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The Digital Skin of Cities:

Urban Theory and Research in the Age of the Sensored and Metered City, Ubiquitous Computing, and Big Data.

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Abstract:

Information technologies are now being developed that transform the physical environment, and the human interactions within it, into a “digital skin” of the city. This skin consists of a sensored and metered urban environment. In concert with ubiquitous computing, and the increasing use of electronically-mediated interactions in general, the physical world is becoming a platform for generating much new data on the workings of human society, its interactions with the physical environment, and manifold processes in economics, politics, and social interactions. The city is a subject of this revolution, in the sense that the technologies are predicted to make it possible to manage the physical city in ways not previously possible, but also to make possible major changes in the political and social interactions of people within cities, and between citizens and government. The city is also an objective basis for the revolution, in the sense that it is the sensored and metered platform that can generate unprecedented “big data” for many new types of uses. This revolution opens up many questions for urban theory and research, and many new issues for public and urban policy, which are explored in this paper.

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INTRODUCTION[1]

Information and Communications Technologies (ICT) will play increasingly important roles in the future management and governance of cities as well as the interactions or experience of people who live in them. In the near term, urban regions will be shaped in certain important ways by the advent of ubiquitous mobile connectivity. Sensors will be integrated into nearly all parts of the physical urban fabric. Social networking between government and citizens and among different overlapping human networks will permeate society. Information access and processing platforms will enable individuals to peer into selected dimensions of the urban and regional environment from their desktops and mobile devices. Moreover, all of these developments will give rise to an unprecedented amount of information on what people, the urban physical environment, and organizations do, and where and when they do it. The rise of such "big data" and the associated analytics and computing power to exploit them, are transforming the possibilities for managing urban infrastructure. They will also generate vast new markets for services, from the management and sale of the data to the markets they identify and analyze. Big data are also giving rise to representations of what human society is and can become. The urban environment, in effect, provides the most potent platform not simply for analyzing essentially urban phenomena, but for analyzing human society; it is both the source of data gathering and a way to peer into many human interactions and behaviors, beyond the urban itself.

There are some estimates, however speculative, that the so-called "smart cities" technology market may be worth anywhere from $100 billion to $1 trillion over the next decade.[2] As with any major technological change, the public space is becoming crowded with predictions and speculations about the city's new "digital skin." The smart (we prefer "digital," "sensored" or "metered") city is the focus of a rising wave of commentary that argues for revolutionary potential for the joining of social media technologies with a sensored/measured/monitored physical environment in which human movements and behaviors unfold. The city's digital skin is thus said to give rise to a new stage in the digital interaction world of human society itself. This thick discursive field includes many participants, from technologists and engineers, to civic activists and policy-makers; it is relatively thin on social scientists, humanists and historians. The narratives are not only operational, but heavily normative.

In this paper, we review the current state of the art of the various movements, advocacies and emerging practice and policy fields – often known collectively by the moniker of the so-called "smart city" -- and outline their principal potential applications to urban management, governance and interaction between

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[2] Pike Research predicts $100 billion of total spending by 2020; Markets & Markets predicts $1 trillion by 2016. The variance can be explained by how the analysts choose to define the market, which is subject to some debate.

people and the urban material environment. Section 1 provides a detailed review of the developments now under way, and section 2 steps back to reflect on the wider implications for society and policy. This enables us to identify some of the critical implications of this important new field for teaching and research, a field which bridges engineering, social science, the humanities, and will involve many areas of interest to public policy.

1. WHAT IS THE DIGITAL SKIN?

The widespread implantation of sensors into the urban and household environments, together with ubiquitous mobile broadband communication technologies, will generate enormous amounts of widely-available data to firms, governments and individuals. For convenience, we can call this new technological infrastructure the city's "digital skin." There are four major ways in which the implantation of this skin will have impacts on urban policy and urban society. First, these technologies make possible new management systems for the efficient administration of cities and urban services, a phenomenon coming to be known as "smart cities" (section 1.1). Second, they may enable new forms of virtual interaction between urban residents and their governments and a wide variety of civil society organizations, so as to generate changes in the ways political voice and debate occur over urban issues. We discuss these developments using the term "urban governance" (section 1.2). Third, the access to information from sensors, combined with the ongoing development of social networking, are changing the ways that we interact with the urban environment and its space, and how we make choices of where to go and what to do. The implications of these combined physical and virtual interaction systems for urban society are as yet scarcely analyzed (section 1.3). Finally, the generation of unprecedented amounts and types of data about human interactions and the interactions of humans with material objects in urban space, give rise to new analytical methods for analyzing human behavior and shaping it, a phenomenon known colloquially as the "big data" revolution, essentially a new intellectual representation of human experience at a very large scale (section 1.4).

1.1. Management Systems ("Smart Cities")

Management Systems, often referred to by practitioners as "Smart Systems", encompass use of ICT-based technologies "to deliver more effective and efficient public services that improve living and working conditions and create more sustainable urban environments." (Menychtas et al, 2011). IBM, for example, states a "Smart City" should be "instrumented + interconnected + intelligent." For practical purposes this means urban systems that are equipped with sensors and systems, which can gather information, connected with the wider network (and thereby all other instruments), and able to react based upon the data gathered. As the European Platform for Intelligent Cities (EPIC) puts it:

> *Technological advances mean that aspects of the operation and development that city managers have previously been unable to measure – and therefore unable to influence – are increasingly being digitized. This instrumentation creates brand new data points about, for example, the efficiency of a city's water or transport systems. In addition to being instrumented, different parts of a city's systems can be interconnected, so that information*

flows between them. With the greater digitization of and interconnection of a city's core systems, the newly gained information can be used for intelligent and informed decision-making. (Menychtas et al, 2011: 12)

The architecture of the hardware is not yet fully known, but probably will involve sensors of many types (visual, such as cameras, auditory, environmental – including chemical, thermal, and flow, and properly digital). Linked to this intake of information is, of course, the ability to process it, using new types of software. The latter will involve some mix of monitoring and troubleshooting tools; analytics (i.e., statistics, programming, & operations); and platforms providing access and visualization of what is coming in and being analyzed.

Major technology companies are now developing hardware and software, and consulting services to provide, customize, operate and maintain them. IBM is an early mover in the urban management area, emphasizing three core areas: **planning and management, human services, and infrastructure**. Figure 1 shows IBM's vision of such services:

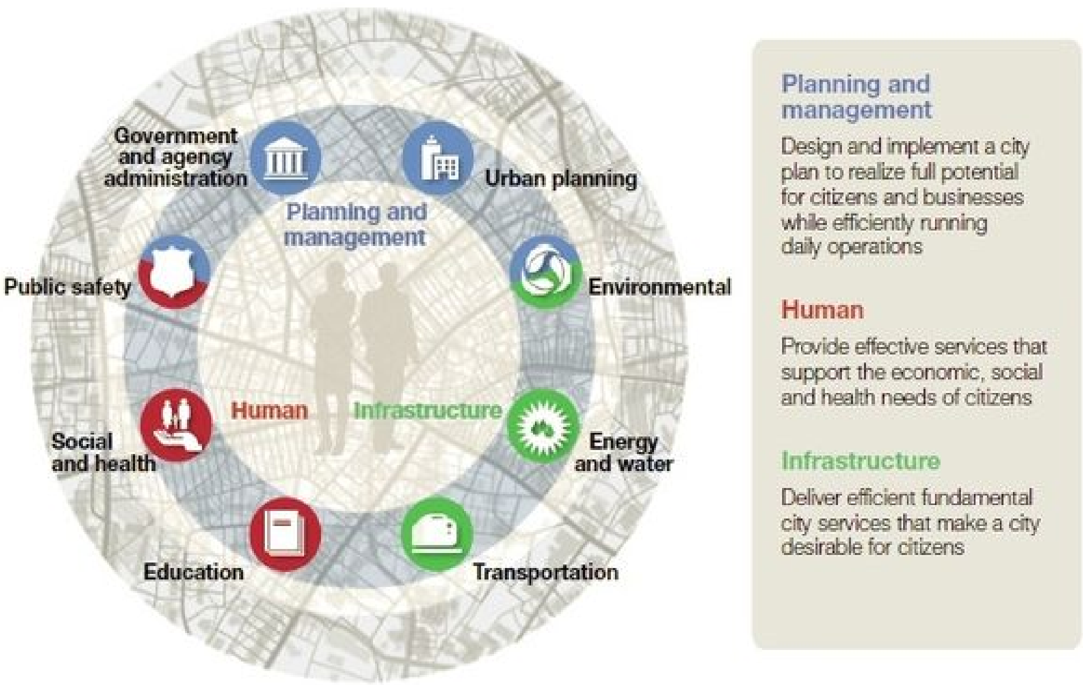


Image courtesy of IBM Corporation

Figure 1: IBM's Map of Urban Management Needs

The primary vehicle for IBM's work has been the "Smarter Cities Challenge," a 3-year $50 million effort to work with 100 cities. Cities were chosen according to the following criteria:

*The cities had to be prepared to match IBM's investment with their own commitment of time and resources. Proposals articulating pressing urban concerns that could be addressed by implementing *smarter* technologies and processes rose to the top of the*

> *list. Access to publicly available data… was an important consideration. And cities that demonstrated a solid track record of innovative problem solving were also viewed favorably*.s (IBM, n.d., *IBM Smarter Cities)*

Representative projects include a NASA-like, integrated operations center in Rio de Janeiro that houses all city departments under one roof; the use of analytics and 'predictive policing' intended to improve public safety in Memphis; integrated fare management for multi-modal transportation in Singapore; and a cloud-based, meter-driven portal to allow Dubuque (Iowa) residents to manage their water usage. Cisco Corporation is another early entrant into the field of ICT-driven urban management. Their primary goal is the creation of what they call "Smart + Connected Communities" through the provision of integrated network services to residents, businesses, infrastructure providers, and government managers and the "platform" is the way they will achieve this (Kondepudi and Baekelmans, 2012). The platform is intended to create "interoperability" between the different network protocols of the many types of devices that need to communicate with each other in an urban environment. This platform can then integrate applications ranging from utilities, transportation, safety and security, to land use and governmental decision-making. Figure 2 shows the "dashboard" format that this platform currently takes.

Figure 2 - Cisco Corporation's Service Delivery Platform – the "dashboard".

Cisco's ICT Master Planning Advisory Service in turn is the service arm that helps cities to think about what they can put in the platform. It is also future-oriented, involving the integration of the platform into revitalization projects and into construction of new communities. And finally, the company advances a theory of organizational development, which they term the “partner ecosystem” (Cisco, n.d.). According to this vision, once the platform is in place, then other public and private partners can bring in their own services, applications, and technologies. The Cisco delivery platform and advisory service open up the way forward. Some of Cisco’s pilot projects to date include: a master ICT plan for Songdo, South Korea – a “Smart City” built from the ground-up; a “connected bus” pilot in San Francisco; ubiquitous urban sensors in Barcelona; and developing services around enhanced energy efficiency in Vancouver (Cisco, 2012). Cisco’s emphasis is thus somewhat different from that of IBM. They are trying to illustrate what will be *possible* in various areas once their infrastructure, which enables inter-operable networks, is in place.

Another example of private-sector involvement is a smaller software firm, Living PlanIT, emerging from Portugal and now with offices in the UK and the USA (LivingPlanIT, n.d.). Their principal product may be a harbinger of things to come. It is a software platform that purports to create a fully integrated city-scale “operating system” to monitor and manage energy, water, waste, transportation, logistics, buildings, and even human interaction through a single unified system. They say their Urban Operating System (UOS) provides “unified sensor data acquisition, real-time control, historical database[s], [an] analytics engine, and [a] application hosting platform for urban environments.” Their partners include Cisco, Microsoft, Deutsche Telekom, Philips, Hitachi, Deloitte, and Accenture, reflecting the integrative nature of their software product. Their vision has four components, of which Plan IT provides the middle two:

> **The Sensor/Actuator Network** – a unified, converged network, which is enabled by the UOS but is not part of it. The Urban Operating System communicates with devices in this layer to collect data, make decisions – sometimes with user input via applications - and issue commands to controllable equipment. In an urban environment the network will typically be a local / metropolitan area network.
>
> **Network Controls Layer** – the ‘first layer’ of the UOS is deployed with network infrastructure and provides for (pre-programmed) autonomous real-time response to incoming stimulus – for example the control of a light or a motorized flap in an HVAC system. This is “the most distributed point of intelligence in the system”, and would generally be integrated with capital equipment from providers such as Philips, Hitachi, and GE. These applications are “often autonomous, leveraging sensors in the environment and actuators integrated with the capital equipment being controlled.”
>
> **Supervisory Control Layer** – the ‘second level’ of the UOS provides higher level, more aggregated intelligence and addresses areas such as traffic management, energy management, safety and security, operations management for a development, complex, region or city. This layer collects, manages, and provides insight to data, ensures that data is propagated quickly to where it is needed, and provides an Application Program Interface or API for third-party applications to leverage.
>
> **Consumer or End-User Applications** – These “PlaceApps” can be thought of as extending the ‘appstore’ model or ecosystem to buildings, infrastructure, and connected

devices. These will generally be developed by independent software vendors – but would rely on UOS data or control capabilities to provide a service to a specific audience. Examples include LED lights turning into context-sensitive exit signage based on structural emergencies; the clearance of a precise 'time and space' window around emergency vehicles; or controlling water supply to a bathtub. (Living PlanIT, n.d.)

For the moment, Living PlanIT is working with real estate developers and seems to be attempting to find larger, urban-scale projects as well as applications to health care, health care, the retail and transportation industries. It is interesting to note that they make relatively little mention of public sector, urban management clients as a target market.

The fourth early mover that should be mentioned here is the German multinational technology firm, Siemens, whose focus is "sustainability," which in this context specifically refers to engineering solutions to optimize resource use attached to the built environment. Figure 3 shows their vision for sensored, monitored, and managed buildings:

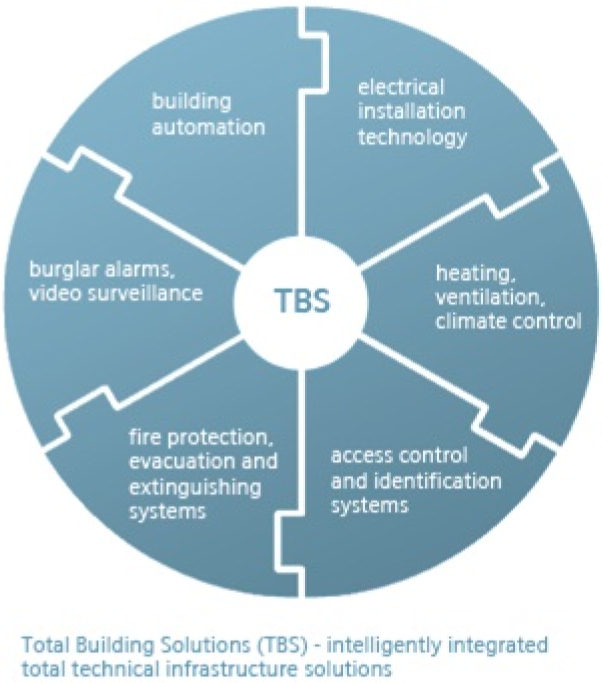


Figure 3 - Siemens' Focus on Sensored Buildings: Performance and Energy Efficiency.

Siemens is also interested in engineering applications in the wider urban environment. For example, their Traffic Management (vehicle and intermodal) division proposes traffic data collection; "Automobile-Infrastructure Cooperation Systems;" street lighting management (monitoring, repair at distance, if possible); and parking space management. They are developing the metering technologies and the control centers, data modeling, and supervisory control software needed to bring the data together and transform it into a tool for optimizing resource and space use, and monitoring and repair of the built environment

(Siemens, n.d.).It is likely that these new technologies are beginning to create substantial new possibilities for monitoring and managing the urban built environment, probable significant economies in resource use, and increased efficiency in maintenance of many physical capital elements of the city. In the transportation field, there could be major new gains in road and highway capacity utilization, and the unit cost savings on infrastructure that accompany such gains, as well as improvements in traffic safety and perhaps encouragement of car sharing.

Professionals working in the urban public sector or the community-based sector will therefore need to become skilled at understanding how to procure and implement such technologies, and in some cases, in how to work with technology firms to co-develop them for specific needs, especially in bigger applications with significant long-term sunk costs and irreversibilities. In the planning field, education for these new skills will require contact between the traditional urban disciplines of planning and architecture, and engineering and construction.

At the same time, and echoing an argument that will be developed in the second part of this paper, social science instructs us to exercise some caution with respect to these new management and engineering possibilities. This caution stems from what economics, sociology and political science has always shown about technological revolutions: they have unanticipated effects, many of them indirect, and many of them counter-intuitive (Mokyr, 1991; Rosenberg, 1992). First of all, it is well known that building new transport capacity never solves the problem of congestion; it enhances carrying capacity, but roads always revert to a pre-existing equilibrium level of traffic speed, as human agents substitute between transport modes.[3] Economics teaches us, therefore, that engineering solutions may enable more efficient utilization of existing resources, but will not eliminate urban congestion effects; even if, for example, totally automated highways flow more smoothly than current ones, economic models suggest that ultimately more people will drive as a result, leading to frustration in getting access to highways or increased overspill onto surface streets (Duranton and Turner, 2011). This leads to the second point: any urban resource that is supply-inelastic or positional (e.g. land, locations and buildings) will remain the object of substantial competition for its use, even if it is managed more efficiently and in part precisely because it is better managed and hence become more attractive. To put it more bluntly, engineering and good management have never eliminated problems of social choice and politics; they just alters the contours of the choice set. Thus, any research program on new urban management technologies should begin with a non-naïve perspective, informed by social science theory and evidence, and histories of past experiments.

[3] This occurs at a global scale as well: because unit transport costs have declined so much, the proportion of economic output devoted to long-distance transport rises, as more (but cheaper) transportation inputs are substituted in, in order to make more long-distance linkages possible (Anderson and van Wincoop, 2004; Hummels, 1999).

1.2. Governance and Participation

The information technology revolution has led to very broad claims about how society will be transformed by such technologies, and these claims will crop up in various parts of this paper. It behooves us therefore to introduce them here. The best-known and most complete treatment of these issues can be found in Benkler (2006), in a tantalizingly-entitled book, *The Wealth of Networks.* Summarizing widely-held views in the new technology field, Benkler argues that the IT-laden world is replacing an industrial economy with a "networked information economy;" that this will lead to a major increase in what he calls "non-market production" centered on the creative activity of individuals, not big organizations; that large-scale cooperative efforts based on peer production of information, knowledge and culture will replace hierarchical ways of producing these outputs; that these technologies enhance the ability of liberal, democratic societies to pursue what he calls their core political values of "individual freedom, a more genuinely participative political system, a critical culture, and social justice" (Benkler, 2006: 8).[4]

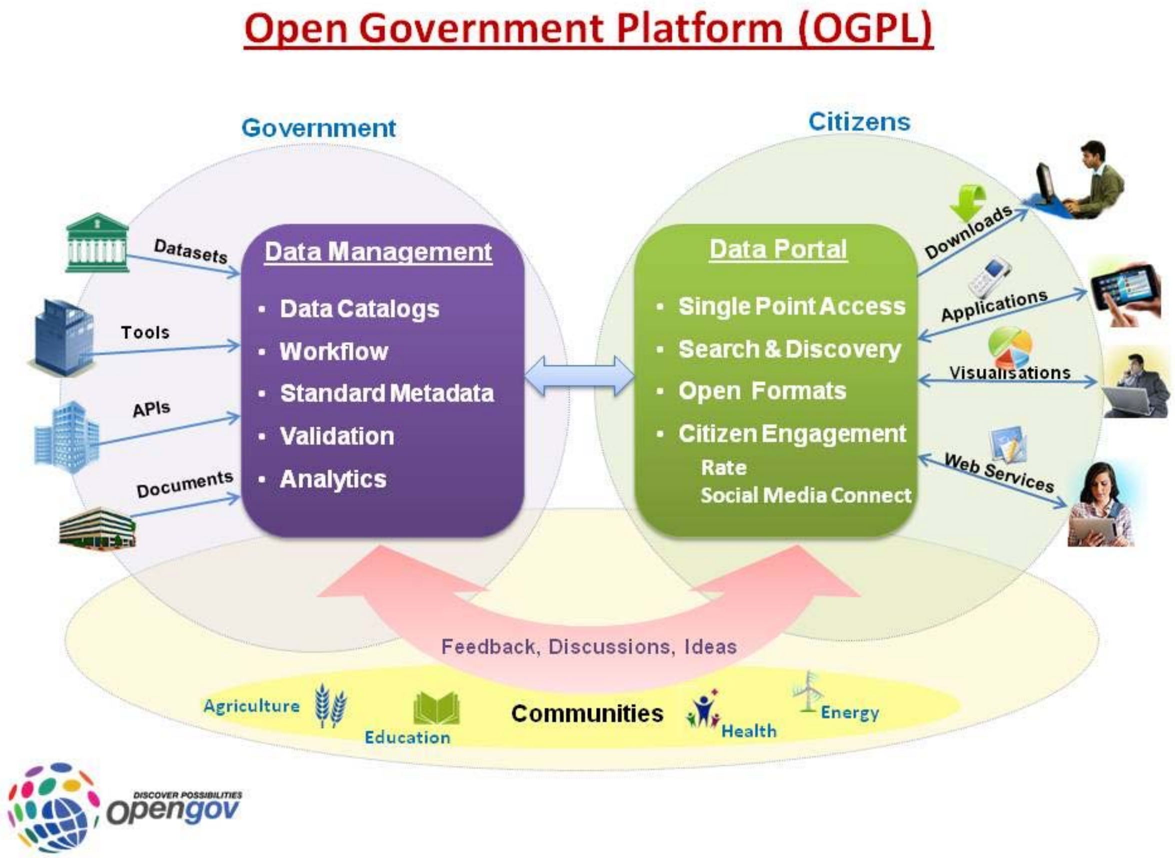
In light of this background, we can now consider a second area of putative applications of new ICTs, to the interactions between citizens, organizations and government. There is a dense thicket of normative language and empirical predictions that proponents deploy to describe these applications. They argue that technologies will enable better access to more data resulting in more informed and intensive interactions between citizens (the "principals") and governments (their "agents"). According to the emerging discourse, it may thereby be possible to improve citizen "empowerment and engagement"; to promote "collaboration" (and implicitly, to avoid conflict); to enjoy greater "accountability" and "transparency" in government; and to improve decision-making, governance, and service delivery (cf. Code for America, n.d.; Data.gov, n.d.; Lepeska, 2012; Orzag, 2009; Socrata, 2009). All this terminology is, needless to say, itself very complex and polysemic. We will defer dealing with these normative claims until Part Two of this paper; for the time being, let us just consider the field as it is currently structured.

The centerpiece of applications to governance and participation is making datasets available for public use: this is what has become known as the "open data" movement. A second element is more interactive: making information available on websites for comment, feedback and deliberation, and then allowing users (such as individuals, firms, or organized groups) to interact with one another, or to interact with public decision-makers (administrative, legislative), either in the form of general public comment and debate (often described as "participation"). For the moment, there seem to be few applications to actual decision-making (i.e. to attaining social choice in the face of heterogeneous preferences, a subject we shall discuss in more depth below). Most of this occurs through interactive websites, linked increasingly to mobile and dedicated applications, in the form of forums and discussions.

[4] Benkler does note that there are many impediments to the emergence of these benefits, especially the "new enclosure movement," which he thinks might foreclose access to the new technologies and to information, but the bulk of his book is devoted to the "nature" of these technologies which, in his view, promote decentralized, flatter social hierarchies, critical intelligence, more participation, and greater freedom and justice.

GIS platforms and mapping tools are in an early phase of being included in these sites, but it is widely thought that they will become the norm in the near future.

There are many examples of such initiatives. For example, in December 2009 the administration of President Obama issued Executive Order M-10-06, the "Open Government Directive" (Orzag, 2009). This directive required executive departments and agencies to take affirmative actions to achieve the following goals: publishing Government information online; improving the quality of government information; creating and institutionalizing a culture of open government; and creating an enabling policy framework for open government. Significant outputs of these federal efforts have already resulted. Data.gov, for example, provides descriptions of the Federal datasets (metadata), information about how to access the datasets, and tools that assist in use of government datasets. And in May 2012 the executive branch released an open-source product called the Open Government Platform (OGPL), which contains a data management system and social networking features (Data.gov, n.d.). The idea is that the platform will be available for any government (national or local) to download and deploy, for any developer to build applications on top of, and for any citizen to access. The following figure shows a conceptual model for this field:



Source: http://www.opengovplatform.org/features

Figure 4 - The Open Government Platform

The United Kingdom has embraced a very similar effort through their Open Government Data initiative and the Government Digital Service unit, as have Canada, France, Norway, Finland, and Brazil.

These government needs often rely on technology packages developed by private sector vendors. For example, *Socrata* is a Seattle-based firm, and a leading developer of Open Data services, *"*a category of cloud-based Web 2.0 solutions that enable federal, state, and local governments to dramatically improve the reach, usability and social utility of their public information assets.*"* (Socrata, n.d.). We will quote them at length, because they describe the objectives of the open data industry in general:

> The cloud-based Socrata Open Data Platform™ transforms information assets – tabular data, geospatial data, unstructured content and real-time data from government transactional systems – into a consumption-optimized and socially-enriched experience, that is automatically accessible across multiple channels of interaction, to enhance governments' ability to accomplish their mission at a reduced cost … (*Socrata's) "social data solution "combines elements of leading-edge technologies - social networking, cloud computing, data visualization and analytics, mobile and location-based services, internet-scale data serving, and web publishing – into a social, participatory online experience for non-technical audiences (e.g., citizens and consumers), journalists and scientists, policy makers, knowledge workers, and business executives."* (Socrata, n.d.)

In effect, Socrata offers three services. First, they identify and prioritize "*raw data to host online, followed by the process of cleaning and transforming the data so that it is accessible by an external audience.*" Second, they create a "*central repository for government data downloads, combining a directory for finding datasets, a state-of-the-art dataset analysis and visualization capability, community participation and moderation, and an advanced set of sharing and social media features.*" Third, they offer "*tools [to] enable dataset publishers to use web analytics to track civic engagement, as well as clearly identify the most active members of the Social Data Discovery Community.*" (Socrata, 2009; nb: the capitalization style is from the original). Thus far, their customers include the cities of Chicago, Seattle, New York, San Francisco, Baltimore, New Orleans, Austin, as well as the States of Illinois, Oregon, Colorado, Washington, Missouri, Oklahoma, and federal agencies such as Data.gov and Medicare.

Figure 5 - Socrata's "Solution".

Data.gov and its private sector providers are basically centralized vendors of data and interaction to a variety of publics. But there exist more bottom-up approaches. Code for America is a non-profit organization that calls itself the "Peace Corps for civic-minded geeks." Their mission is to help make governments more "open, connected, lean, and participatory" (Code for America, n.d.). They recruit fellows from the technology industry, and embed them for a year with local governments nationwide to solve civic challenges through customized web platforms.[5] According to the *Wall Street Journal*:

> *CfA fellows have designed more than 35 apps, for everything from urban blight to school buses. In New Orleans, they coded a system to more accurately sort the backlog of properties for demolition. In Santa Cruz, Calif., they're streamlining the application process to open a business. The group runs an Accelerator for civic start-ups. Its work presses governments to make information more visible (530 data sets liberated) and helps*

[5] This year there are 26 fellows for eight cities, and 550 have applied for the 25 to 30 spots next year.

> *communities to mobilize (write-a-thons with 2,500 people). Textizen, a citizen feedback app built this year, has already been repurposed in three cities.* (Finn, 2012: C12)

Traditional planning consultancies are also becoming providers of interactive city planning services. *OpenPlans* is a non-profit technology organization that builds open-source software with a particular focus on transportation issues and open, participatory city planning. Their goal is to create "better planning outcomes through the intersection of planning, technology, and public participation" (OpenPlans, n.d.). Their transportation services have provided cities with trip-planning, real-time tracking, and analytic tools; while their city planning software provides tools for public input and decision-making. Significant Open Plans initiatives include: *Meeting Matters* - a community-edited directory of public meetings; *Open Block* - a flexible open-source platform for local news gathering; *FixCity* - an application to help agencies 'crowdsource' streetscape improvements, thus inviting the public to suggest, discuss, and vet bike rack locations; and the *Urban Bikeway Design Guide* - city transportation officials share best practices for urban bikeway design (OpenPlans, n.d.).

Returning to more bottom-up approaches, interactive technologies are increasingly being used in the NGO and community-organization sector. These efforts extend the notion of crowd-sourcing and extend it to funding, thus potentially opening up new avenues for creating and funding CBOs in a decentralized way through virtual interaction. A number of examples of this phenomenon can be cited:

- *ioby (In-Our-Backyard – this is an environmental nonprofit organization with "a mission to deepen civic engagement in cities by connecting individuals directly to community-led, neighbor-funded environmental projects in their neighborhoods" ;*
- *Citizinvestor – a crowd-funding platform for small, local government projects;*
- *Neighborly – allows citizens to support major planning projects from cities or civic organizations, often exchanging government perks or tax breaks in exchange for support;*
- *Popularise – an online platform that allows citizens to review local development project proposals, submit their own ideas, and indicate their support to see projects built;*
- *Fundrise – an investment platform for citizens to invest in local real estate, purchase equity in development proposals, and "build the city you want to live in*." (Lepeska, 2012)

The developments described in this section open up forms of interaction between citizens, firms, organizations and government that were hitherto impossible. Access to data will eliminate some information asymmetries that have historically existed between experts and non-experts, elites and non-elites. Use of visualization and mapping tools will enhance the ability to present meaningful and more complex social choice possibilities to decision-makers and citizenry. Interaction tools may reduce political transaction costs facing the community and non-profit sectors, as well as traditional lobbies or interest groups.

Will these changes allow cities to be "better" governed? What is the measure of "better" in this context? Will problems of social choice (conflict) be attenuated through more interaction, or will conflicts merely become clearer? Will new asymmetries in understanding the world emerge, or will technology act as a great leveler of understanding, given that "knowledge" and "information" are not identical? How far can crowd-sourcing and crowd-funding overcome significant inequalities of access to organization and relations that now characterize politics and hence governance in our cities?

At the present time, we do not really know much about the nature and magnitude of these effects. Therefore, as academia becomes involved in this field from social science and public affairs vantage points, it will not be enough to teach urban professionals how to "do" all of these things, and to assume that we know what their consequences will be. In-depth theoretical reflection and empirical research on all these issues will be required to understand their potentials and their limits and hence, what stance teaching programs should take in relation to them.

1.3. Human Interaction Systems

As noted, new technologies provide inputs from embedded sensors, mobile devices, and databases that enable mapping and locating. Taken together, they allow a digital representation of the city (visually in the form of maps and images; informationally in the form of lists, recommendations, tags, and categories of what exists in the urban environment). In some ways, we are coming to choose what to do, where, when, and with whom, on the basis of this new digital representation. Is it complementing the old way, which was based on human relationships and a substantial role for traditional, customary and inter-personal knowledge, or is it substituting new choice tools and criteria for the old ways? What are the potential consequences of such a change? It should be remembered here that agents in cities have always mixed information from their direct experience with the environment and that which is derived from their membership in wider social networks that are not spatially-bounded, and that this has always generated a mixture of sharing with those around us and of parallel realities in the same space. But it is possible that the new technologies will lead urban society over a threshold never before attained in this regard; the current generation is the first to have grown up entirely in the age of the internet. These "digital natives" are thus coming of age with a larger dose of information derived from the information technology world, and channeled to them through the platforms of major firms such as Google, Facebook, Yelp, Twitter and others, and hence structured by their algorithms, presentation styles and search channels.

An illustrative example of where we may be headed beyond the current standardized search format is a product called "CitySense," developed by Sense Networks. This product offers "real-time nightlife discovery and social navigation." From their site:

> *CitySense evolved searching to sensing. It passively "senses" the most popular places based on actual real-time activity and displays a live heat map. The application intelligently leverages the inherent wisdom of crowds without any change in existing user behavior, in order to navigate people to the hottest spots in a city. And it's not dependent on having a critical mass of users on the system. Sense Networks built a unique back-end infrastructure that processes years of data encompassing billions of points of positioning data. Created on the MacroSense platform, CitySense leverages this historical data analysis to normalize live location data originating from tens of thousands of devices and users moving throughout a given city.* (CitySense, n.d.)

The SENSEable City Laboratory at the Massachusetts Institute of Technology seems to be the most advanced academic effort devoted to promoting the "real-time city" of "crowd-sensing, actuation, data analysis, and computation" (Nabian and Robinson, 2011). The lab has been active for about eight years and has completed many projects, often in partnership with the private sector and cities. Representative areas of focus include: participatory sensing, urban mobility, open source architecture, and pervasive urban computing.

These developments can be expected to alter our experience of the city by augmenting, annotating, indexing, and filtering 'reality," much in the same way that the Google page algorithm influences the use of information. Imagine that such information about the local – hitherto subject to significant entry barriers (for the locals, the initiated, those with good interpersonal networks) – is now increasingly available to different sets of actors and over wider spaces and with different rules of access. One obvious example is information about property quality and value; in many areas, customary knowledge about neighborhoods has been necessary in order to make good investment decisions. Only a few, highly exposed (generally central city) areas, have offered truly cosmopolitan knowledge of their local quality to the entire world (e.g. downtown Manhattan, central London, and so on). But what if that became the norm? Local real estate agents would perhaps disappear or have their roles (and their economic monopoly power) redefined; demand curves for land in many cities in the world would be merged together and dramatically reshaped. A host of other effects on how prices are formed for services, land, and locations in cities might arise, with major implications for zoning, management, housing policy and local planning.

The economic effects would involve creating new markets and effectively destroying certain pre-existing ones (for example, as paid intermediaries are no longer required, much in the same way that local travel agents disappeared through "disintermediation"). The sociological effects would involve reconfiguring the boundaries of community knowledge, as the hitherto customary becomes formalized and extracted from its traditional spatial and social contexts.[6] In the example of the real estate industry, a potentially revolutionary change in the matching of urban supplies of land and services and the demand for them may be underway, expressed in the terms dis-intermediation, de-contextualization and digital ranking and re-contextualization. These processes and their effects should become the focus of a significant research effort in planning and associated social sciences.

1.4. Big Data and analytics: a new science of human interactions?

The Economist magazine writes in its October 27th, 2012 issue that "cities are turning into vast data factories" (p.14) and that the "physical and digital world are becoming increasingly intertwined." They are

[6] We develop this idea of a contrast between traditional territorially-rooted context and spatially-distributed context in Storper (2009)

referring to the advent of the "Big Data" era. Big Data is the term assigned to the large, complex streams of data generated by a ubiquitously sensored, connected, and digitized way of life. Big data is, essentially, everything captured or recorded digitally by modern information and communications technologies such as networked sensors, "smart" objects and devices, the web and social media. It can take the form of text, web data, tweets, sensor data, audio, video, click streams, log files and more and could encompass everything including banking data, social network chatter, traffic flow sensors, mobile phone GPS trails, and smart energy meters (Eaton et al, 2012). The superlatives abound, and even if they consist of a certain hyperbole, nonetheless capture a real trend. Thus, more than 30 million networked sensor nodes are now present in the transportation, automotive, industrial, utilities, and retail sectors. The number of these sensors is increasing at a rate of more than 30 percent a year (Manyika et al, 2011). According to IBM, 2.5 quintillion bytes of data are created every day and 90 percent of the data that now exists has been created in the last two years alone (IBM, n.d.). McKinsey Corporation predicts 40% projected growth in global data generated *per year* (Manyika et al, 2011.) There are currently 10 billion connected consumer devices, and there are projections this may rise to as many as 50 billion by 2020 (Ericsson, 2011). Thirty billion pieces of content are shared on Facebook every month (Manyika et al, 2011). A global telecommunications company, for example, collects billions of detailed call records per day from 120 different systems and stores each for at least nine months. An oil exploration company analyzes terabytes of geologic data, and stock exchanges process millions of transactions per minute (Schroeck et al, 2012). Taken together these components produce the "digital breadcrumbs" or "digital exhaust" of the modern age.

These breadcrumbs can only be reconstructed into a loaf of bread, however, by some kind of forensic method. This starts with identifying the clues, essentially by categorizing the crumbs, much in the same way that modern statistics was invented through standardization of categories (Stigler, 1992).. New analytics enable "sense" to be made, or thought to be made, through inductive analysis at a scale never before possible, due to limitations on computing power. Many of the first big data concepts and methods were pioneered by private-sector technology companies such as Google, Facebook, Amazon, IBM, Yahoo, and Twitter. These companies found themselves sitting on enormous quantities of data, which they needed to analyze in order to refine their recommendation, advertising, and search engines. For these firms, "big data" refers to "datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze" (Menychtas et al, 2011). The novelty of Big Data is not only due to the quantity of input (significantly greater than in the past), but the way it is analyzed. The modern scientific revolution is heavily hypothetico-deductive in method, driven by an incremental process of falsification of previous hypotheses and leading to deductive, structured approaches to information.

The use of abundant computing power to tack back in an inductive direction -- "seeing what the data say" in any direction or possible pattern – is different from the way most science has been done in the past several hundred years. It leads some in the technology industry to declare, with considerable hubris, that we are on the verge of being able to see relationships that are obscured by deductive epistemology, and thereby liberating humanity to reach a new level of depth and completeness in its understanding of the vastly complex puzzle of human social life. In extreme versions, these visions take the form of the futuristic "singularity" theory that has many adherents in Silicon Valley, the notion that we will soon be able to upload all of human experience into the world's computing system and see what emerges out of it in terms of patterns, categories, interactions and structures that we have never before been able to see, much less conceptualize (Vinge, 1993; Kurzweil, 2005).

Short of this comprehensive vision, there is considerable agreement that Big Data is arriving and may be the biggest harvest of the sensored, networked world made possible by the new technologies. Cesar Hidalgo of the MIT Media Lab and Harvard's Center for International Development, says big data must meet three criteria: it should be big in size, encompassing millions of people or entities; it should be high in spatial, temporal, and typological resolution (as in, not just averages); and finally big data should be big in scope and assist in understanding things about the world (Hidalgo, 2012). The core promise of big data is that through analysis unseen patterns will be revealed, producing knowledge, increasing operational efficiencies, creating value, and improving decision-making. In a more critical spirit, Danah Boyd, of Microsoft Research, MIT, and NYU, identifies big data as a "socio-technical" phenomenon, with cultural, technological, and scholarly components.

> *(1) Technology: maximizing computation power and algorithmic accuracy togather, analyze, link, and compare large data sets.*
>
> *(2) Analysis: drawing on large data sets to identify patterns in order to make economic, social, technical, and legal claims.*
>
> *(3) Mythology: the widespread belief that large data sets offer a higher form of intelligence and knowledge that can generate insights that were previously impossible, with the aura of truth, objectivity, and accuracy*. (Boyd, 2012: 663)

Though in its infancy, the field is developing rapidly. Google, for example, just released a big-data analytics infrastructure product called "BigQuery," which is able to run inquiries over trillion-row database tables within seconds, scaling to thousands of computers and petabytes of data (Melnik et al, 2010). And unlike past services which were designed for programmers, this new service runs through a command-line interface – so even non-technical individuals can essentially "ask" the service a question by running a simple query. Google states the service can be utilized in the following kinds of scenarios:

- *Customized, real-time reporting on hundreds of millions of sales transactions to understand changes in demand;*
- *Segmentation analysis on millions of customers to identify discreet cohorts for targeted marketing;*
- *Monitoring dashboards for operations management;*
- *Combining diverse business data to discover previously-unknown correlations.* (Google, 2012)

Google promotes the service by arguing that it allows businesses to glean "insights from big data in seconds rather than hours".[7]

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[7] The scientific community has also produced some interesting results through the use of Big Data. In a 2009 *Science* article, "Distilling Free-Form Natural Laws from Experimental Data"[7], Cornell researchers Michael

Social scientists, though less hyperbolic than Google, nonetheless share some of Silicon Valley's conviction that a fundamental new era in analysis is arriving. In 2009 a cross-section of prominent researchers laid out an agenda for what they labeled "Computational Social Science" in *Science* magazine. Noting just how much information our digital, 'networked' lives produce, the researchers stated their belief that "digital traces… can be compiled into comprehensive pictures of both individual and group behavior, with the potential to transform our understanding of our lives, organizations, and societies" (Lazer et al, 2009). Albert-laslo Barabasi, complex network scientist at Northeastern University, notes that there is so much data recording occurring now that residents of globalized, cosmopolitan cities could have "much of their life, almost in minute resolution… reconstructed from the many data streams [they] leave around [them]" (Barabasi, 2012). This is a particularly ambitious version of Singularity-type theories, because it involves not just aggregating all social patterns, but simultaneously disaggregating at the level of agents.

This can be stated another way. Much empirical social science to date is limited not only by the quantity of data available, but by the fact that it is typically reported in aggregations that eliminate much of the agent-level heterogeneity of human social life, as well as by the pre-existing categories we impose upon it when we gather it in a "top down manner." According to the new optimists, these problems are being overcome, and the new inductivism (mentioned above) ties it all together in a way that could generate radically improved insights into the nature of human social life; the Big Data community believes we now have on our hands a new tool on par with the introduction of the microscope, and this tool will reveal a completely new way of understanding individuals – their actions, choices, and behaviors – and our social systems. As a result, they argue, Big Data could allow us to design better institutions, and perhaps eventually control the feedbacks to our social and economic systems.[8]

Schmidt and Hod Lipson showed how machine-learning algorithms could be used to "*identify and document analytical laws that underlie physical phenomenon" in nature. Or, as one observer framed it, the experiment was designed to answer the question: "[C]an we algorithmically extract models to fit our data?*" (Voytek, 2012).

The Cornell team observed the dynamics of a double-pendulum and a double-harmonic oscillator using sophisticated motion-tracking technology, and through the use of algorithmic computational search was able to detect "*nonlinear energy conservation laws, Newtonian force laws, geometric invariants, and system manifolds in various synthetic and physically implemented systems without prior knowledge about physics, kinematics, or geometry*".

The researchers proposed a principle of nontriviality, explaining what made the correlations found within the data important and insightful to system dynamics. They continued: "[*the algorithm's] discovery rate accelerated as laws found for simpler systems were used to bootstrap explanations for more complex systems, gradually uncovering the 'alphabet' used to describe those systems*." (Schmidt and Lipson, 2009)

[8] "*If you could see everybody in the world all the time, where they were, what they were doing, who they spent time with, then you could create an entirely different world. You could engineer transportation, energy, and health systems that would be dramatically better. It's this history of thinking about signals and people together, and how people work via these computer systems, and what data about human behavior can do, that led me to the realization that we're at a phase transition. We are moving from the reasoning of the enlightenment about classes*

1.4.1. Big data and a "New Science of Cities?"

Cities are the ultimate complex and noisy human system. Big Data are thus being proposed as an important new source of insights into the management, governance, and experience of urban life: travel patterns and transportation systems, resource distribution and operations, crime and emergency management. MIT researchers Nashid Nabian and Carlo Ratti imagine Big Data as part of the "conversation" between cities and their residents:

> *People play key roles in this system as agents of sensing, regulation, and actuation. In terms of sensing, they voluntarily and involuntarily leave digital traces on various networks deployed over space. The network records every time a credit card is used, a text message or an email is sent, a Google query is submitted, a phone call is made, a Facebook profile is updated, a photo is tagged on Flickr, or a purchase is made in an online store. Once the datasets are attached to physical space, landscapes are transformed into new info-scapes. In turn, these info-scapes provide citizens with a better knowledge of their environment, and allow them to make more informed decisions. Indeed, this seems to be the most promising characteristic of the city of the future, which becomes "smart" through the collaborative activity of the sentient, self-reporting agents who are its citizens.* (Nabian and Ratti, 2011: 20)

As noted above, the rise of Big Data is generating yet another wave of speculation about transformation of social science, with the utopian dream of a comprehensive science of human behavior and society. This has a direct parallel in urban studies. Beyond the basic optimization of decision-making and management, there is renewed enthusiasm for an inductive, comprehensive empirical "science" of cities. Luis Bettencourt and Geoffrey West led the charge in a 2007 article entitled "Growth, Innovation, Scaling, and the Pace of Life in Cities". They revived the classical theme of the controversial rank-size rule (Zipf, 1949), presenting a new and improved version of the mathematical notion of "power laws" applied to the pattern of urbanization. Their urban growth equation purports to show that "the social organization and dynamics relating urbanization to economic development and knowledge creation, among other social activities, are very general and appear as nontrivial quantitative regularities common to all cities, across urban systems" (Bettencourt et al, 2007). The article was treated as highly problematic by many in the profession (Lehrer, 2010), just like its forebear in the rank-size rule. The rank-size rule is a (debatable) statistical regularity in search of a theory of human behavior and social organization; to put it more bluntly, it is a "what" without a plausible "why" that can be tested and evaluated. Big Data will undoubtedly give rise, inductively, to many observable statistical regularities; the question will be whether social science can make any sense of them in terms of human social behavior, or whether these regularities can at least suggest

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and about markets to fine grain understanding of individual interactions and systems built on fine grain data sharing." (Pentland, 2012).

new features of human behavior to that will increase understanding of the causes of such behavior and how they aggregate and interact to shape human social life and its trajectory over time and space.[9]

The advent of big urban and regional data calls for engagement by urban researchers. There are already several university-based research programs that are positioning themselves to develop expertise in the manipulation and processing of big urban data; it seems probable that scholars interested in cities and urbanization, will need to develop this practical skill, much in the same way that has GIS been institutionalized as a technique for analyzing and representing urban data. Professionally-oriented programs will need to respond to demand, in the policy and practice worlds, for graduates who have a feel for big data and the techniques for analyzing it.

But behind the rush to develop such practical skills, urban theory and research has a rich opportunity, and we would argue an obligation, to engage with the epistemological and social science issues alluded to above. An analogy to the GIS revolution may be helpful here. GIS has indeed proved to be very helpful in representing data and peering into them; it has not, however, revolutionized our explanations of the urbanization process nor has it led to a new era of transparency in explaining policies, their costs, their consequences or their opportunity costs. A major new research agenda that confronts Big Data with substantive issues of causality and explanation in the field of urban studies deserves to be on the agenda.

2. THE SHAPING OF A TECHNOLOGICAL REVOLUTION: A CRITICAL EXPLORATION OF THE DIGITAL SKIN

It is perhaps among the most basic impulses of the human species to try to master, manipulate and alter nature, that is, to create technology (*techne, praxis, poesis).* This impulse is reflected in the earliest archeological finds of cave-dwelling and nomadic societies, and the production of technology has followed a largely upward arc ever since then. It follows that technology does not spring directly from laws of nature, but rather from the intersection of the state of humanity’s knowledge of how nature works, in combination with the mobilization of resources and definition of priorities for how to exploit scientific discoveries and to organize them into technologies and then how socio-technical systems structure and diffuse the use of technologies in human society.

There is considerable debate within the history of science as to how much our understanding of nature (“science”) is dictated by some external, objective reality of the world, and how much is filtered or “constructed” by human epistemology. That is a debate we shall not enter here. Less controversial is the

[9] One of the strongest statistical correlations in the study of economic development, for example, is that per capita income increases with distance from the equator up to about the 55 degrees latitude. Does this mean, as some have suggested, that tropicality is inimical to development? How, then, to explain Singapore today, or the fact that per capita income in India was superior to that of Western Europe in 1700?

notion that there is a considerable degree of "social constructivism" in the relationship between science and technology; this relationship is influenced by human priorities, perceptions, organizations, incentives, resources, and so on (Mokyr, 1991); thus, technology does not spring directly from the internal logic of nature. Detailed histories of previous technological revolutions demonstrate the open-ended and non-deterministic pathways by which technologies unfold, and the different roads not taken in relation to those that ultimately were taken and hence came to dominate and crowd out the others (Hodgson, 1992). It should not be surprising that the ICT revolution to date was shaped in certain specific ways by the choice of roads taken and the exclusion of those that were technologically possible but not taken: protocols, file structures, data presentation are designed by humans, not given by nature, but they become "second nature" and shape human perceptions of the world and its possibilities, but in ways that become opaque to the users (Lanier, 2010). And by extension, the digital skin of the city and its uses will grow not just by autonomous laws of nature and science, but through human choices about the ways they are institutionalized and organized collectively.

As we have seen in Part I of this paper, the growing digital skin of the city offers tools to deal with the problems of rapid urbanization in the form of the planning of new and expanding cities and communities; enhanced efficiency, productivity, livability, and service delivery for all cities, with predictions that this will bring major improvements in their "sustainability"; the overcoming of inefficient governance of the public sector (e.g. its fragmentation among many jurisdictions within metropolitan areas) through electronic coordination; and more generally, for everyone ranging from public servants to citizens, a major gain in visibility, legibility, and control of the urban environment and of decision-making processes that affect it. The underlying premise of these early labors is that technological tools and practices can become solutions to many of the social, political, economic, and environmental problems we are faced with, in addition to simply making life easier and more pleasurable.

There are many participants in shaping the rapidly-proliferating discourses and narratives about the new technologies. There is exhilaration about the new modernity they offer, and significant hyperbole: "the second economy", "a universe of self-replicating code", "smart cities", "sentient cities", "a planetary nervous system", "digital skin," "a vast global brain", and so on. As in the past, then, the challenge for analysts of this emerging phenomenon is to be fully involved in taking its potential seriously, while avoiding the tendency for hyperbolic narrative and discourse to cloud analytical clarity and realism.

Beneath the poetic discourses that claim singular originality for this revolution, the emerging field of creating the digital skin shares many characteristics with previous technological revolutions. Its participants have roots in rational planning, cybernetics, and systems theory; they are based on a notion that problems are amenable to engineering solutions; they emphasize efficiency as a means to achieve social, economic, and environmental goals, with less emphasis on distribution or the questioning of social preferences; and they tend to believe that certain political problems (conflict, failure to achieve social choice) can be resolved or at least significantly reduced through these means. Thus, for example, Carlo Ratti of MIT creates a narrative that embodies these features:

> *Th[e] feedback loop of digital sensing and processing could begin to influence various complex and dynamic aspects of the city, improving the economic, social, and environmental sustainability of the places we inhabit. Feedback loops could grow inside one another: buildings and other spatial devices throughout the city could become probes and ambient displays, but also evolve into real-time, responsive devices in their own right.* (Ratti, 2011: 8)

Thus, it behooves us to establish a critical framework for research on the organization of this revolution, its intellectual orientations and underlying assumptions, and the relationship of these to the efficiency and distributional effects of the revolution on cities and their people. To begin this task, we can place the current revolution in historical, political and economic context.

2.1. Technological Utopianism and Planning: An Historical Perspective

This is hardly the first time that technological optimism has been advanced as a way to solve or preempt social, political, and economic problems. Though examples are numerous in all areas of human life, the urbanization and urbanism fields now look back on twentieth-century ideologies of modernism and rationalist city planning as naïve, if not deeply misplaced. Modernism and rational planning had many successes, at certain limited scales, such as individual buildings and developments; it was when they were elevated to all-purpose solutions to systemic problems of human collective life that they lost their compass. Large-scale master-planned cities, the apotheosis of modernism, including Corbusier's Chandigarh or Costa and Niemeyer's Brasilia, were explicitly premised on the belief that the problems of the city could be solved through scientific approaches to urban design. Their focus was on logic, order, efficiency, functionality, and – above all – a self-proclaimed "rationality," as the way to wipe out the irrational effects of tradition in urban life (Holston, 1989). Modernist utopias such as Brasilia were designed with the best of intentions and were hailed at their time as cities appropriate for the dawning 'jet age'. The bet of Brasilia's designers was that by leveraging a self-evidently rational design, self-evidently rational ends would follow: an egalitarian, scientific, forward-looking, economically efficient society. Costa and Neimeyer's hubris would prove short lived, as the rational apartment blocks were invaded with traditional, grafted-on spaces and functions, and squatter settlements surrounded the sterile planned city. The project is widely regarded as having failed because it abstracted people out of their normal, social, individual lives and leveraged an a-historical aesthetic divorced from Brazil's particular cultural context. As the critic Benjamin Schwartz notes, Brasilia "is quite correctly regarded as a colossally wrong turn in urban planning" (Schwarz, 2008). In the United States the experience of urban renewal was perhaps an even starker failure, with neighborhood after neighborhood demolished and thousands of residents displaced, raising concerns about legitimacy and participation, and heightened rather than lowered segregation, which vex cities to this day.

It is important to remember that, at the time, modernist logic seemed invincible, self-evident and hence ineluctable: large-scale apartment blocks were efficient, healthy and desirable; highways were spectacular achievements of efficient engineering; piercing boulevards through older neighborhoods would bring about fluidity and beauty in the urban environment; and the list could go on and in, rather depressingly. It seems obvious, at the present time, to ask ourselves whether the dominant symbol of the failed modernist era – the 'machine' – is not simply being replaced with overweening optimism about the current information age: the network, algorithm, index, or control system.

> *The network concept has recently undergone a revolutionary process that has led it to reaches well beyond its twentieth century embodiment. 1950s' architectural readings of networks looked at a top-down infrastructure where functions were plugged in, and through which commodities—material and virtual— were distributed from their sources to consumers. Twenty-first century versions of networks are distributed, bottom-up structures that for the first time allow humankind to gain constant, seamless access to real-time information…* (Nabian and Ratti, 2011: 20)

2.2. Democracy, Participation and Social Choice

It is not just the modernism of the machine age that has failed to live up to many of its predicted positive effects on human society; the internet itself was the subject of such predictions that it would usher in major improvements in the social order. Nobody would doubt that the internet has vastly expanded and reshaped opportunities for aggregate economic efficiency, and in some areas, for new forms of human choice, autonomy and satisfaction. That is not the subject of debate here. Rather, it is in the more thorny area of human *collective* choice and the shaping of the social order that the picture is murkier. Perhaps no document better captures the mix of enthusiasm and hubris than essayist and activist John Perry Barlow's widely circulated letter of protest against the Communications Decency Act of 1996, "A Declaration of the Independence of Cyberspace" (Barlow, 1996). The letter spoke of "increasingly obsolete information industries" and global governments as "weary giants of flesh and steel" whose presence was not welcome in cyberspace. It stated that the 'citizens' of the internet (it must be noted: mostly white, heavily male, and generally of socioeconomic means at the time) were forming their own Social Contract and that the internet's governance would emerge from "ethics, enlightened self-interest, and the commonweal." It argued further that traditional legal concepts of "property, expression, identity, movement, and context" did not apply and that a "Civilization of the Mind" would emerge in cyberspace. More recently, Peter Thiel has expressed a set of views that are apparently widespread in upper spheres of the world technology elite, that the IT revolution is largely a replacement for government and all organized forms of human action (Packer, 2011). There is obviously a wide range of social and political views among the technology elite of the USA and the world, and we need therefore to beware of caricature. But these types of views do not seem rare or marginal; one need only spend a limited amount amongst the literature of 'smart cities' or 'open data' or 'big data' to ascertain the dominant flavor of the utopia as involving some kind of final stage in humanity's evolution where traditional forms of collective action (ie government and big organizations), with all of their messiness, conflict and high transaction costs, are replaced by superior forms of automatic, crowd-based, or decentralized interactions, and that these types of interaction systems will have better (more efficient; more satisfying) outputs than what they are to replace.

There is a rapidly-proliferating literature on this subject, notably with respect to such areas of collective life as the infosphere (and thus, journalism and public debate); elections; public involvement in decision-making more generally; and whether in any of these areas there has been improvement in the quality of debate, the processes of choice, and levels of satisfaction attained by the society and its members.

Social science is not at the point where it can offer hard results on these issues, but social choice theory does offer a perspective on what we should expect, however. Social choice theory owes its seminal observations to the work dating from Lionel Robbins (1938), through to Kenneth Arrow's "impossibility theorem" in the 1950s, and the many extensions that have since been worked out in economics and political science (Arrow, 1951). The basic argument is that there are no electoral-type collective processes that can overcome fundamental differences in preferences in a complex world. This is for two reasons. One is that sequential and hierarchical choices (as in multiple-round elections) lead to progressively high levels of unsatisfied preferences. The second is that social choices are "intransitive," meaning that they involve different things that have no single index that can rank them. The thrust of these theories is that social choice is pretty much impossible, and that wherever possible, markets will do better if they can offer more choice in a decentralized way.

However, this rival ("public choice" as it is known) perspective has also been subject to withering criticism. Markets do well when decentralization of supply is possible, so that if one individual wants a red car and another wants a blue car, there isn't a reason why both can't have what they want. Social choice is not necessary in this case. But in the design of infrastructure, health care, the tax system, an urban neighborhood, land use regulation, drug safety, the air traffic control system, and so on, there are externalities, economies of scale, irreversibilities and sunk costs, positionalities, and many other features that require social choice. This is where some of the more revolutionary or utopian promises about a decentralized, interaction-governed world come in; they suggest that because we can radically improve access to information and lower costs of interacting, social choice can become something more generalized, through the new "wisdom of crowds." This type of logic has been mostly used in models of financial markets, where it is shown that many agents interacting do better at predicting correct prices of things than do individuals (assuming, of course information correctness and transparency; if not, we just get more tendency to price bubbles and busts).

The problem is that it is difficult to extend this logic to social choices of the type mentioned above, for the simple reason that they are not about "transitive" dimensions of things that can be traded off against one another, and hence an optimal point on a single index can be attained; instead, they are about possibly incompatible and mutually exclusive views of the world. Crowd-sourcing will not work in these cases. Some advocates then make a softer claim: that the "dialogue" or interaction will itself move actors toward consensus. But this certainly has not been in evidence in the break-up of the public information sphere away from traditional journalism and media into the more diverse world of the internet, because it seems to have been accompanied by silo-ing and sorting, rather than interaction and mutual comprehension.

In other words, theory provides us with some questions that a research program on the possible effects of technologies on participation, social choice, and preference aggregation systems in an urban context. It is inevitable that these forms of interaction will come about; so the research program should include not only a critical perspective on the predictions being made, but also an open investigation on what they will do, irrespective of the predictions of vendors and optimists. This need is now urgent, in light of the increasingly crowded space of predictions, promises and advocacies.

Another example can be found if we move up in scale from democratic social choice processes, to the Arab Spring, where social media tools were used by protesters to coordinate and communicate while organizing against repressive regimes (the so-called Facebook and Twitter "Revolutions" in Egypt, Iran, Tunisia, Libya, etc.). These events were widely taken as evidence of the emancipatory potential of social networking technologies, essentially that they lower political transaction costs and allowed social choice to emerge and knowledge of it to be diffused in spite of the existence of centralized and authoritarian power. The initial euphoria over those events failed to anticipate the gaps between the rush and excitement of the protests themselves and the follow-through needed to firmly establish new social and political orders; Iranians are still struggling with the same regime; while Egyptians and Libyans are facing serious questions about whether the 'new boss' will be the same as the 'old boss.' Many commentators in those countries have also since remarked that countries such as Egypt and Iran have their own particular traditions of popular resistance that American and European observers rushed to reduce to the use of information technology, thus involving – ironically – another bout of condescension from the West to the "rest." Moreover, other analysts argue that a fundamental error has been made in attributing these revolutions to the use of social media; as Gladwell puts it, "weak ties" such as those we maintain on Facebook or Twitter are not the ones that mobilize people to engage in high-risk rebellion, nor are they those that allow the levels of trust to emerge among people about to take such risks (Gladwell, 2010). Facebook and Twitter helped the protesters to get the word out to the world, and perhaps to one another, but in no way did they create the basis for the protests.

In light of these observations, a rigorous research program is required, one that would start with more neutral questions and hypotheses about the nature of change, and avoid allowing utopian predictions to crowd out more sober and realistic hypotheses.

2.3. Open Data: Commodification, Disintermediation and Local Context

Big data and "open data practices" can be expected to alter the organization of markets, in several ways: reducing or changing intermediaries ("disintermediation"); extraction of data use and interpretation from local context; and creation of markets where previously they did not exist.

In a thought-provoking article entitled "Seeing Like a Geek," commentator Tom Slee notes that Open Data has two primary effects:

> *1. By cutting the price of the data to zero, for everyone and for any purpose, it undermines the power of those who previously controlled access to it. 2. Just as cheap*

> *fish increases the demand for chips, so free data increases the demand for, and raises the value of, complementary resources and skills.*[10] (Slee, 2012: 3)

This process of disintermediation is a widespread feature of economic development, as with recently, the elimination of local travel agents when travelers were able to access airline and hotel websites to make their own reservations. Disintermediation is supported, in theory and evidence, as a welfare-producing process, when it increases the amount and type of information available to consumers, effectively increasing the ability of consumers to compare cost and quality, and hence making it more likely that the Law of One Price will function in reality, and across more extensive markets. The issue then becomes: is the urban environment likely to generate these effects, and especially with respect to locationally-fixed goods and urban land itself?

Benjamin et al (2007) examines a land record digitization project in Bangalore, India. This project, promoted as a pro-poor, pro-transparency initiative, in reality led to "increased corruption, much more bribes and substantially increased time taken for land transactions [and]… facilitated very large players in the land markets to capture vast quantities of land…" In this case, information previously available only in the local contexts became available to those outside the local context. Only those with the wherewithal to make sense of the information (through data mining or other means of investigation) were able to increase their use of the new, digitized data. In practice, open data enabled outside actors with different sensibilities, attachments, and interests to establish control of local land resources, where members of the local community found themselves excluded. Thus, disintermediation and de-contextualization went hand in hand, with important distributional consequences. The research team concluded that :

> *… When e-governance projects intervene in land issues, the political economy of land markets rather than techno-managerial features of the project can shape outcomes. By raising fundamental issues in understanding the societal aspects of e-governance, it highlights the need to replace politically neutered concepts like 'transparency', 'efficiency', 'governance', and 'best practice' [with] conceptually more rigorous terms that reflect the uneven terrain of power and control that governance embodies* (Bhoomi, 2007: 3)

This is not a surprising outcome, since urban land has highly complex attributes, and as a consequence there is no comprehensive index for comparing the quality and value of land and buildings, unlike simple and easily comparable goods and services such as airline tickets and even more complex ones such as cars. Moreover, many of the attributes of urban land and buildings have significant non-sovereignties (or "interdependencies"), including externalities, which make up a significant part of their use value and market value; they are bundled together, so indexing does not allow each different attribute to be

[10] Relevance to Clayton Christenson's "Law of Conservation of Attractive Profits": "*When attractive profits disappear at one stage in the value chain because a product becomes modular and commoditized, the opportunity to earn attractive profits with proprietary products will usually emerge at an adjacent stage*" .

compared and mixed-and-matched. This leads to what are known as backward-bending preferences or Condorcet problems in making choices. Understanding these, even with abundant digital descriptions, require significant skills and analytical tools, much in a way analogous to understanding complex financial products. It is very unlikely that large numbers of people will have such abilities, no matter how much data they are given.

Increased commodification (or "market-ization") is a related probable consequence of big and open data. Private companies have every incentive to utilize the "digital exhaust" or "digital breadcrumbs" they are sitting on to seek profit. Many useful services will likely result from the information deluge. It does mean, however, that the actions and behaviors that are being sensed by big data, and many of the interaction spaces themselves, are now potentially subject to commodification – a result we are already seeing in the web space with search and information (Google), and social media and recommendations (Facebook). Though interacting on the street does have costs (getting there and being there), it is not itself commodified for the most part. Sandel (2012) investigates the many consequences of extending markets to areas of social life, a shift he describes in terms of leaving behind a market *economy* and moving toward a market *society*. He explains:

> *A market economy is a tool—a valuable and effective tool—for organizing productive activity. A market society is a way of life in which market values seep into every aspect of human endeavor. It's a place where social relations are made over in the image of the market* (Sandel, 2012: 66)

2.4. Smart Systems, but Smart Enough People?

The advent of smart energy grids, water systems, roads, and parking allocation systems is – as noted in Part One, a significant potential advance in the management of cities. Paradoxically, such smart systems are likely to be more opaque to non-technically educated citizens and users than existing systems. As it is, few citizens understand how their electricity is produced and priced. Most, however, do understand where the parking is and how it is priced and how it affects the neighborhoods in which they park. Most can see traffic jams form, though few have the conceptual tools for understanding why they form. If smart systems can reduce traffic jams and increase access to parking, most citizens will be satisfied, whether or not they understand exactly how such beneficial impacts were generated.

However, as Duranton and Turner (2008) point out, and we noted above, increasing capacity – whatever the means (physical or digital) in transport infrastructure is likely to have its main effects in capacity, not in speed. As speeds increase (whether through more roads or more rail transit alleviating roads), they will soon return to their previous clogged equilibrium speed. These are still considerable and positive effects, if they allow urban growth to continue, and allow density to increase without significantly deteriorating fluidity of movement and other aspects of quality of life. But behind such new systems will be decisions that are made using algorithms that are chosen. In "The Relevance of Algorithms," Tarleton Gillespie notes that :

> *…[a]lgorithms play an increasingly important role in selecting what information is considered most relevant to us, a crucial feature of our participation in public life… [and] provide a means to know what there is to know and how to know it, to participate in social and political discourse, and to familiarize ourselves with the publics in which we participate. They are now a key logic governing the flows of information on which we depend…* (Gillespie, 2012: 1)

These algorithms will have efficiency and distributional consequences. They are unlikely to be transparent to citizens, and are likely to be presented as inevitable. In addition, there is increasing generation of new algorithms by machines themselves, a form of artificial intelligence. Imagine that public policies or management practices are being guided by algorithms that have themselves been generated by machines that were originally programmed by algorithms. From a public policy perspective, who is making the choice? How does the public get access to information on algorithms which evolve "automatically," and on how those developments affect what information is presented to them, as well as their effects on real systems of service delivery or infrastructure management?

Data and algorithms present a new version of the classic dilemma of economic theory: looking for one's keys under the lamppost where the light is shining, rather than where they may be hidden.

> *The data that are being generated are rich, detailed, and eminently crunchable. But it's not quite correct to think of these datasets as all-encompassing. The advent of Big Data also has a paradoxical risk: that by sending us down the narrow paths of the data we have available, it may cause us to mistake those paths for the whole world… This might sound like a minor concern, but it's actually a recurring problem with human knowledge, with how science works. Throughout history, in one field after another, science has made huge progress in precisely the areas where we can measure things—and lagged where we can't…. The result, over time, has been that we know a lot about the things that are closer to our size, our altitude, our spot in the universe—and less about things that are hard to reach, hard to dig up, and hard to quantify. What we know has a bias, in other words, and is biased in favor of what we can measure.* (Arbesman, 2012)

Neither citizens nor political leaders have ever had full purchase on the socio-technical systems in which they live, and smart technologies are not worse in this regard than previous systems. But their advent presents an interesting challenge for research and practice to see to what extent parallel tools to make their logic more accessible to citizens could be developed, so that public discussions are not only end-of-pipe, but concern the upstream processes such as "who chose that program" and "why did you use that particular algorithm?" This is as true of elected officials and even public administrators as it is of citizens. It is a reasonable guess that few members of Congress have anything more than the most superficial understanding of macroeconomics, but they are called upon to vote on tax and spending policies quite often. They rely on experts, but they don't necessarily know how good the experts are. If cities are going to become one of the main physical supports for gathering information about human social and spatial behavior, will the political and administrative officials, and citizens be trained to understand what the data are used for, to whom they are sold or leased, and which data are openly accessible and which are not? Smart city technologies will present the public sphere with another round of information asymmetry and technical complexity, and attention should be paid to enhancing the ability of the public sphere to understand not only what it is deciding about, but how and with what assumptions the tools that generate information and choice sets were themselves developed and chosen. This is related to what is known in cognitive psychology (and behavioral economics) as "framing;" it is likely that we are entering a major new period of framing by data and analytics, but where there is growing opacity about this framing (Kahneman and Tversky, 1979).

Finally, there is also unlikely to be a one-way street to openness. As the technological revolution unfolds, so do problems of hacking, cyber-terrorism, cyber-war, and the classical political dilemma, in a liberal democratic society, of the tendency for citizens to be subject to a Panopticon (Bentham, 1995) The sensored and metered city, its buildings, infrastructures, and households, will generate unprecedented amounts of data that will also become vulnerable potential disruption. New security concerns will necessarily lead to new measures for protecting and hence keeping secret, certain data and their sources and the ways they are aggregated and processed. Who will decide where the border between the new transparency and the new secrecy should lie? The notion, then, that we are on a one-way street to greater transparency is itself a theme for research, and the borderline a theme for normative, legal and policy concern.

2.5. The persistence of "real" economic geography

Some of the discourse on smart cities and the digital skin tend to imply – without being fully explicit about it – that the new technologies will somehow level the playing field of places (cities, regions, nations). This echoes the old and now-discredited "death of distance" argument. Despite many early prognostications the proliferation of ICT has not led to the "death of distance," that the landscape of economic specialization is more differentiated than ever, that spatial income hierarchies are not disappearing, and that location continues to matter in productivity and technological innovation (Leamer and Storper, 2001). Many providers such as IBM implicitly acknowledge this in their marketing material, where they note the 21st century will see a "global war for talent", and that "Smart Cities" will be those that improve service delivery to attract the best and brightest (Dirks et al, 2010).

It may indeed become possible to better manage more places. And this can be expected to have positive effects in both highly-developed and less-developed cities, and possibly to raise the standards of living in the disadvantaged cities. But we need to specifically evaluate how such technologies are likely to fare in a less-developed context, as opposed to wealthy cities and regions. Along these lines, Dan Hoornweg, urban advisor for the World Bank, notes:

> *Selling more [information technology] and sophisticated algorithms might help a few of the very fortunate cities. Being really smart about cities is improving service delivery to the one billion urban poor now going without clean water, or the two billion without sanitation*. (Hoornweg, 2011)

Moreover, even if benefits accrue to all cities, they may accrue in unequal ways. For example, in the last two decades, the industry, which is most dependent on information technology -- the financial services industry – has actually increased its level of spatial concentration of its most innovative and highly-rewarded functions. This has been one of the forces behind income divergence among the world's metropolitan regions. The geographical concentration of the finance industry is counter-intuitive, since this is an industry whose product is weightless, highly virtual, and has close to zero transport costs to its final market. Financial services is concentrated because its production process depends on informal knowledge and on human relationships, which require considerable face-to-face contact; the economic value of these relationships and meetings is enhanced by the ability to serve geographically-dispersed markets with the final product (the "deal") (Storper and Venables, 2004). The effects of the digital skin on the geography of the rest of the economy should therefore be a focus of research; specifically, whether and how they may alter the geography of agglomeration economies in other sectors and hence the geographical pattern of development and the shape of city systems. We know virtually nothing about this.

Another dimension of possible economic geography effects of the digital skin can be identified here. There is currently a vogue for making the digital skin not just a "handmaiden" to the economy of the city, but its key focus. But this is worrisome to many. A 2011 report published by the Harvard Business School notes that "Smart Cities" (or as they call them, "ecocities") lack clear economic models.

> *Every new city needs an economic foundation based on jobs. Not every new ecocity can be a research city whose purpose is the development of new technologies for building other ecocities. To thrive, a city requires a range of jobs, spanning multiple sectors, such as technology, financial services, retail, entertainment, education, and health care… too many ecocities are implicitly or implicitly based on a real-estate development model – a kind of 'if we build it they will come' approach that often lacks serious consideration of who will come and why.* (Alusi et al, 2011: 19)

2.6. Cyber City and Spontaneous City: Choice and Serendipity

Urban theory since the 19th century has centered on the fundamental sociological characteristics of the city, and especially in relationship to a notion of modernity. Tonnies, Simmel, Weber and Durkheim wrote the classical texts about cities as sites of the complex and varied social interactions of modern society, and that remain valid today (Tonnies, 1887; Durkheim, 1893; Simmel, 1903; Weber, 1921). All saw the city as an environment in which a kaleidoscopic combination of people and information occurred and in which, as a result, the structures of traditional society, based on kinship and interpersonal knowledge, clan and village, were fundamentally weakened. In their place, new structures of social life were created, based on choice, ascriptive identity, individualism, unplanned and unplannable contacts and encounters, embodied personal ethics, as well as participation in democratic processes and occasional mob rule, would come about. The apotheosis of these ideas in terms of architecture was noted above, in the failed modernist experiments of Corbusier, Niemeyer and urban renewal. Oddly enough, those modernist experiments would have done away with the fundamental basis in urban theory for the social modernity of the city, which is unplanned, serendipitous, contact.

The debate between a sociological modernism of the city and an architectural modernism finds a neat parallel in the advent of the digital skin. Will the skin help the city to develop along the lines of Jacobs, or become another version of Corbusier? Implicit in the engineering, cybernetically-oriented view of the city, is the idea that the city can achieve a kind of perfection of efficiency and operation through the proper use of control systems: a digital version of Brasilia. We quote at length here:

> *We may conceive of the digitally enhanced, postmodern city as a cybernetic mechanism that accommodates interaction and actuation in its capacity as a spatial system capable of extracting contextual information, acknowledging the inhabitants' desires and needs, and adopting behavior patterns based on what it learns. Such a cybernetic urban system achieves its monitoring with sensing technology. It is conditioned through computational processes that are based on detected spatio-temporal changes. It is actuated through embedded virtual or physical agents, human or non-human- that provoke changes detectable by the inhabitant, or that enhance the spatial experience of the occupant in an explicit or implicit way.* (Nabian and Ratti, 2011: 18)

> *In the context of ubiquitous information services, the city shall not only be seen as a place of social interactions, financial transactions, a network of technology nodes, a geographical agglomeration area or as a political landscape, but more as an actuated multidimensional conglomerate of heterogeneous processes, in which the citizens are the central component. In other words, the city can be regarded as a complex near real-time control system, creating a feedback loop between the city itself, the city management and the citizens, which is achieved by pervasive sensing…* (Resch et al, 2012: 175)

> *As the booming popularity of local shopping networks such as Groupon and LivingSocial shows, connecting local businesses and city dwellers through mobile social networks is a powerful catalyst for action. These new ways of scripting the city can create more lasting kinds of social touch points, too… This programmable world will extend beyond the physical city.* (Ratti and Townsend, 2011: 46)

> *By receiving real-time information, appropriately visualized and disseminated, citizens themselves can become distributed intelligent actuators, pursuing their individual interests in co-operation and competition with others, becoming prime actors on the urban scene. Processing urban information captured in real time and making it publicly accessible can enable people to make better decisions about the use of urban resources, mobility and social interaction. This feedback loop of digital sensing and processing can begin to influence various complex and dynamic aspects of the city, improving the economic, social, and environmental sustainability of the places we inhabit.* (Ratti, 2011: 8)

This view runs counter to the social science and humanities view of the city, as represented in the long line of thought from Weber to Jane Jacobs: the city is a place of spontaneity, heterogeneity, and limited chaos, and this is precisely the basis for its ability to invent new forms of modernity. A geo-tagged map or an algorithmically organized index may create "filter bubbles" and an unintended, but still very real, virtual segregation or, its extreme opposite, herd effects that end up limiting diversity and creating the "Hotelling effect" on a massive scale within the space of the city.[11]

2.7. The Politics and Epistemology of Attention: Crowding in and crowding out

Political scientists Jones and Baumgartner (2005) note that political institutions focus their attention selectively on problems, and that agendas are set by many processes, some of them deliberate and other unintended. The unintended effects of actions in one sphere can crowd out or reshape attention to other issues. It is legitimate to ask whether the emerging popularity of open data efforts with city, state, and federal governments is that it gives the appearance of doing something without having to make difficult decisions. Compared to investing in infrastructure, or asking residents to make drastic changes to their behavior, opening data-sets is relatively inexpensive, and it tells a good story.

Moreover, in discussing open data initiatives in the United Kingdom, Jo Bates notes how there is a tension between the fact datasets are available for use at marginal cost (which is generally close to zero for digital assets), but commercial interests are allowed to build products off the 'backs' of the public data. She states that

> *….Whilst democratic ends are claimed in the desire to enable 'the public' to hold 'the state' to account via these measures, there is an issue in utilizing a dichotomy between the state and a notion of 'the public' which does not differentiate between citizens and commercial interests. The 'we' in this construct thoroughly displaces the notion of citizens as state ("we are the state") to a 'we' that is a mass of private interests (both individual and commercial) outside the state.* (Bates, 2012: 8)

In other words, it is worth thinking seriously about the extent to which efforts to make data open and available are not crowding out, perhaps unintentionally, other conceptions of the public sphere and of the roles of citizen, government, and the private sector. To put it as bluntly as possible, the notion of citizen, as used traditionally, is very different from the notion of the open data user, which appears to be the dominant vision of the MIT SenseAble City Lab.

> *Once spaces become dynamic, their inhabitants can be incorporated as entities with transient preferences and needs. Instead of generic "occupants" they become hyper-individualized "users." They interface with a world embedded with networked microprocessors, where the digital and the physical merge in the Ubiquitous Computing paradigm first recognized by Mark Weiser.* (Nabian and Ratti, 2011: 20)

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[11] The Hotelling Effect is the canonical model of the two ice cream vendors on the beach who ultimately move to the center of the beach, through game theory type interactions, in order to capture market share. It is used as a locational model, but also as a model of serving the "median" taste rather than the tails of a distribution of preferences.

This vision of individualized but connected “user” and the traditional notion of “citizen” or “inhabitant” are not necessarily incompatible; but not necessarily compatible either. Along these lines, one of the originators of artificial intelligence cautions us about the hyperbole of the MIT vision represented in the quotations above:

> I *hope no one will think I'm equating Cybernetics and what I'm calling Cybernetic Totalism. The distance between recognizing a great metaphor and treating it as the only metaphor is the same as the distance between humble science and dogmatic religion. Here is a partial roster of the component beliefs of cybernetic totalism:*
>
> *1) That cybernetic patterns of information provide the ultimate and best way to understand reality.*
>
> *2) That people are no more than cybernetic patterns.*
>
> *3) That subjective experience either doesn't exist, or is unimportant because it is some sort of ambient or peripheral effect.*
>
> *4) That what Darwin described in biology, or something like it, is in fact also the singular, superior description of all creativity and culture.*
>
> *5) That qualitative as well as quantitative aspects of information systems will be accelerated by Moore's Law.*
>
> *And finally, the most dramatic:*
>
> *6) That biology and physics will merge with computer science (becoming biotechnology and nanotechnology), resulting in life and the physical universe becoming mercurial; achieving the supposed nature of computer software. Furthermore, all of this will happen very soon! Since computers are improving so quickly, they will overwhelm all the other cybernetic processes, like people, and will fundamentally change the nature of what's going on in the familiar neighborhood of Earth at some moment when a new "criticality" is achieved- maybe in about the year 2020. To be a human after that moment will be either impossible or something very different than we now can know.* (Lanier, 2000)

Lanier’s point can be extended to the digital city movement. Even though cybernetic totalism is unlikely to become reality, for the many reasons adduced in this paper, it will be important for urban research and practice to have an open mind and some distance toward this revolution. This is not merely a technical issue; political philosophy, political sociology and the humanities have significant potential insights to offer on the normative basis of the digital skin, and empirical social science should be able to provide hard data and cases on the distributional effects of growing the digital skin. Cybernetic theorists are undoubtedly very talented, but at least up to this point, they have not shown much interest in these questions.

3. CONCLUSION: A REVOLUTION IN TECHNOLOGY, A NEEDED REVOLUTION IN RESEARCH, AND CHALLENGES FOR TEACHING

The purpose of this paper has been to consider the emerging technological revolution in the sensored, metered city – its digital skin – in light of issues for urban theory, research and education. In the first part of this paper, we reviewed the principal dimensions of the revolution and the many areas where theory and data are lacking; these represent many fascinating areas for a program of research on the digital skin of the city, and that can become structuring elements in teaching programs, as they are designed, in the social and policy sciences. In the second part of the paper, we took a step back to gain a critical perspective on the revolution, and this generates another set of substantial issues for theory and research. If nothing else, the technological revolution is generating many questions for urban research. In this paper we have endeavored to show that such research will be more productive if it starts with a perspective informed by rigorous theory, and with a neutral stance toward results. This is going to be difficult, as we pointed out, because any technological revolution generates considerable excitement about its possibilities, and very typically leads to hyperbole and to the capture of researchers, many of whom justifiably would like to be participants and practitioners at the same time as they would like to generate rigorous scientific results. This same challenge is present in considering how to teach about this revolution. Practitioners are needed who will understand the potential of the digital skin to enhance human welfare; and yet they will be caught in a force field of asymmetrical and partial information, rapidly changing markets, very big financial stakes, competitive hubris, and career ambitions. An ideal education would equip them to practice, but to do so in the public interest, and that will require teaching that is informed by the distanced and rigorous research program, whose outlines we have attempted to sketch, in a very preliminary way, in this paper.

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