Count! to record findings. This is counter intuitive, because advocates of participatory digital urbanism routinely point to mass ownership of smart phones as a fundamental enabler of citizen urban science — yet each of the projects saw the need to invest considerable resources and

time in deploying a new, customized data collection platform. A key question going forward is whether increasing fragmentation of infrastructure is expected and / or desirable, or if, as Array of Things and Smart Citizen Kit implicitly aspire, there is an opportunity to co-locate most of the required sensors for a portfolio of efforts, organizations and projects on a single physical infrastructure. If this is technically feasible, who can it be made financially and institutionally feasible? (For instance, what happens when conflicts over sensor requirements, etc. occur?)

2. *Open Data* - The open data movement has demonstrated how sharing of information without restrictions can, as Code for America founder Jennifer Pahlka describes it — “...allow us to collaborate without talking about it”.⁴⁵ However, significant obstacles inhibit realizing the full potential of open data to catalyze and accelerate citizen urban science. As we saw in environmental justice, government officials and even academic researchers are often skeptical of the quality and bias of citizen-generated data. Even where it is collected, and pressing policy issues exist, it is likely to be ignored. Citizen advocacy groups may balk at sharing data that could be used to frame a case against their preferred course of action. Researchers, while increasingly being pressured to open research data for review and subsequent use, have powerful incentives to hoard valuable research data. Future research should probe further into the value chains that develop and can be developed around urban sensor data, and the way open sharing can help accumulate and distribute that value in equitable and productive flows. We expect that this will require deep ethnographic and managerial types of studies.

3. *Networked Social Capital* - The key to understanding and enabling these value chains will be focused effort on catalyzing and cultivating the networked social capital that gives rise to and sustains citizen urban science undertakings. Each of these cases addresses this node of collaboration in a substantial way — the Array of Things has created a dense network of institutional partnerships, the Smart Citizens Lab is focused on recruiting and training a grassroots cadre of citizen-scientists, and Trees Count! seeks to mobilize an army of volunteers who can be called on in times of need by government to provide a public service. Yet important questions remain: How can these models be made replica-

ble? How do they complement or compete with each other? What models are best suited to which aspirations of citizen urban science - e.g. collection of scientific data, issue advocacy and policy change, community and economic development?

Thinking About the Unthinkable

There is no doubt that smart cities are a key area of concern for urban planning, and that urban environmental monitoring is a key application area at the highest levels of federal policymaking — recent statements by key Obama administration officials at smart city events to this effect make this clear.⁴⁶ And there are competing visions for how to accomplish this - through coordinated, centralized, city-led and corporate-enabled deployment of comprehensive sensing grids, or through more citizen-driven, distributed frameworks. There is every reason to believe that at least one of these approaches might work, both could work independently, or they might even complement each other in some new beautiful synergy - in fact, that wouldn't be all that different from how the internet and the World Wide Web has worked out (with a few caveats).

But I would be remiss as a forecaster if I didn't paint a somewhat darker picture of what might lie ahead. For we need to approach smart cities with skepticism, to think about the worst that could happen, and how we might face it. For the implicit assumption in nearly all framings of the smart cities concept is that they will be more efficient, and better for the environment than contemporary urbanization frameworks. But there are many scenarios, eminently plausible, where this is false. Let us close by considering a few.

First, smart technology might not deliver enough efficiency. The improvement needed to stabilize carbon dioxide emissions are “neither trivial nor impossible,” according to a 2007 United Nations Foundation report. But they are certainly not a sure thing. In the worst case, more efficient smart infrastructure will actually work to hold down the price of energy and stimulate even more consumption—what economists call the “rebound effect.”⁴⁷

Second, smart technology might turn out to be less effective in curbing energy use, yet highly effective for reducing traffic congestion and fighting crime. Although cities would become more appealing places to live as quality of life improved, and in America, this might help with the energy problem indirectly, by enticing people back from the suburbs to denser communities, in the developing world it could speed up the growth of megacities powered by today's dirty energy technologies. That would be an economic success story of epic proportion, but a global ecological disaster. Imagine a smart Johannesburg suddenly free of crime and booming, absorbing millions of migrants from sub-Saharan Africa into a ramshackle infrastructure of dirty minibuses and smoky coal- and dung-fueled stoves.

A third doomsday story goes like this—we do crack the code of sustainable design and bring the needed technologies to market, just not in time. Even in Singapore, with its long and proven tradition of technocratic planning, smart infrastructure projects move at a snail's pace. Digitization of the nation-state's congestion toll system in the 1990s took twelve full years to implement.

A fourth possibility is economic stagnation. If the malaise of the developing world is too much growth, for the rich cities of the global north it may be too little. If smart technology doesn't improve our productivity - as many economists now doubt - we might not be able to pay for further improvements in energy efficiency.

In a final unthinkable future the wealthy fall back on smart technology to retreat to gated enclaves, sustained by captured resources managed solely for their own benefit. This is already the norm across much of the developing world, where the poor have less access to clean water, healthy food, and basic sanitation, and pay vastly higher prices for them when they do. As competition for natural resources heats up over the next century, and the impacts of climate change disrupt supplies, the rich may be able to wall themselves off from the consequences of their own overconsumption. Instead of making cities more resilient to the challenges of rapid growth and climate change, smart technology could limit the ability of poor and vulnerable communities to adapt.

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