Urban Operating Systems

Producing the Computational City

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1 Introduction: Producing the Computational City

> The PlanIT Urban Operating System™ is the smartest, most flexible way to converge infrastructure with a world of sensors, devices and people across developments of scale and entire cities. A single intelligent system to manage it all. The PlanIT UOS enables systems such as energy, water, waste management, transportation, telecommunication, healthcare, security and potentially everything around you to communicate intelligently with each other—and with a world of ever-proliferating sensors and devices. And because we do this in ways that make obvious bottom-line sense, almost everything is about to change.
>
> —Living PlanIT (n.d.)

> Cities could soon be looking after their citizens all by themselves thanks to an operating system designed for the metropolis. The Urban OS works just like a PC operating system but keeps buildings, traffic and services running smoothly. The software takes in data from sensors dotted around the city to keep an eye on what is happening. In the event of a fire the Urban OS might manage traffic lights so fire engines can reach the blaze swiftly. The OS completely bypasses humans to manage communication between sensors and devices such as traffic lights, air conditioning or water pumps that influence the quality of city life.
>
> —*BBC News* (Moskvitch 2011)

Technology companies are targeting a new market, producing hardware and software to run cities. Using preexisting technologies developed in a corporate context, international players like IBM, Hitachi, and Cisco have gained a foothold in a new sector that is attractively framed by aspirational narratives centered on smart cities, transparency, and open data. IBM has developed Smarter City, Urbiotica has the City Operating System, and Microsoft has produced CityNext, all software-hardware packages that claim to transform

the city. They promise to improve the quality of urban services, to make the city more efficient and sustainable, and to automate the operation of urban infrastructures. Alongside these commercial innovations, municipal authorities are mobilizing resources toward the development and operationalization of a variety of digital platforms aimed at transforming both service delivery and infrastructures. Meanwhile, a loose network of IT aficionados is creating a vast informal ecology of digital projects aimed at the systemic operationalization of the urban world (Marvin, Luque-Ayala, and McFarlane 2016). The vision of those working in this area is that these computational interventions will eventually control the essential hardware, software, and data components of the city. The aim is that they will sit quietly in the background, directing urban informational flows, and will interface with one another via shared languages that ensure interoperability across multiple infrastructures. Within the IT and built environment industries as much as in the media (Living PlanIT, n.d.; Moskvitch 2011), these products, platforms and ecosystems integrating the digital and material domains of the city are often referred to as *urban operating systems*—the Urban OS.

Urban Operating Systems: Producing the Computational City explores the rationalities and techniques that constitute these emerging computational forms of urbanization, including work on smart cities, digital urbanism, and, more recently, platform urbanism. A wave of enthusiasm for smart cities, urban data, and the Internet of Things has produced the impression that the mobilization of computation in the city can resolve almost any urban problem. Far from being new, these claims have a long lineage, stretching back over six decades. At their base is the assumption that rational calculation and transactional decision-making can account for every part of the urban world. This book examines the cultural, historical, and contemporary contexts in which urban computational logics have emerged, with the intention of subjecting the claims of the current wave of digital urbanism to critical scrutiny. Taking our cue from David Golumbia (2009), we argue that computation is a metaphor, method, and organizing frame that occupies a privileged but underanalyzed role in urban studies. Drawing on this, our book investigates the ways that digital products, services, and ecosystems (and a very specific set of conceptual logics embedded within them) are reshaping the ways in which the city is imagined, known, and governed. In so doing, we explore the reconstitution of the contemporary city through digital technologies, practices, and techniques, including

data-driven governance, urban sensing, digital mapping, predictive analytics, digitally enabled control rooms, civic hacking, and open data narratives. Focusing in particular on how power in the city operates and urban control is achieved, we interrogate the way that code, software, hardware, and platforms—and their underlying logics—entrench the status quo while also underpinning radical changes in contemporary urbanization.

For over three decades, urban scholars have pointed to the critical role of urban infrastructures in structuring and delineating the experience of modern urban life. Urban infrastructures, in "subtle and powerful ways . . . define, shape and structure the very nature of cities" (Graham and Marvin 2001, 30). Electricity grids, water and transport networks, and sanitation, waste collection and telecommunication systems, among others, have long been considered key physical and technological assets of cities. They "provide the technological links that make the very notion of a modern city possible," enabling exchanges and dynamic relationships between different actors, and embodying capital and knowledge investments in the city (Graham and Marvin 2001, 13). However, they are neither limited to material technological devices nor free from political, cultural, and symbolic representations and implications. Alongside their function as a collection of material components and flows (pipes, cables, switches, buildings, resources), they operate as political and symbolic devices supporting a visionary ideal of the city's future (Nye 1999). Both a means and object of governing, infrastructures are sociotechnical assemblages that include practices, regulations, and standards, as well as a range of state and nonstate actors and human and nonhuman agencies (Hughes 1983; McFarlane and Rutherford 2008; see also Bennett 2010). In this book, we will examine the tensions, contradictions, and limits of the coming together of computational logics and these assemblages. We argue that computation dramatically transforms the very nature and meaning of urban infrastructures, engendering not merely new infrastructural capacities within the city, but also new infrastructural forms altogether.

Our central argument is that, in constituting the urban as a calculative entity and advancing functional simplification and heterogeneous reintegration at a city scale, the Urban OS puts in place a new technology of governing—a calculative diagrammatic of control focused on the *operationalization* of the urban. This is, in Deleuzian terms, a new diagram of power, an abstract machine generating "a new kind of reality, a new

model of truth" (Deleuze 2006, 30; Knoespel 2001). As an abstract diagram, paraphrasing the French philosopher Michel Foucault (1995), the Urban OS transmutes a mechanism of power into a function and vice versa. This effectively makes the Urban OS into a political technology, but one that is particularly concerned with depoliticizing urban processes while prioritizing operational efficiency, optimization, and management. Such a theoretical position sees the Urban OS as an overarching urban infrastructure operating as a non-neutral matrix through which meaning in the city is generated and negotiated. Paired with the traditional infrastructures of the city, the Urban OS engenders a new generation of infrastructures, both digital and corporeal, co-constituted through the affordances of each other—an intelligence incarnate of the urban (cf. Dillon 2003) that, now inescapable and endlessly mutable, operates through *infrastructural trans-actionability*. Through a range of computational logics, from datafication to sensing, among others, the urban operating system becomes a form of knowing that takes bodily form. This is an urban infrastructure that is always already co-constituted with digital technologies.

One of our core aims is to understand how the city has emerged as a key site for the systemic commercial and societal application of digital systems, through what initially appeared to be computational products that were designed for the urban market. The Urban OS puts in place a form of control in which the city is governed through computational logics—ways of thinking and ways of knowing—that assume that the urban can be treated as a calculable entity. Giving primacy to computational processes, it is claimed, leads to an audited, rationally managed, efficient, controlled, and integrated city: the urban realm as a commodified logistical enterprise. *Urban Operating Systems* traces the transmutation of these processes and approaches from military, corporate, and logistical domains to the city and interrogates the politics and ways of operating of this emerging wave of digital urbanism.

Examining Urban Computational Logics

This book aims to produce a multifaceted account of the formal and informal constitution of the Urban OS across diverse urban contexts. Our wide-ranging analysis focuses on the politics of municipal open data platforms and the work of civic hacking communities, municipal and citizen sensing

platforms, digital mapping, predictive analytics platforms, digitally enabled control rooms, and the mobilization of an ecology of digital technologies in support of prodemocracy protests. We have identified seven urban computational logics, each of which is the subject of a chapter of the book. They are operationalization, datafication, sensing, mapping, prediction, circulation, and (digital) resistance.

In chapter 2, we examine *operationalization* and analyze the "diagrammatic abstractions" present in the marketing material written by corporate providers of urban operating systems. Our aim is to uncover a logic that underpins all aspects of the computational city. This chapter therefore provides the initial building blocks for a critical analysis of the rationalities at play in the practical rollout of digital urbanism. It traces the historical roots of the Urban OS within the military and corporate domains, focusing on the means by which computational logics transmute from defense and business contexts to the urban environment. By reconstituting the city as a set of ordered relationships, the Urban OS sets the foundations for the ways in which all things urban are to be measured and calculated. As such, this technology digitally operationalizes the city in a way that establishes future rationalities for governing it.

An important argument mobilized in this chapter is that the Urban OS tends to collapse corporate and urban problematics so that the city is increasingly viewed and managed as a corporation. In transmuting the logistical and corporate rationality of software packages, such as enterprise resource planning (ERP) systems, to the city, the urban becomes amenable to digital interventions aimed at developing interoperability, interconnection, and integration. However, these make a series of assumptions about how the city is envisioned, known, and acted upon. While in the Western world the city has always been seen as a site for business and exchange, where the boundary between urban and commercial worlds is never clear-cut, its ideal condition as polis both results from and depends upon citizen debate, contradiction, contestation, contingency, and a multiplicity of viewpoints and ways of being. Yet the latter are anathema to the singularity, functional simplification, and overall consistency required by a computational structuring of the world. The collapse of the division between city and corporation can therefore be seen as the first step of the Urban OS toward the removal, or hollowing, of the political from the city on account of operationalization and flow.

In chapter 3, we examine the computational logic of *datafication*, through an analysis of the making of New York City as a data-driven city. With the constitution of data as a key urban flow that underpins a new type of urban utility (data-as-infrastructure), the Urban OS arguably creates a common language for all urban processes. Like operationalization, datafication underpins all aspects of the Urban OS; through interventions such as municipal open data platforms and the work of civic hackers, among others, it enables the possibility of recombination and *trans-actionability*—the generative power of recombining urban processes and the city's traditional ecological flows (of water, transport, waste, air, and so on) into new flows, processes, and bodies. Critically, *the interplay between datafication and urban infrastructures embodies urban data*; as data lines flow in the city, their binary (im)materiality is reconstituted as a powerful urban flow. The resulting city-in-formation embodies data toward a form of *intelligence incarnate of the urban*: the materialization of data through urban flows on account of flexibility, mutability, and adaptability, a process that affords power and effects control.

Chapter 4 looks at the computational logic of *sensing*, drawing on a case study of sensors and sensor platforms in Barcelona. Sensing, like datafication, is a strategy to render calculative intelligibility across urban processes. It also *embodies* the informational diagrammatic characteristic of the Urban OS: the urban sensor is the body that translates and mediates between the digital and material domains of the city; in doing this, it creates new bodies and urban forms. Sensing effectively fragments urban flows into discrete and small spatiotemporal units of data and thus plays a key role in the ability of the Urban OS to dis- and re-assemble urban circulations. In so doing, sensors afford the technomaterial substrate of the city a new urban economy based on the way in which data flows create new circuits of commodification and profit. Sensors therefore constitute a new technology for both governing and monetizing the urban. They remake the sites of value creation of the city and generate new forms of value via digital assets. We describe this as a form of *urban commodification through digital hyperfragmentation*, and we argue that it is likely to lead to a relocation of value through flows.

In chapter 5, we examine the computational logic of *mapping* via its digital incarnation in Google Maps. Through an analysis of efforts to map Rio de Janeiro's favelas, we uncover the ways in which the process of digital

mapping simplifies and homogenizes the city, integrating all urban territories into global circuits of economic flows. Within Google Maps, in the coming together of space and the database characteristic of this urban computational logic, the database of business is prioritized. This process recasts what is considered a "point of interest" in the city, emphasizing entrepreneurial sites and narratives and excluding urban knowledges and practices that are not amenable to digitalization. Furthermore, techniques of enumeration and spatial calculation are used to exert power and relocate sovereignty: new forms of territorial control emerge as the computational logic redefines which groups have the ability to gather and control information and therefore to shape market configurations and capital flows. We argue that this amounts to *the computational production of territory*.

Chapter 6 homes in on the urban computational logic of *prediction*, based on an analysis of the use of predictive analytics platforms in Chicago. Prediction reworks time and space via mathematical calculations, producing an understanding of the city as a calculative machine. It is a process that translates space into standardized units of data, enabling interoperability across seemingly disconnected urban domains while also allowing for calculating the urban across time. In practice, prediction is about targeting and spatial fragmentation: a conceptualization of the city via microgeographies or the use of a microgrid. Despite numerous claims about the transformative potential of predictive analytics in the city, we argue that it is a process that reinforces and reproduces the status quo.

Interventions like digitally enabled control rooms and digital dashboards underpin the computational logic of *circulation*, whereby the city is reconfigured as a logistical enterprise. We examine this in chapter 7, focusing on Rio de Janeiro's Operations Center (in Portuguese, the *Centro de Operações Rio* or COR), designed and implemented by IBM. We argue that the control room represents a new mode of urban infrastructure, based on the partial and selective rebundling of urban space in order to achieve real-time, efficient, and effective circulatory flow under conditions of disruption. This form of Urban OS is increasingly mobilized in response to growing conditions of economic, political, and ecological turbulence across the world. Here, through the close coupling of crises and the everyday, the city's political debates take a backseat to an operational rebundling aimed at guaranteeing flow maintenance. Constant information flow becomes the new nature of the city, the milieu that needs to be created. The emphasis

on circulation, achieved via the rationalities and technologies immanent to the Urban OS, is so strong that it risks becoming the end as well as the means of governing the city. Forcing this emerging digital city to remake itself in the image of its own narrow epistemology, the Urban OS gives precedence to circulatory management over agonistic politics and thus contributes to the digital hollowing of the polis mentioned earlier.

Chapter 8 asks questions about the possibility of thinking about *resistance* as an urban computational logic. Through an analysis of the 2014 prodemocracy movements in Taipei and Hong Kong and the role of a mashup of digital urban systems within them, the chapter explores the extent to which civic hacking and a range of digital interventions can configure an operating system for occupation. From the Arab Spring to New York's Occupy Wall Street, contemporary political protest within cities operates through logics of occupation—immobilizing the very flows that enable urban life. In this chapter, we look into the possibility and significance of the mobilization of a loosely connected ecosystem of urban digital platforms, social media, digital communication tools, and other IT interventions, in support of contemporary political protest. Computation plays a role in enabling the disruption needed for protest, by raising local, national, and international awareness and enabling the agglomeration of diverse groups of people who might have an interest in participating. Yet sustained occupation also relies on traditional urban flows (e.g., energy, potable water, waste collection) and a temporary infrastructure for the occupation itself (e.g., sanitation and logistics). The material obduracy of urban occupation therefore resists and challenges the power of the Urban OS: such protests rely on the sustained presence of human bodies on the street and on a range of infrastructural forms that provide basic forms of life support. In this context, the power of computation is relatively limited; the mobilization of digital systems for political protests in cities highlights the limits of digital systems and the preeminence of traditional material infrastructures and urban flows. Ironically, the attempted contribution of the Urban OS to contemporary forms of occupation is, to a large extent, about operationalization, and therefore it is a move that does not offer unorthodox perspectives by failing to question the epistemologies embedded within the digital.

The remaining sections of this introduction place the Urban OS in a historical context, looking at both professional practice and academic inquiry within digital urbanism. They also provide a guide to the Urban OS and an

outline of the conceptual approach of the book, explaining how we undertook our research and offering a preliminary summary of our argument. Our hope is that our work illustrates how the seemingly banal and hidden ways of thinking embedded within computation are being refocused on the city in ways that have far-reaching implications for almost every aspect of contemporary urban life. We hope it shows the ways in which calculative technologies, techniques, and rationalities are transforming urban flows and modulating urban infrastructures, reshaping the politics of the contemporary city through a new set of relationships with networked technologies.

Computing the City: A Brief Genealogy

The ideas that we present in this book build on an extensive body of critical work within the humanities and social sciences on the role of digital technologies within the city. For over two decades, human geography, urban studies, STS (science, technology and society) studies, sociology, computer science, architecture, urban studies, media studies, and other disciplines have examined the interface between computing, information communication technologies, and the city. We draw significantly on these works, but we argue that there is also a need for studies that unearth the history of computational logics in the city, in order to develop a deeper critical analysis of the relationship between urbanism and computational technologies. Such an approach is important because it complicates popular ahistorical, normative, and technodeterministic narratives of the digital urban. Uncovering the role of military, corporate, logistical rationalities in this history can provide an insight into the ways in which digital technologies can be used not only to govern and control the contemporary city, but to enclose new parts of its infrastructure for privatization and surplus value creation. Furthermore, such an approach calls into question the notion that technical forms of urban knowledge, control, and calculation are ideologically neutral, instead foregrounding the profound political, epistemological, and ontological consequences attached to the adoption of urban operating systems.

Cybernetic Cities: 1960s–1990s

Since Norbert Wiener outlined the principles of cybernetics in the 1950s, urban researchers and practitioners have increasingly viewed the city as a communication system (Light 2003; Meier 1962; Webber 1964). Drawing

on a set of information technologies developed by scientists working within the American defense industry, they reconceptualized the urban as both a machine and a living organism. From the 1960s onward, urban planners sought to apply advances from mathematics, systems analysis, and computing technologies to the urban, transforming it into a domain for high-tech intervention and decision-making. American cities such as Pittsburgh, New York City, and Los Angeles started experimenting with their urban renewal programs, using a combination of computing, cybernetics, and military expertise to take a more problem-oriented approach to local administration. Urban planners and administrators began to frame the city from a militaristic/defense perspective, looking for solutions to urban problems in the informational management of urban processes. The city thus became a "battleground" on which experts fought "a war on poverty"; urban problems were a matter of processes going awry, arguably to be solved via the implementation of better feedback loops and continual self-adjustment (Halpern 2014; Light 2003). The *Journal of the American Institute of Planners* hailed computers as the drivers of a revolution in urban planning (Harris 1966): with their databases and simulations, they were not only capable of enhancing existing planning tools, such as maps and 3-D models, but also of handling large datasets and visualizing problems in novel ways. Most importantly of all, computers were seen as having the ability to turn planning into a scientific endeavor (Light 2003). As examined in more depth in chapter 2, information systems became a form of urban response that was notionally capable of producing scientifically verifiable outcomes from a value-free, neutral perspective, thus depoliticizing the planning process.

Beyond the domain of urban planning, from the 1960s onward (and perhaps all the way to the early 1990s), the growth in computer use led to a belief in the dematerialization of society—one that would arguably undermine processes of urbanization, threatening the very existence of the city. The "theology" of cyberspace—a belief in the ability of computers, digital systems, and new media to create an immaterial world of information that we can inhabit (Bolter and Grusin 2000)—underpinned a futuristic and euphoric technological utopianism in which reality was to be replaced, bit by bit, by information. Insightfully captured by Steve Graham in his pioneering *Cybercities Reader* (2004), this was a period when scholars and technologists (from Marshal McLuhan [1964] and Alvin Toffler [1980] to Nicholas Negroponte [1995] and Bill Gates [1995]) regularly commented

on the extent to which digital communications would overcome the need for spatial proximity, causing cities to collapse. Of course, such predictions never came to fruition, in part because this posturban fantasy had failed to grasp the complex relationship and multiple interdependencies between computer technology and the city.

The Networked City: 1990s–2000s

Rather than causing cities to collapse, the world of information technology and computers has facilitated global urbanization (Graham 2004). Throughout the second part of the twentieth century, global telecommunications developed in parallel with the urban transformations characteristic of advanced industrial societies; to an extent, the configuration of the postindustrial city became a matter of the relationship between the two (Graham and Marvin 1996). No longer were cities simply dense physical nodes of buildings, transport networks, economic activity, and cultural life; they also became electronic hubs, the centers of demand for telecommunications, and the powerhouses of global digital communications. The ubiquitous nature of computing established an urban world governed more by interconnectivity than by boundaries. In the emerging *networked city*, the urban was no longer defined by physical enclosure (i.e., the city walls), but by digital connectivity (Mitchell 2004). Here, "control of territory means little unless you also control the channel capacity and access points that service it" (10). The production of the internet itself provided a form of urban geography, with selected cities playing an important role in its genesis through the clustering of IT activities (Townsend 2001; Zook 2008). From the physical networks that allow digital connectivity—fiber optics, copper cables, communication towers, antennas—to the patterns of employment and political-economic landscapes associated with the digital economy, information technologies materially co-constituted the city. Three dimensions of this networked city attracted significant critical attention within the social sciences: hybrid spaces, surveillance, and social sorting.

In 1992, Christine Boyer developed one of the first critical analyses of the popular dematerialized account of cyberspace, challenging the way in which the technologically oriented city was envisaged as a huge megalopolis without a center (Boyer 1992, 115). Advancing the idea of the *cybercity*, Boyer instead highlighted the hybrid material and sociotechnical nature of the informational network that was developing in the contemporary urban

realm. In response, social scientists who engaged with the cybercity, particularly within human geography, began to foreground the roles of space and materiality in the digital world. In contrast to earlier discussions, academics no longer saw technology as a substitute for the city or embodied experience, but rather as a force mediating social, physical, economic, and cultural relations (Graham 2004). Digital technology, they argued, effectively transforms the cultural geography of the city and everyday life in a myriad of ways (Crang 2010). Wakeford, for example, draws on feminist approaches to examine the hybridity of internet cafés and the ways in which digital mediation affects the gender identities of their users. She argues that the city forms part of a wider technological and computational landscape, consisting of a multiplicity of hybrid spaces and forming a set of "material and imaginary geographies which include, but are not restricted to, online experiences" (Wakeford 1999, 180). Following a similar approach, Forlano (2009) examines the ways in which Wi-Fi technologies produce sociocultural and economic reconfigurations of the city, thus generating a set of new *codescapes*.

Perhaps some of the most discussed hybrid spaces in the interweaving of digital technology with the city are the *spaces of surveillance*. Digital technologies facilitate and enable urban surveillance not simply through data collection and recombination but also through techniques of visualization and simulation (Graham 1998). Taking Foucault's notion of panopticism to new heights, and drawing on the ability of computers to store and recombine large quantities of information in near real-time, Graham and Wood (2003) suggest the imminent emergence of a super-panopticon: "a system of surveillance without walls, windows, towers or guards"(Poster 1990, 93; cited in Graham and Wood 2003, 230). In this way they point to a quantitative change in the state's ability to govern via direct surveillance. The implications of this process, they suggest, go significantly beyond issues of privacy and/or disciplinary control. From CCTV and smart utility metering to social targeting and marketing facilitated by data collection, surveillance fuels the growing information economy of the city while supporting a particular political-economic configuration. This continuous and real-time tracking of bodies and behaviors supports a segmentation of service provision (differentiating users between levels of ability to pay, risk, or eligibility) and fosters a neoliberal logic that prioritizes the privatization of public

services, the commodification of the city, and the development of urban markets (Graham and Wood 2003, 229).

As both academics and the wider public became more aware of the potential inequalities embedded in the urban operations of code, interest in *software-sorted geographies* rose. Studies began to explore the digitally mediated sorting techniques applied "in efforts to try to separate privileged and marginalized groups and places across a wide range of sectors and domains" (Graham 2005, 562). Software-sorting, exemplified by face-recognition, CCTV, and electronic mobility systems, illustrates the role that code and programming can play as mediators of urban practices, shaping both the city and its politics (Kitchin and Dodge 2011; Thrift and French 2002). Such a digitally mediated city is a *sentient city*, a ubiquitous computing environment that is "not a passive backdrop but an active agent in organizing daily lives. . . . It is a world where we not only think of cities but cities think of us" (Crang and Graham 2007, 789). This ubiquitous computing characteristic of the contemporary urban condition, described by Greenfield (2006) as *everyware*, "seeks to embed computers into our everyday lives in such ways as to render them invisible and allow them to be taken for granted" (Galloway 2004, 384).

Smart Urbanism: 2010s–Present

The idea of the *smart city* has grown in popularity recently, as an extension and actualization of digital utopianism. Promoted by the corporate sector, international organizations, and national and local governments alike, the dominant vision of the smart city is one of a digitally enhanced urbanity that combines intelligent infrastructure, high-tech urban development, the digital economy, and electronically enabled forms of citizenship. Narratives around smart cities are deeply rooted in seductive and normative visions of the future, in which technology stands as the primary driver for change (Luque-Ayala, McFarlane, and Marvin 2016), an idea that has gained global recognition through the publicity associated with the IBM-owned product Smarter Cities. However, the smart city concept also inherits elements from academic ideas developed in the 2000s around *intelligent cities*, which emphasized a problem-solving approach to the urban—advocating partnerships among academia, business, and government in which ICT (information and communications technology) operates as a key input for regional

innovation, competitiveness, and economic development (Caragliu, Del Bo, and Nijkamp 2011; Komninos 2002).

Since its inception, the smart city has been a vague and nebulous concept. It comes charged with aspirations for a better future, alongside expectations that it can help achieve environmentally sustainable growth, infrastructure flexibility, new urban services, transparency, demand responsiveness, and social inclusion. Smart city interventions take a broad range of forms, and in most (but not all) cases these foreground the role of urban computing and digital technologies. Emblematic examples include Chicago's SmartData Platform, an experimental predictive analytics platform; Barcelona's Sentilo, a municipally owned open-source platform aimed at operating and collecting data from urban sensors; and Rio de Janeiro's Operations Center, all of which will be analyzed later in this book. Smart city initiatives are often an amalgam of loosely connected projects of various sizes, under the leadership of both public and private stakeholders. For example, the Amsterdam Smart City initiative involves a collection of around two hundred projects involving a broad range of stakeholders and digital technologies.

Over the past decade, scholars within geography and urban studies have started to ask critical questions of the smart city (Hollands 2008; Luque-Ayala and Marvin 2015). How are these new forms of digital technology transforming urban flows and reshaping urban politics and governance? What are the dominant logics and pathways in play, and to what extent can the smart city embrace a progressive agenda? How do different forms of urbanity and various citizen imaginaries take shape through the smart city, and to what extent does the smart city allow their contestation (Luque-Ayala and Marvin 2015)? Analyzing this literature, Kitchin, Lauriault, and McArdle (2016, 17–22) have identified a set of common critiques of the smart city. First, there is the argument that advocates of the smart city advance a reductionist form of technocratic governance, one that presumes that all aspects of a city can be measured or monitored. In this view, smart cities treat urban problems as technical problems, and accordingly prioritize technological solutions. Second, critics argue that the smart city is buggy, brittle, and hackable: it is "prone to viruses, glitches and crashes" and "vulnerable to being maliciously hacked" (Kitchin, Lauriault, and McArdle 2016, 17–22). Third, in line with the critique of digital surveillance identified in the previous paragraphs, academics have argued that the smart

city's mobilization of big data leads to dubious forms of panoptic surveillance, predictive profiling, and social sorting. Finally, many writers have contended that smart city interventions and their mobilization of data create the illusion of neutrality, overlooking both urban politics and the politics of big data. Data collection and code development, they argue, are not value-neutral and as such constitute a political intervention in the city. One strand of criticism that is discussed more fully in subsequent chapters argues that the smart city plays a major role in the corporatization of urban governance (Barns 2016; Greenfield 2013; Söderström, Paasche, and Klauser 2014; Townsend 2013; Vanolo 2014). Both smart urbanism and urban big data can be seen as agendas mobilized by ICT corporations to enclose government functions and develop them into new market opportunities. The smart city, in other words, can be a commercial endeavor advancing entrepreneurial goals.

During the late 2010s, these critiques have been refined and nuanced, as academics have opened a new set of theoretical questions, many of them in dialogue with feminist critiques of science and postcolonial urban theory (cf. Elwood and Leszczynski 2018). This work problematizes common understandings of smart urban spaces as straightforwardly "mediated" through digital technologies. Authors are careful to avoid granting excessive agency to digital technologies, and they also challenge the emphasis within conventional critical social theory on resisting digital intervention. Here the human is brought back into the picture; this is an inventive and creative posthuman agency, "both mediated through techniques and diverse" (Rose 2017, 779). Agents, in this view, actively work toward progressive new modes of urban activism through a productive and proactive engagement with digital urban technologies (Cardullo, Di Feliciantonio, and Kitchin 2019; Lynch 2019).

A broader engagement with critical social theory has "provincialized" the smart city in myriad ways, as writers have rethought its narratives from the perspective of the Global South—for example, unpacking the "smart citizen" as a postcolonial subject and exploring the gendering of the smart city (Datta 2019; Datta and Murray 2018; Datta and Odendaal 2019; Gurumurthy, Chami, and Thomas 2016; Strengers 2014). These perspectives follow long-standing traditions within STS and geography that unpack the symbolic and material power of technology, recognizing the extent to which "smart and digital technologies are now the key policy and political tools

of postcolonial states to embrace and imagine new urban futures" (Datta 2018, 417).

All of the critiques cited in previous pages unpack the power/knowledge dimensions of digital urbanism. At times, critics have focused on the ways in which digital and smart cities, as techno-utopian discourses, promote neoliberal rationalities and specific private interests; at others, they have adopted a cautiously optimistic approach to explore the epistemological implications of encountering the city through digital narratives and technologies. Our work is inspired by this body of analytical literature, but focuses more clearly on the relationship between the Urban OS and traditional infrastructures of the city in order to shed light on the political and economic consequences of using these technologies to come to know (epistemology) and generate new urban spaces and flows, altering their ways of being and becoming (ontology). It is to this subject that we now turn.

Urban Operating Systems as the Urban OS

In this book, we point to the need to question the ontological and epistemological implications of what is now a pervasive computational urbanism. We argue that in order to understand how digital technologies transform and shape the city, it is necessary to analyze underlying computational logics themselves. Research on digital urbanism, in other words, cannot simply be limited to a disconnected analysis of individual technologies or to an examination of where and on whose behalf they are used. Drawing on philosophy and media studies, we see computation as a "metaphor, method, and organizing frame" (Golumbia 2009, 1) for the city; an abstract machine that "constructs a real that is yet to come, a new type of reality" (Deleuze and Guattari 2004, 157). As such, urban operating systems are not simply a "top-down attempt to discipline citizens"; neither can they be "challenged by a simple inversion of this relation, via a bottom-up liberation of technologies in the name of people" (Krivý 2018, 21). In other words, the implications of the corporate takeover of urban functions via digital technologies cannot simply be counterbalanced by embedding into the latter the "liberal humanist values of inclusion, empowerment, sustainability and digital privacy" (Krivý 2018, 21). Seeking to transcend simplistic top-down versus bottom-up analyses of the smart city, we argue that the emerging wave of digital urbanism,

regardless of who it is enacted by and for, puts in place a distinctive regime of urban governance. This is a regime that, in instilling a new way of mapping and shaping relationships between forces, inscribes particular ways of seeing the city, representing relationships and anticipating a changed material future through the making of new connections, disconnections, and flows.

The entry point for our analysis of urban computational logics is the Urban OS, as an abstraction made of pluralities. Scholars have not themselves critically evaluated urban operating systems previously, but they have discussed the idea of the city as an operating system in a number of contexts. First, urban studies scholars have drawn metaphorical comparisons between the complexity and processes of the city and those of a computer. Such comparisons often draw on an early understanding of an operating system (OS) within the IT sector, developed to control multiple and different processors within a computer and to provide a language of interoperability for handling inputs and outputs (cf. Cloot 1965). In computers, the OS acts both as a technology for controlling and coordinating separate processes and as the medium for handling and interconnecting complexity. Used metaphorically to describe a city, this understanding of the OS becomes a way of emphasizing complexity and control within the city: the urban becomes a complex information processing system based on exchange of goods, information, and cultural practices—an operating system in its own right (de Waal 2011).

Second, developing this idea further, Pieterse (2014, 208) suggests that a participatory and "democratic, horizontal, network-based, 'Wiki' model of urban development" could provide an alternative "operating system" for cities, an urban equivalent to a nonproprietary response to the dominance of the "ubiquitous Windows computer platform." A nonexclusionary form of urbanism that is not based on ability to pay is thus imagined in the language of the OS. The comparison between a computational OS and the city starts to move beyond metaphor here. Other scholars have taken a still more literal approach to the ways in which digital technologies are giving rise to a new city-scale operating system, exploring the new ways in which they are coupling information and infrastructure. Written in software code and capable of sensing individual actions in real time, this type of OS aggregates data to effect action at a distance. The resulting real-time city operates through sensor networks that aggregate data streams into new services and products for consumers or citizens (Townsend 2000, 2015).

Third, academics have focused on the links between infrastructural development and wider questions of urban control in relation to a city-scale OS. Easterling has examined how a new combination of infrastructure space, sensors, and software uses the medium of information to envisage the city as a collection of "invisible, powerful activities that determine how objects and content are organized and circulated"—calling this "an operating system for shaping the city" (Easterling 2014, 5). Here, the concept of an OS is that of a platform that is both updated over time and unfolding in time to handle new circumstances and situations, using software "protocols, routines, schedules and choices" to encode relationships between buildings or to manage infrastructural logistics (Easterling 2014, 6). This moves significantly beyond earlier formulations of the OS as a relatively straightforward coordination mechanism between different urban processes (discussed earlier), instead seeing it as a set of integrated informational products, platforms, and interventions loosely interconnected into a broader digital ecosystem *that imposes a form of order on the urban context*. This is the meaning of the Urban OS that informs our work: we wish to emphasize chaotic bundles of hybrid techniques, tools, products, and systems, rather than a standardized unified product. Urban operating systems of this type are being trialed and tested in multiple configurations and urban contexts, with potentially transformative implications for how the city is imagined, planned, and governed (see, e.g., Gabrys 2016 and Halpern et al. 2013 on ubiquitous sensing and data recording infrastructures; Kitchin, Lauriault, and McArdle 2015 and Mattern 2015 on digital urban dashboards; and Barns 2016 and Perng and Kitchin 2018 on municipal open data platforms and civic hacking practices). Viewed in this way, the Urban OS attempts to develop informational/computational ecosystems for urban applications, generating the capacity to integrate the functional and informational dimensions of the city and to coordinate between the previously separate (or, at best, loosely coupled) spheres of infrastructure networks, public services, and everyday life.

In our definition of the Urban OS, we emphasize the ways of thinking, knowing, acting, and being that are embedded in these calculative technologies, and the ways that urban planners, civic technologists, consultants, and business entrepreneurs are using digital and IT systems to establish particular ideas of urban order. The Urban OS is a way of both knowing the city and making it actionable. As such, we are interested in the mechanisms

at play in the ongoing transformation of the city via digital technologies. Our concern thus is not so much the technological arrangement itself (e.g., hardware, software, sensors, platforms, clouds, etc.); rather, we are concerned with *how* that technological arrangement is re-assembling the city. The Urban OS, therefore, could equally be *singular* (and often commercial) packages of information systems put together by large and small IT and software companies, or *collective and loose* ecosystems of technologies and associated practices operating in tandem (yet with varying degrees of integration). They seek to coordinate and integrate services across fragmented urban functions, and comprise software (databases, predictive systems, analytics, modeling and simulation) and associated hardware (computers, sensors, control rooms) assembled into a purpose-built urban system aimed at functional and spatial integration. What makes both of these configurations of urban digital assemblages into a form of Urban OS is not the fact that they are digital technologies applied to an urban setting but that they both operationalize, homogenize, reintegrate, and simplify the urban.

As singular commercial packages, urban operating systems are largely based on preexisting, large-scale integrated computational products that were initially produced for the corporate market. ERP systems, initially developed in the 1980s and central to the ascendancy of the corporate business model, are a clear antecedent of the contemporary Urban OS. They consist of software management systems aimed at integrating business processes (e.g., payroll, procurement, quality management, customer acquisition, and product/service delivery) through common databases and information flows across corporate departments (sales, accounting, human resources, etc.). These are complex products, and their implementation in the corporate sector is an expensive and demanding process that has been criticized. The problem is that the assumptions built into the software tend to reshape the organization of the corporate entity implementing it in significant and material ways (Kallinikos 2011). As a result, ERP systems often generate a range of inflexibilities and obduracies described within the business world as *electronic concrete*. This configuration of the Urban OS is perhaps better illustrated in the book by Rio de Janeiro's Operations Center, designed by IBM based on an integration of some of its preexisting software packages (see chapter 7). The grounding of the Urban OS within ERP systems is important because it underpins the idea that the corporation and the city are alike, and that they suffer similar problems of functional

integration that require separate and disconnected processes to be fragmented, reaggregated, and digitally integrated.

Currently, however, the Urban OS is being constituted in a multiplicity of ways that move far beyond the simple repurposing of ERP systems toward urban functions. As such, it transcends code/software/hardware, as well as corporate configurations, to include the work, views, and politics of a multiplicity of stakeholders who, by using digital technologies, interact with, complement, build upon, reinterpret, and transform city systems in ways that can be considered to have broader systemic qualities. Here the Urban OS is not the result of a single product or package, but a loosely connected assemblage of IT practices and technologies—an ecosystem made of digital platforms, social media, mobile phone apps, clouds, software packages, and sensing devices, but also coding practices, civic hackathons, data activism, and so on. While this provisional, territorially dispersed, and distributed assemblage (cf. Anderson and McFarlane 2011; Li 2007) of urban digital interventions is characteristic of all urban operating systems, in the book this configuration comes across more explicitly when analyzing the work of civic hackers in support of Hong Kong's prodemocracy movement (chapter 8). As such, using the language of Easterling (2014), the protocols, routines, schedules, and choices embedded in digital urban technologies transcend a single software package, to shape the politics of emerging and dispersed forms of digital or smart urbanization. We therefore argue that it is critically important to understand the systemic qualities of the computational logics that underpin the Urban OS and the ways in which this, as an emerging computational urbanism, is transmuted and reapplied toward governing a much wider set of urban processes.

Conceptual Lenses: An Emerging Urban Computational Apparatus

Drawing on governmentality literature, Chris Otter (2007) and Patrick Joyce (2003) have explored the historical relationship of infrastructure, technology, and power in the city. Both authors are concerned with the consolidation of urban infrastructures in the nineteenth century and the ramifications of this for governing the city. Otter criticizes traditional perspectives on governmentality (e.g., Dean 2010; Miller and Rose 2008) for focusing on bureaucratic and discursive governmental techniques, silencing "the brute materiality of technology" (Otter 2007, 578). He suggests

that technological systems are endowed with an agency of their own and play a key role in the creation of the self-disciplining liberal subject. Their materiality carries a political charge, enabling "government *through* and *by* technology" (Otter 2007, 580; original emphasis). Here, multiple machines and sociotechnical networks, from roads and sewers to electricity grids and gas networks, secure in a dispersed way while materializing an indirect mode of rule. In the city, these infrastructures operate as technosocial solutions of a political nature. As with later digital technologies, like the Urban OS, their politics is enhanced by the fact that the solution that they offer is apparently "technical" and therefore seemingly neutral and external to the agonistic world of politics (Joyce 2003). As explored in more depth in chapter 2, urban infrastructures and the practices associated to their use and establishment imposed a new diagram of power, with implications that mapped and shaped wider societal relationships. As historians and sociologists of the nineteenth- and twentieth-century city have argued (Joyce 2003; Osborne and Rose 1999; Otter 2007), the materiality of urban infrastructures plays a critical role in territorializing government—signaling the urban as a domain for the exertion of government and authority, as much as a laboratory for generating new truths about the social world.

The Urban OS continues this historic imbrication of technology in the establishment of modes of governing and the generation of truths about the city (cf. Osborne and Rose 1999). Yet the contemporary moment intensifies the relationship between power and infrastructure present in earlier configurations of the city by bringing together material and digital flows—an *intelligence incarnate of the urban*. A calculative logic is thus mobilized as the supreme rationale for imagining the city and for effecting actions to change it. Drawing on a Foucauldian interpretation of power as creative, enabling, and productive of subjects, meanings, and interventions (Miller and Rose 2008; Patton 1998), our analytical framework seeks to understand the emerging urban computational apparatus as a governing device, with an embedded politics that, in transmuting the city into a calculative and logistical enterprise, does not question established orders. Instead, it seeks to ensure their maintenance without changing organization, ownership, or orientation. This mobilization of technical domains in the making of the city represents an *eclipse of politics* (cf. Agamben 2009), an operationalization of the urban that speaks of management as "a pure activity of government that aims at nothing other than its own replication" (Agamben 2009,

22; see also Braun 2014, 61). As mentioned previously, we describe this as a *digital hollowing of the polis*. The diagrammatic logics of the Urban OS signal toward new ways of imagining the city, establishing urban meaning and opening or closing modes of inclusion; this is a regime that embodies important presumptions about what constitutes appropriate knowledge and forms of decision-making.

Researching the Urban OS

Far from being passive backdrops to technology, cities complicate, enable, disrupt, resist, and translate the Urban OS. However, there is a lack of comparative analysis and a dearth of knowledge about the range of urban contexts within which the Urban OS is emerging. To analyze the social and political implications of the Urban OS and examine how specific urban conditions enable and constrain digital urban technologies, we needed to generate new knowledge about the forms, dynamics, and consequences of the Urban OS in an internationally comparative context. We sought to address three key challenges in particular. First, we wanted to examine the Urban OS from the inside, rather than relying solely on promotional and publicity material from product developers or on secondary literature. This meant we needed to engage with the participants who were involved in shaping urban operating systems across the world, undertaking fieldwork across a range of sites in which it is being applied. Second, we wanted empirical research to inform the priorities of the fieldwork in an iterative manner that would allow us to trace pathways emerging from interviewee feedback. This led to a reconceptualization of the Urban OS halfway through the project as both a singular and formal commercial package and an informal, multiple, and unbounded ecosystem of urban digital technologies operating in loosely connected ways. Third, in the absence of a single source of funding for the project, we adopted creative, flexible, and improvisatory approaches that were able to make use of financial and practical opportunities as they arose.

As mentioned previously, we have identified seven computational logics that are driving the political transformation of the city and its infrastructures: operationalization, datafication, prediction, sensing, mapping, circulation, and resistance. This list is not meant to be exhaustive, nor is each logic exclusive to the specific empirical case study that illustrates it. However, we do believe that these computational logics are emblematic of the

types of processes at play in the digital re-assembly of the city. We examine each from three distinct perspectives. First, we analyze the *production* of computational logics, uncovering the domains in which these calculative ways of thinking were initially developed. Here, looking into the histories of the specific digital products and computational techniques at play gives us an insight into the origins and lineage of the logic before its adoption within urban contexts. Second, we trace the circulation of computational logics in different contexts and the specific mechanisms for their *transmutation* into the urban. This illustrates the context of emergence of the logics. It also shows the extent to which, underpinned by broader ecosystems and ways of thinking (such as the military, logistics, or the corporate world), they go beyond specific digital technologies or software products and both engulf and transcend computation. Third, we investigate the *urban politics* that result from the implementation of computational logics in the city, examining the forms of support and resistance that they provoke, with a view to identifying their implications and how they reshape the governance of urban infrastructure.

We began by researching single computational packages developed by the IT sector and aimed at municipalities. We were able to inquire into these products via visits to IBM labs in Dublin and Delhi, conducted as part of a wider university relationship. We also carried out pilot work by visiting smart city projects and facilities in Glasgow, Bristol, and London and by interviewing IT professionals working in these cities. During this initial period, we discussed our intentions with (and at times interviewed) software engineers working in both the academic and the private sectors, including colleagues and friends. We also conducted a desktop analysis of the marketing material prepared by large companies to promote their developing range of smart city products. The critical issue that our early analysis raised was the extent to which forms of knowledge and rationalities embedded within broader computational products and processes also provide the foundational underpinnings for the wider set of technologies and products aimed at the urban segment, in this way giving shape to a new form of computational urbanism.

We then traced the development of particular systems, platforms, and digital ecosystems, through a bricolage of approaches and taking advantage of a range of funding opportunities. The role played by municipal open data platforms and a process of datafication quickly emerged as a central

component of the Urban OS, providing the primary data flows for other urban applications. To explore this, we used small-scale project funding to carry out a series of interviews in New York City. We also briefly participated in the local civic hacking scene, which was particularly lively partly thanks to the Bloomberg administration and its conceptualization of New York as a data-driven city. We advanced our analysis of sensing platforms through a case study of Barcelona, where the city council was at the time working with private sector partners to develop specialist skills in the construction and testing of sensor-based technologies. As in other cities, our research involved site visits and interviews with government officials and businesses, particularly start-ups involved in deploying sensors in the city.

We examined the implications of digitally mapping the city by looking in depth at an initiative by Google Maps to map favelas in Rio de Janeiro. We were able to do this thanks to UK and Brazilian research funding available for the development of international research networks, and most importantly via a collaboration with Dr. Flávia Neves Maia, a Brazilian academic and practitioner looking at the role of digital technologies in Brazilian cities. Thanks to this collaboration, our analysis of Google Maps in favelas involves not only interviews but also participatory observation, as well as an extensive review of documents and marketing material associated with the initiative.

Meanwhile, our analysis of predictive analytics platforms focused on Chicago, given the high profile achieved by the city on this front. Here we also took part in events within city's civic hacking scene, alongside interviewing a number of active and former senior government officials who were playing pivotal roles in developing the use of predictive analytics to police and manage the city. In 2014 and 2015, we visited the Rio Operations Center (COR), a control room in Rio de Janeiro designed with extensive input from IBM. Combining site visits with interviews and media analysis, this led us to identify circulation as one of the main logics advanced by the Urban OS.

Finally, we initially focused on the Sunflower Movement in Taipei for our examination of the role of digital technologies in forms of political resistance and urban protest. While visiting Taiwan, we established relationships with civic hackers through a number of interviews and participation in civic hackers' conferences. These interactions, occurring toward the end of 2014, revealed links between Taipei's Sunflower Movement and the

then-evolving Umbrella Movement in Hong Kong. As a result, the focus of our examination shifted, and we did fieldwork in Hong Kong by visiting the protest sites and conducting interviews there while the occupation of the Umbrella Movement was still active.

In total, our fieldwork activities extended across eleven cities, where we conducted over one hundred interviews involving more than 125 IT professionals, government officials, civic hackers, activists, and IT aficionados. Where these interviews are used in the book, they are either indicated by double quotation marks or set off, and preceded by a brief explanation of the working context of the interviewee. With very limited exceptions, all of the interviews were audio recorded. In all cases, we complemented these methods with site visits, document reviews, and desktop research targeting relevant web-based sources. In some cases, we also analyzed a range of forms of digital media (e.g., Facebook pages, smartphone apps, "collective interviews" conducted via the Hackpad real-time collaborative text editor, platforms created by civic hackers) and video sources (available through online media channels). We were able to make two visits over a period of two years to four of the five case-study sites that are discussed in chapters 3 to 8 (Chicago, Rio de Janeiro, Barcelona, and Hong Kong/Taiwan; the exception was New York City, which we visited only once). This allowed us to conduct follow-on interviews with key respondents.

Andrés conducted the bulk of the fieldwork, while Simon was able to participate in most of the follow-on fieldwork visits. When we analyzed the case of Google Maps in Rio de Janeiro's favelas, the interviews, participatory observation, and site visits were conducted by Dr. Flávia Neves Maia, who focused on four of the twenty-five favelas where Google has had a presence: Cantagalo, Pavão-Pavãozinho, Santa Marta, and Vidigal. Flávia and Andrés jointly conducted additional documentary analysis. We enriched the research with additional visits to "model" smart city initiatives and IT labs in Glasgow, Bristol, Delhi, and London. Overall, through attending political demonstrations (Hong Kong), carrying out participant observation in civic hacking events (Taipei, Chicago, and New York), spending social time with corporate developers of urban operating systems, seeing how communities in favelas engage with digital technology, and sitting in the staff coffee room of Rio de Janeiro's COR, we were able to build rich and in-depth understandings of the key dimensions of the applications of computational logic in exemplar cities.

In the practical world of city-making, the Urban OS is not a single informational product but rather a varied set of computational ecosystems, from digitally enabled operation centers to municipal data platforms, mapping initiatives, infrastructural sensing systems, and predictive analytic models, among others. Differentiating among these has enabled us to identify the specific techniques through which digital urbanism operates and the way that these stake a claim to a new form of authority that is transforming the ways in which the city is governed. Chapter 2 provides a more detailed analytical understanding of the Urban OS as an informational product, exploring the ways in which it conditions understandings of the city. Chapters 3–8 then analyze specific computational ecosystems through empirical detail. These are understood both as ways of thinking and acting (means, mechanisms, procedures, instruments, tactics, vocabularies) and the very material and digital technologies involved (cf. Dean 2010). We argue that it is through these techniques that the political rationalities embedded within the Urban OS effect change, bringing about new forms of urban control and reconfiguring the nature and meaning of urban entities. Chapter 9 reviews the main argument that an evolving range of digital logics are advancing new ways of imagining, knowing, and governing the city. This conclusion is careful to show how contested, multiple, and often contradictory logics are being developed in this experimental phase of digital urbanism, drawing on these tensions to develop a future research agenda.