Urban Operating Systems: Diagramming the City

(Forthcoming in the International Journal of Urban and Regional Research - IJURR)

Simon Marvin* and Andrés Luque-Ayala**

** Urban Institute, Sheffield University*
*** Department of Geography, Durham University*

Abstract

A set of software/hardware packages developed by IT companies for the urban market are reconfiguring the way in which cities are imagined and configured. These Urban Operating Systems (Urban OS), embody important presumptions about what constitutes appropriate knowledge and forms of decision-making, pointing to how novel forms of 'smart' or 'computational' urbanism may govern urban life. Arguing that an analysis of the interface between the urban and IT requires a broader historical and theoretical perspective, the article traces the ways in which the city has been diagrammed as a space of power since the nineteenth century and highlights the antecedents of Urban OS present in different domains of life—particularly military and corporate enterprises. Relaying the urban as an efficient logistical enterprise, and operating as a piloting device (Deleuze and Guattari, 1988), the Urban OS appears as an emerging urban diagram introducing an informational diagrammatic of control. We focus on five archetypal framings of how Urban OS envision the city, illustrating how a new corporate rationality of control based on functional simplification, heterogeneous reintegration, re-engineering, agility, modularity, flexibility and configurability attempts to take hold in the city.

Introduction

Framed by aspirational narratives around smart urbanism, and drawing on pre-existing products and technologies developed for the corporate sector, companies such as IBM, Hitachi and Cisco are increasingly targeting the urban market. From IBM's *Smarter City®* and Urbotica's *City Operating System®* to Microsoft's *CityNext®*, large and small electronics and IT companies are developing software-hardware packages that claim to improve the quality of urban services whilst making the city more efficient and sustainable. Alongside them municipal authorities are mobilizing resources towards the development and operationalization of a variety of digital platforms aimed at transforming both services and infrastructures (Marvin et al., 2016). These computerized technologies are positioned as 'operating systems': essential hardware, software and data components that quietly sit in the background directing urban flows, providing shared languages towards interoperability across multiple infrastructures. Within media and the industry (e.g. BBC, 2011; Living Plan IT, n.d.), these platforms integrating the digital and material domains of the city are often referred to as an 'urban operating system' (Urban OS).

This article aims to examine the emerging Urban OS, tracing its historical roots within military and corporate domains whilst also establishing how its contemporary application may generate new relations and embody a new logic of urban control. Critical guiding questions are how IT rationalities of control are transferred to the urban context and through which 'diagrammatic abstractions' the city is reconfigured as a computational space. The article builds on an extensive body of scholarship within geography, computer science, architecture, urban studies and media studies examining the interface between computing, information communication technologies (ICT) and the city (Graham and Marvin, 1996; Graham, 1999; Galloway, 2004; Foth, 2009; Kitchin and Dodge, 2011; Kitchin, 2014). Here, within an emerging body of work that seeks to critically interrogate the idea of the smart city, 'smart' rationalities have been uncovered as grounded within the corporate world (Söderström et al., 2014; Vanolo, 2013; Luque-Ayala and Marvin, 2015), altering contemporary functionings of power, space and regulation (Klauser et al., 2014; Gabrys, 2014). Whilst the Urban OS as such has not been critically evaluated, the idea of the city as an operating system has been discussed in a number of ways. First, it has been used as a 'metaphor' in which cities are seen as interchangebale with computer systems. Such understanding of urbanity as an 'information processing system' sees the city as a complex system based on exchange of goods, information and cultural practices—an 'operating system' (de Waal, 2011). Second, moving beyond metaphor, there is the observation that digital technologies are giving rise to a new city scale operating system. Written in software code and capable of sensing individual actions in real time, this operating system aggregates data to effect action at a distance. Such 'real-time city' operates through sensor networks that aggregate data streams into new services and products for consumers or citizens (Townsend, 2000, 2015). A third conception of a city scale operating system focuses on the linkages between infrastructural development and wider questions of urban control. Easterling (2013: 5) examines how a combination of infrastructure space, sensors, and software are specifically designed to use the medium of information in "invisible, powerful activities that determine how objects and content are organized and circulated… [in] an operating system for shaping the city". Here an operating system as a platform—both updated over time and unfolding in time to handled new circumstances and situations—uses software "protocols, routines, schedules and choices" to encode relationships between buildings or managing logistics of infrastructures (Easterling, 2013: 6).

We argue that this later conceptualization of the operating system as a platform for urban control—an emerging 'platform urbanism'—is exemplified through specific Urban OS products and processes developed by corporates and urban technologists and represents a distinctive regime of urban governance. The Urban OS, drawing on rationalities and techniques originally developed in the interface between defense, corporate and IT sectors, prioritizes a highly technocratic style of integrative urban control. This is analyzed here through an uncovering of what we refer to as the informational diagrammatic of control of the Urban OS. We do this two ways.

First, arguing that an analysis of the interface between the urban and IT requires a broader historical perspective, we trace the ways of thinking that both transferred and mutated as information systems traveled between different domains of life, briefly discussing the historical transfer of digital applications from military and corporate contexts to their more recent application in the urban market. This analysis traces the early origins of Urban OS packages to practices of urban computing that, drawing on knowledge developed within the American defense industry over the post-war period, where tested in a number of US cities in the early 1970s. It also draws on the development of corporate integrated information packages such as enterprise resource planning systems (known as ERP), which in the 1980s and 1990s laid the foundations for more contemporary ways of coding the urban and became the precursors of Urban OS configurations.

Second, we examine the way in which Urban OS understand the city—its complexity and operations—through an examination of the contemporary frameworks used by corporate providers of Urban OS. The Urban OS, analyzed through Deleuze and Guattari (1988) and De Landa's (2000) post-representational understandings of the diagram, inscribe particular ways of seeing the city, representing relationships and anticipating a changed material future through connections and disconnections. Beyond the representational and communicational nature of the Urban OS frameworks mobilized by ICT companies, these emerging urban diagrams establish operative rationalities that shape the workings of power and constitute novel governing forms (Osborne and Rose, 1999). The relational models embedded within the Urban OS uncover its nature as a transitory or relay device. The Urban OS, as an essential component of the smart city, emerges as a new urban diagram which "does not function to represent, even something real, but rather constructs a real that is to come, a new type of reality" (Deleuze and Guattari, 1988: 142).

For our analysis we selected five framings of the Urban OS—by Hitachi, Microsoft and IBM—given their emblematic archetypical form, examined through common graphic illustrations associated to them (Figures 1 to 5). As a result, our analysis relates more to the formalised and commercial side of the Urban OS (exemplified by, for example, IBM's *Intelligent Operations Centre for Smarter Cities*, the technology behind Rio de Janeiro's *Centro de Operações*, or Barcelona's *City OS*, developed by the city's Municipal Informatics Institute), rather than accounting for the breadth of formal and informal digital urban applications currently constituting a novel bricollage of hybrid informational ecologies. In our analysis, the five selected framings correspond to understandings of the city as a cybernetic entity, disconnected strata, a computing form (the urban CPU), a set of closed data flows and a space of possibilities for the digital dis- and re-assembly of urban circulations. We argue that Urban OS construct a new rationality for a regime of control based on functional simplification and heterogeneous reintegration.

Placing Urban OS: From defense applications to the urban

Computation (the method used by computers) and its rhetoric (a belief system around computerization as a superior form of social and political organization) plays a role in legitimising emerging and established institutional powers (Golumbia, 2009), particularly through the consolidation of specific rationalities as ways of conceiving and producing knowledge about the world (Cowan, 2014; Rossiter, 2012). Urban OS, as information systems put together by large and small IT and software companies as much as local authorities and social actors, seek to coordinate and integrate services across fragmented urban functions. They are comprised of software (data bases, predictive systems, analytics, modeling and simulation) and associated hardware (computers, sensors, control rooms) assembled into a purposefully built urban system aimed at functional and spatial integration. Operating in practice as a chaotic bundles of hybrid techniques, tools, products and operating systems—rather than simply as a standardised unified product—, Urban OS are being trialed and tested in in multiple configurations and urban contexts with potentially transformative implications for how the city is imagined, planned and governed (see for example Luque-Ayala and Marvin, 2016 on digitally enabled control rooms for the integration of municipal functions; Barns, 2016 on municipal open data platforms; Mattern, 2015 and Kitchin et al., 2015 on digital urban dashboards; and Halpern et al., 2013 on ubiquitous sensing and data recording infrastructures). The Urban OS attempts to develop informational/computational ecosystems for urban applications, gaining its distinctiveness through the generation of capacities enabling the functional and informational integration and coordination of what are currently separate, or at best loosely coupled, infrastructure networks, public services and everyday life.

Whilst the 21st century has seen a significant increase in computational applications to the city, the idea of thinking about the urban as a complex digital system to be managed through data flows has its origins in the mid-twentieth century. In 1968 Arnold E. Amstutz, writing from his desk at MIT, made a case for a new style of city management. Amstutz, an associate professor of management, believed that the way to manage complexity in the modern city was through systems analysis. In his view, man (sic) could make the city responsive to his needs via a threefold strategy: structuring the environment into categories and sub-categories, developing clear objectives and criteria for evaluation, and using computers to "synthesize and maintain a representation of the total environment" (Amstutz, 1968: 21). Such claims illustrate a wider trend towards using cybernetic thinking and systems modeling to solve, in the words of John Collins, Mayor of Boston between 1960 and 1967, "the crisis of the cities, the greatest domestic crisis to challenge America in a century" (cited in Forrester, 1969: vii). Amstutz's approach rested on the delegation of authority to computer systems. Thanks to the pre-programming of urban functions, city executives would 'finally' be able to approach urban problems with "increased effectiveness due to the availability of more meaningful data and an increased (model based) understanding of [the] environment" (Amstutz, 1968: 21).

Since the late 1950s, drawing on the principles of cybernetics developed by Norbert Wiener, the city had increasingly come to be seen as a communication system (Webber, 1964; Meier, 1962; see also Light, 2003). Social science and policy analysts alike relied on flow charts and data visualizations to compensate for the unknown, whilst data recombination and a search for patterns heralded a reorganization in knowledge and new forms of cognition (Halpern, 2014). This understanding of the urban as a space of data flows and environmental modeling draws on the digital computation work of Jay W. Forrester (1961; 1969), the father of system dynamics and a pioneer in the application of modeling techniques to social systems. Forrester, also one of the forefathers of a more contemporary *Science of Cities* (Batty, 2013; see Townsend, 2015 for a critique), saw the urban as a complex (yet arguably linear) system of interacting parts experiencing growth, equilibrium and stagnation, easily modeled through calculated flows and an account of conditions in the surrounding environment. Technology was not to target the symptoms of urban decay; rather, it would provide unique access to "the dynamics of urban structure… [and through that] a set of revival policies that can reverse a city from economic stagnation" (Forrester [1971] 1975: 247 and 249). The belief in computer applications, system dynamics and digital modeling as a mechanism to solve urban problems was espoused by a generation of American planners and technologists. By 1966 the *Journal of the American Institute of Planners* was reporting on a practical and theoretical revolution within the discipline as a result of computerization (Meier and Duke, 1966; Harris, 1966).

Yet, computer science and simulation on its own was not the only source of inspiration for this urban revolution. It was underpinned by the vast amount of knowledge around systems analysis developed by scientists working within the American defense and aerospace industry. This early history of the cyber-city, traced in detail by Jennifer Light (2002; 2003), reveals how the military-industrial complex of the mid-20th century became a fundamental tool for city planning (see also Farish, 2010). Organizations such as NASA, the Lockheed Corporation, the RAND Corporation and other defense contractors operating as consultants to municipal governments transferred techniques and technologies from military research programmes into urban management. As the cold war settled, companies in the IT-defense sector, concerned with reductions in government spending resulting from the missile test ban and project reductions within the Apollo program, recognized the need to transfer their innovations and technologies to new markets. City planning and management quickly emerged as "targets of opportunity" (Light, 2003: 46). This postwar coming together of wartime research, cybernetics, communication sciences, computation and urban planning had long-term epistemological connotations, as new ways of observing and knowing the city were developed: data visualizations and 'the interface' became central concerns of city planning, whilst the urban comes to be produced via "new techniques of calculation, measurement and administration" (Halpern, 2014: 17). For historian of technology Orit Halpern, "cities become systems with an endless capacity for change, interaction and intervention, and problems of urban blight, decay, and structural readjustment have no clear definitive endpoint". In this new model of the urban, structure, race and class are replaced by 'the environment', as urban politics are negotiated through design, aesthetics and personalization; an inundation of data emerges as a new form of truth (objectivity) and moral virtue (ethics) (Halpern, 2014: 121).

The confluence of urbanism and the military-industrial complex in the post-war period embedded the city with new meanings—now seen as a 'battleground', 'fighting a war on poverty' and 'battling against urban chaos', 'blight' and 'unrest' (Light, 2003; Graham, 2004; Farish, 2010; Vanderbilt, 2002). As the urban problem is framed from a militaristic/defense perspective, its solution is increasingly imagined as a function of managing processes. Jennifer Light's work is unique in that it explains the coupling of military technologies, computer systems and urban planning. First, computer simulations were seen as an extension of existing planning tools, such as maps and 3-D models, through which planners built up an image of the city and its potential transformation. They were also seen as offering relief from monotonous tasks, capable of handling a larger number of variables and visualize problems in novel ways. Second, the city became redefined in cybernetic terms, as systems analysis and computing offered an opportunity for unifying different planning traditions that saw cities as either organic systems or as machines. Key to this was the incorporation of action and feedback in tools such as databases and computer simulations where real-time information could properly represent cities and urban processes in ways that maps and models could not. Third, urban planning and management could be turned into a scientific endeavor. In the American post-war, in the search of enhanced prestige and federal funding and partly as a response to the failure of the Housing acts of 1949 and 1954, urban disciplines tried to remake themselves through data and computer models (Light, 2003). Information systems became a form of urban response, capable of depoliticizing the process whilst forcing scientific verifiable outcomes. This lead to a major expansion in government initiatives on urban dynamics, systems analysis and urban cybernetics, under the leadership of the United States Department of Housing and Urban Development. It involved incentives to create closer relationships between military and urban experts through funded programmes of urban experimentation, leading to urban observatories, urban data centres, and urban information systems

(Light, 2003). An amalgamation of diagrammatic abstractions—both ways of seeing and doing—led city planning to adopt a language of feedback, homeostasis and control.

Coding behaviour: modes of 'IT-thinking'

The urban context was not the only domain where experimentation with computing technologies beyond military applications was occurring. In the post-war, computer systems offered a promise for streamlining corporate production processes. In 1957 IBM supported the foundation of the American Production and Inventory Control Society (APICS), a non-profit dedicated to knowledge generation within supply chain and operations management. Soon afterwards a computerized time-based planning and inventory control system was born (Mabert, 2007; Jacobs, 2007), adopted by APICS as one of its key principles of operations management whilst gaining popularity throughout the 1970s. A computer package capable of fully integrating 'all' aspects of corporate operations would not be achieved until the late 1980s, with the development of Enterprise Resource Planning systems, or ERP (Jacobs, 2007). By the turn of the century ERP systems had created a global market of over US$38 billion (Rashid et al., 2002), consolidating IT as the largest capital expenditure in US business.

Within municipal government, ERP systems have been used extensively to streamline internal operations, linking finance, procurement, payroll and human resources and e-government in cities such as Des Moines, Pasadena, San Diego and Cape Town. However, the influence of ERPs in city making is not the result of their specific usage within municipalities. Rather, it is through their deployment in business organizations and the resulting refinement of corporate rationalities through technological systems that ERP packages come to affect the city, becoming antecedents that transmuted into Urban OS.

Critically, the arrival of ERP systems to the business sector implies the adoption of particular regulatory regimes within organizations. ERP packages function by linking all business operations to a single database, "promis[ing] the seamless integration of all the information flowing through the company—financial, accounting, human resources, supply chain and customer information" (Davenport, 1998, cited in Rashid et al., 2002: 3). They are noted for forcing business to reengineer systems in order to accommodate to the software logic (Rashid et al., 2002). Kallinikos (2011) argues that the implications of ERP systems go beyond the simple integration of operations across functions and production sites. Their systemic logic and data-based relations establish a standardized way of receiving inputs and prescribe ways of instrumenting and conducting operations. As a result, organizations are drastically simplified, operating through normative workflows that stipulate transactions and processes. ERP systems limit capacity for contextual and local adaptation in a variety of ways: the presumptions of the software package cannot be overridden; evaluation is restricted to a limited number of criteria; cognition processes rely on the identification and deployment of common elements across experiences; and finally, the black-boxed nature of the technology itself—the software—protects it from deliberate manipulation or transformation.

Off-the-shelf information packages such as ERP systems, in their effort to render internal relations predictable and controllable, come to transcribe their reality "into the language of the package rather than the other way around" (Kallinikos, 2007: 61).

Specific forms of software programming embed ways of thinking about the world, constructing forms of agency and establishing a micro-order within the everyday (Kallinikos, 2007; 2011). Advancing a rationality that superimposes logistical thinking to the practices of organizations, ERP software "functions as a technology of governance and control" (Rossiter, 2012: online). Technology embody routines and procedures that generate particular forms of perception and cognition, both shaping and governing behavior "thanks to the variety of strategies of *functional simplification* and *reification* by which it lays out its prescriptive order" (Kallinikos, 2011: 7, original emphasis). Kallinikos looks in detail at different techniques of coding, focusing particularly on object-oriented programming. Here an intensely structured form of software coding—highly governed by structures and procedures—divides reality into objects, which are further divided into other objects; each one of these objects has attributes, and by recombining attributes the relationships between objects can be reconfigured. This computational logic by which reality is rendered as information is sustained by an elaborate vertical integration. Through an emphasis on modularity, alongside pre-determined structural features and intrinsic qualities, IT packages and knowledge are constituted as both specialized and transferable—from company to company or organization to organization (Voutsina et al., 2007). The use of ERP implies a functional understanding of the organization, where the fragmentation of operations into functions and sub-functions is crucial for the appropriate functioning of the whole. Organizational operations are reconstructed after a detailed breakdown of components into sites, agents, functions and relationships. Corporates using ERP systems become reconfigured as a collection of procedural steps, patterns, subfunctional categories, modules and cross-modular transactions that lose sight of processes to be replaced by procedures—a linear sequence of transactional steps (Kallinikos, 2007).

The implications of an informational diagrammatic of control for corporates have been profound. Underpinned by modularity, transferability and an alleged flexibility, this diagrammatic of control is based on functional simplification and selective integration. It implies the establishment of narrow channels for knowledge circulation alongside specific forms of decision-making. In spite of claims for multiplicity and widespread interconnectivity, technique and procedure become obligatory passage points and data flows become a tangible route to a new cartography of power. Rather than increasing the flexibility and adaptability of organizations to deal with important changes in the external environment, these systems have instead increased obduracy and rendered internal relations predictable and controllable as they become reduced to transactional steps embodied in the software. Yet, systems such as the ERP are now being re-badged and lightly reconfigured into a new set of corporate IT technologies targeted at the burgeoning urban market: the Urban OS. The critical question this raises is how IT rationalities of control are transferred to the urban context, and what 'diagrammatic abstractions' shaping our understanding of the urban emerge as part of this process.

Diagramming the City

In the same way that an informational diagrammatic of control transformed the corporation, the contemporary wave of computation in the city is likely to have long-term effects, impacting in particular forms of knowing and governing as much as the ways in which power operates in the urban. The initial post-war introduction of computation to the city already advanced a novel epistemology of the urban; one where the city was a space of linear control and where complexity and contradiction could be rendered manageable via workflows and processes. Whilst such computational approach to the city quickly went out of fashion, computation as both governing rationality and technique lived on throughout the 1980s and 1990s in the confluence of IT, business and logistics. This computational logic was more than an attempt in simplifying complexity via a series of communication and information techniques for re-arranging flows. It accounted for a novel diagram of power; a new way of mapping and shaping the relationships between forces, imposing a form of conduct through spatio-temporal composition and serialization. This was a diagram as an abstract machine; a transitory relay producing “a new kind of reality, a new model of truth” (Deleuze, 1988: 30; Knoespel, 2001).

Deleuze and Guattari’s understanding of the diagram offers a useful analytical device to understand the power of computational logics in shaping the contemporary urban. Transcending representational approaches (e.g. Taylor, 1988 and Taylor and Blum, 1991, where the diagram is an abstract simplification that, in representing the world, creates the object of study), diagrams here are seen as non-neutral construct matrices through which meaning is negotiated and generated (Knoespel, 2001). They have the capacity to operate “as a means of seeing something never seen before”, embodying momentum towards further definition and elaboration (Knoespel, 2001: 147). Their meaning is framed by the setting, enforced by the narrative within which it is placed whilst serving as an agent for conceptual mapping. The diagram “does not function to represent, even something real, but rather constructs a real that is to come, a new type of reality” (Deleuze and Guattari, 1988: 142). It can be seen as having a dual role, both stabilizing and society in the making (Callon, 1987). Knoespel (2001: 147) points to Deleuze’s understanding of a diagram as a ‘piloting device’ that “embodies a practice of figuring, defiguring, refiguring and prefiguring”. As an abstraction, its effect is not bounded by an attempt to reproduce or imitate but by a productive, pragmatic and creative essence. It denotes a new cartography, shaping unformed and unfinalized matter and function (Deleuze, 1988).

Critically, the diagram transmutes a mechanism of power into a function, and vice-versa (Foucault, 1977). Foucault’s understanding of the diagram is linked to his analysis of panopticism. The panoptic as a diagram is not only an optical arrangement (affecting visible matter and allowing ‘to see without being seen’), but an abstract technology—an abstract machine—that “*impose[s] a particular conduct on a particular human multiplicity*” (Deleuze, 1988: 29, original emphasis). It acts as an immanent cause, penetrating, permeating and overlapping the whole social field, and in doing so, executing the relationships between forces so that these “take place ‘not above’ but within the very tissue of the assemblages they produce” (Deleuze, 1988: 32). Originating and evolving within an entity, such diagrams of control in themselves enclose together intentionality and technique for acting. As explored in the following section, the Urban OS as an emerging technological diagram of the city collapses governing intent, technique of action and material technology.

Osborne and Rose examine different diagrammatic conceptions of the city as a space of government and authority, or the territorialization of government through a diagram of power. Their overarching aim is an understanding of how contemporary modes of power operate—this time with the city as “a governed and ethically saturated space… a way of diagramming human existence” (1999: 737).

> "These diagrams are neither models nor Weberian ideal-types but operative rationales. Each diagram depicts and projects a certain 'truth' of the city which underpins an array of attempts to make urban existence both more like and less like a city" (Osborne and Rose, 1999: 738).

Using a governmentality perspective (Foucault, 2009), where governing is not limited to the thoughts, policies and strategies of those in formal positions of power but occurs through silent and informal styles of self-government, Osbourne and Rose examine how urban diagrams have transformed modes of governing throughout history. The Greek *polis*, as the emblematic diagram linking urbanity and political forms around citizenship and participation, embeds the immanence of an authority that results from political sociability. It is linked to a form of 'natural government' where, rather than calculated intervention, what predominates is an antagonism that gives rise to self-government (Osborne and Rose, 1999). In the 19th Century the forces of power embedded in the urban diagram experienced a significant change: the city became "*inseparable from the continuous activity of generating truths about the city*" (Osborne and Rose, 1999: 739, original emphasis). Truth and government became entangled through spatiality; a truth that was technical rather than philosophical or political. This *practical* urban thought operated through the management (gathering, organizing, classifying and publishing) of information (Osborne and Rose, 1999), albeit in combination with its own material form by way of urban infrastructures (Joyce, 2003; Otter, 2007). What was new was the extent to which authority became linked to specific knowledges and technical expertise. This was not about imposing discipline and subordination; it was about the emergence of a "regulated and civilized freedom". The 'liberal' city was not a result of the emergence of liberal thinking, but of a change at the diagrammatic level with the adoption of the city as the milieu for realizing and modulating freedom—the city as a laboratory of conduct (Osborne and Rose, 1999: 740). The emerging urban diagram of the 19th century, for instance, rather than focusing on domination and control, sought to balance an autonomous public sphere, markets, individual liberty and the rule of law. The sanitary city positioned Victorian public health and sanitary systems as a privileged technology for governing the urban (Rabinow, 1995). In the context of urban slums, the body of the citizen itself became a privileged governing site. Over the course of the following 150 years a variety of other urban diagrams made their mark in the history of conducting human conduct, subjectivity and life, including the garden city, the colonial city and the zoned city (Osborne and Rose, 1999).

In this article we argue that, in the context of the Urban OS, a new urban diagram is now emerging based on new forms of managing information and flows; a result of information communication technologies and their interface with the very material infrastructures identified by Joyce (2003) and Otter (2007) as the force behind the full—yet subtle—expression of liberal politics of the 19th century. As anticipated by Osborne and Rose, such emerging diagram based on "telematics and informatics [and] computerized models of flows of power, water, traffic… is to allow life in the city to be governed in a new way" (1999: 750). Here, entangled with metaphors around "configuring and reconfiguring, flexibility, multiplicity, speed, virtuality [and] simulation… [the city] marks out a concrete field of localization and concentration where the exercise of government appears potentially possible" (1999: 749). The Urban OS, a practical and material manifestation of the 'smart' or 'computational' city, embeds new ways of thinking about the urban and new rationalities underpinning its governing. Our concern is now to understand how the city is reconfigured as a space of agility, efficiency, modularity, flexibility and configurability through re-assembled digital/material flows and new logics of control.

Urban Operating Systems as an emerging urban diagram

In the context of contemporary smart city narratives, the definition of an urban market for IT applications rests on narratives establishing analogies between corporate and urban contexts. With an estimated value of US$1,265.85 billion in 2019 for smart city technologies (Transparency Market Research, 2014), the urban market has increasingly emerged as a strategic priority for IT corporates (Paroutis et al., 2014). Urban OS, distinct from the use of software and ERP systems in municipalities given their outward facing aim, provide of a set of techniques and capacities for bringing together urban infrastructures, urban services and everyday life that often sit outside direct municipal control. City functions that are usually kept separate and loosely coupled (e.g. waste collection, transport provision, energy services, security and emergency response) are reconfigured into a more integrated and tightly coupled relationship. In transmuting the logistical and corporate rationality of the ERP into an urban product, a collapse between corporate and urban problematics is required. IBM's *Intelligent Operations Center for Smarter Cities Administration Guide,* for example, identifies fragmentation and dispersal of control, lack of real-time updates, system isolation and inability to generate insights from existing data as the key problems of the city. In this context, the Urban OS "addresses these and many other challenging issues by providing insight, management, and oversight capabilities for any city or enterprise (as they both face many of the same issues)" (IBM, 2012: 3). If the problem of a city, just like that of business, is one of fragmentation of functions and disconnected information, then the city can become amenable to software/hardware packages that are able to develop interoperability, interconnection and integration. What is the vision of the city—governing rationalities and regimes of control—that is being created through these digital analogies and their corresponding diagrams of power?

We argue that the Urban OS establishes a diagrammatic form of relationship with the city. In a similar way that the ERP re-shapes the corporation, the Urban OS attempts to see into urban futures by imitating a horizon of thought. It functions as a vectoring tool that tests or suggests new connections whilst extending the possibilities of thought (Deleuze and Guattari, 1988). This section examines how the city is being diagrammed, through an inquiry into the system manuals and promotional materials of Urban OS. We focus on the illustrations associated with five archetypical framings found within this literature, taken from Hitachi's *Vision for Smart Cities* (2013: 14 and 21), Microsoft's *CityNext Technical Reference Model Overview* (2013: 3 and 7) and IBM's *Intelligent Operations Center for Smarter Cities Administration Guide* (2012: 15). These five archetypical forms combine to illustrate the Urban OS as an emerging urban diagram, transmuting a corporate informational diagrammatic of control to the city.

The cybernetic city – a system of systems

Marketing material for the Urban OS shows the city as system of systems (Figure 1); a total bounded entity that renders the city as a set of ordered relationships. It speaks of interconnected complexity, yet simplified and rendered manageable. Using metaphors from technology and biology—but also cybernetics—by combining human and technology systems (Light, 2002, 2003), this archetypical image calls upon imaginaries of interconnection, integration and intelligence. The city is constituted through a multiplicity of separate systems (e.g. water, energy, schools and buildings) feeding different urban domains (e.g. agriculture, commerce, industry, tourism and energy). The Urban OS is conceived as a platform able to make connections between what is currently separate. Both the software and hardware components of the Urban OS sit at the center, making connectivity possible and echoing analyses of smart city narratives as obligatory passage points for the technological urban (Söderström et al., 2014; see also Callon, 1986). Most importantly, data collection, storage and flow—also occupying a central stage—is positioned as the primary mode and language for interoperability.

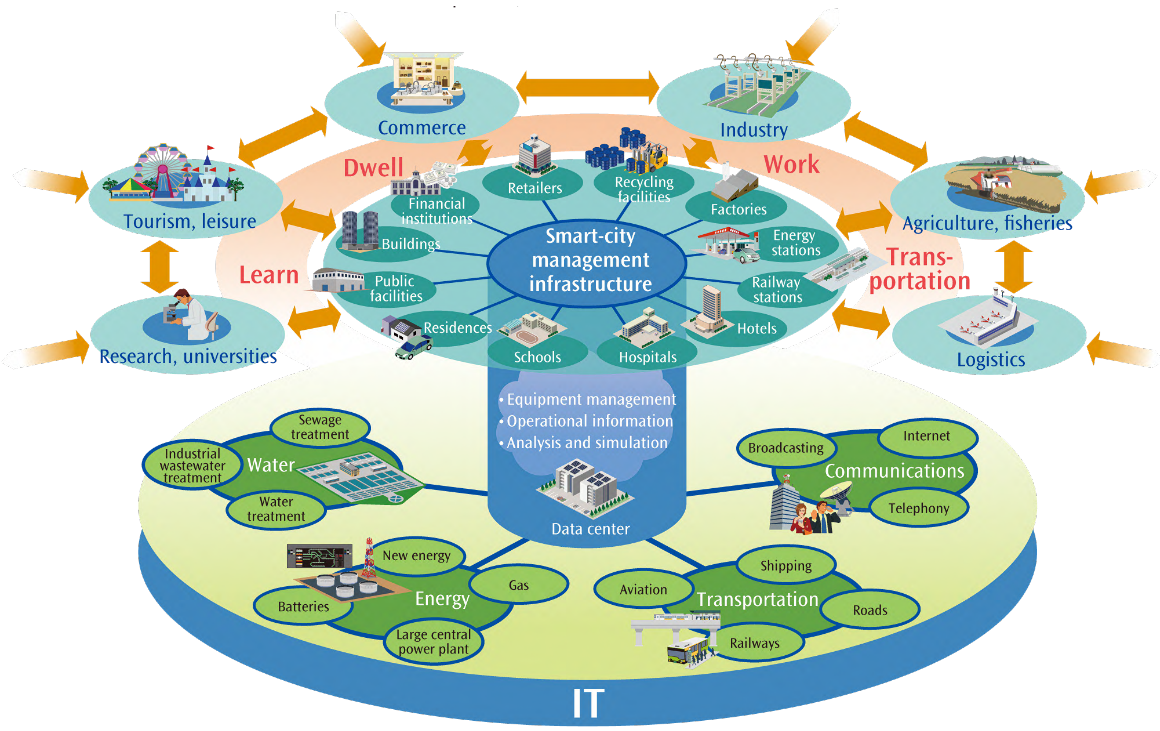

Figure 1 - the cybernetic city: “Relationships between smart cities and IT” (Hitachi 2013: 14)

The city as a system of systems operates through techniques of classification, resulting in the provision of a system for organization and in this way, a framing for an objective reality. This involves the development of typologies, the establishment of hierarchies and a broad mapping of connections between these components. Such concern for the interconnectedness of currently segmented function is motivated by the desire to render the entire system of internal relations predictable and controllable. The emphasis on classification also has an ontological function, by determining components and establishing a set of relationships, thus creating entities and boundaries. Beyond a proposal for integration, the framing of the city as a system of systems is concerned with dissecting the complex nature of the city into steps and then foregrounding the manageability of the city/organization. It is less about the adaptability of the city to external contingencies than to build a detailed map for organizational action and control. Yet, it is difficult to distinguish between the form of organization proposed and the city itself, two aspects that collapse into each other.

The city as (disconnected) strata

Urban OS conceptualize the city as a series of homogenous and sorted layers, typically structured around a set of domains of urban life such as the social and or economic, technological/infrastructural, governmental and environmental (Figure 2). Categorization and taxonomy are important here, as the resulting model aspires for functional simplification. These layers are composed of relatively homogenous, sorted and ordered components that are the product of earlier phases of sorting and cataloguing. A further presumption is that these layers are functionally self-contained, discrete and poorly coordinated. Such layering process becomes critical in providing the real or material city for 'smart'—rationalities, techniques and technologies—to work with, as new Urban OS infrastructures are coupled above or below urban domains.

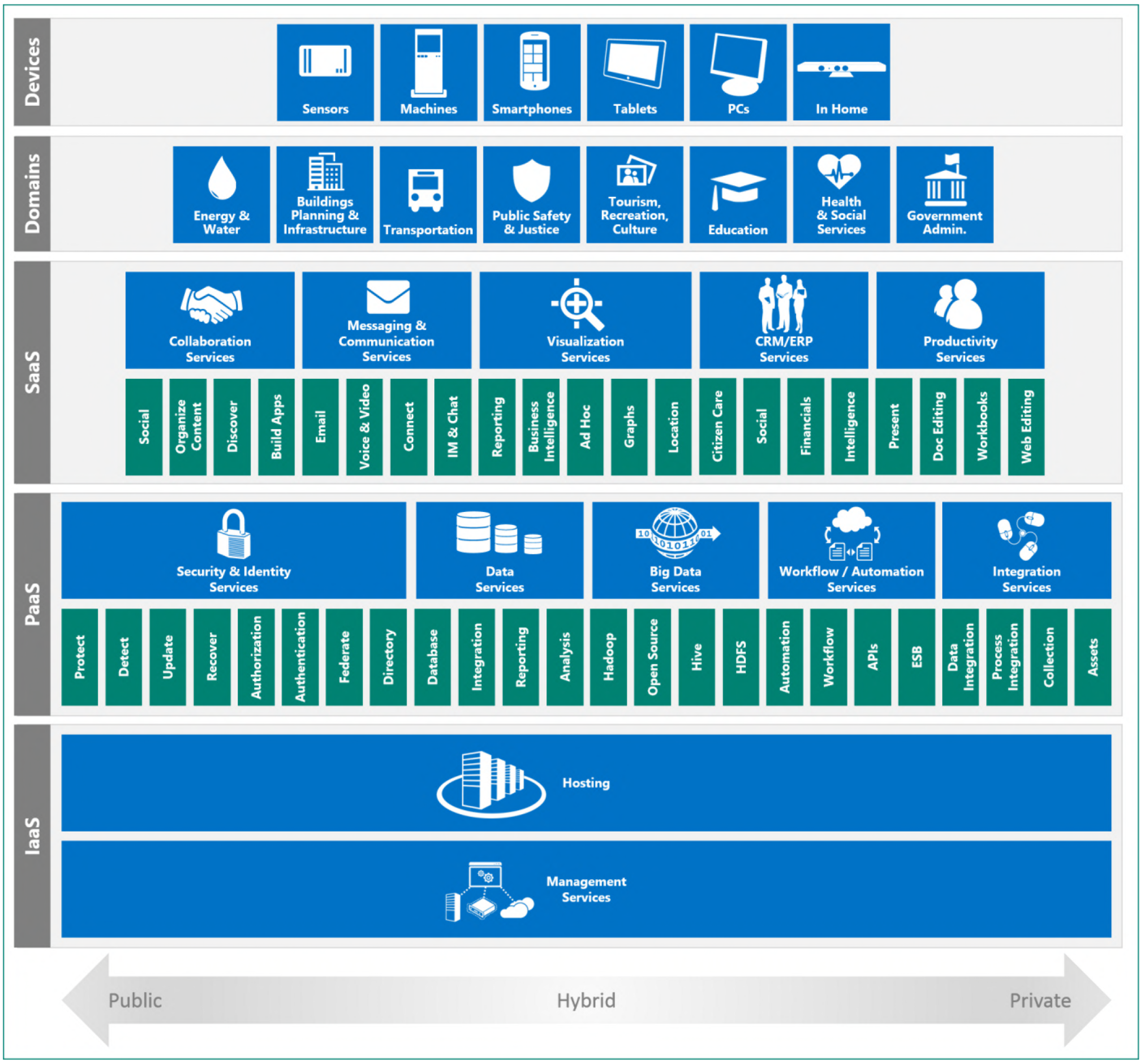

Figure 2 - the city as (disconnected) strata: "CityNext capabilities across devices, domains and service layers" (Microsoft, 2013: 3)

This horizontal understanding of the city as a collection of overlapping layers is akin to what Deleuze refers to as 'strata': an assembly of consistent homogeneous elements. Strata, as a diagrammatic formation playing a role in the genesis of form and thus creating reality, stands in direct opposition to the 'rhizome', which is a non-hierarchical form more amenable to hybridization (Deleuze and Guattari, 1988). Such horizontal strata is highly dependent on sorting machines, devices that take a multiplicity of objects and their heterogeneous qualities and distributes them into uniform layers (De Landa 2000). Thus, Urban OS—in effect a sorting machine—constitute the city into a set of disconnected, separate, closed, loosely coupled layers. Each layer is configured and sorted according to particular techniques and history. It enables a link back to earlier regimes of control, suggesting that a form of integration across layers is needed.

Just like the cybernetic city, the city as (disconnected) strata operates through classification and taxonomy, not only providing an order but, beyond that, establishing an ontology: categories, attributes and sub-categories are created, and in doing so, they create their very object of intervention. Drawing inspiration from binary models that assign attributes to objects and establish differentiation through the presence or absence of such attributes, local specificity is lost. An homogenizing drive (via modelling systems) takes over. It is possible to link this archetypical image with a form of software programming known as object oriented design, echoing the way in which ERP systems configure business organizations (Kallinikos, 2007; 2011). As practices around object oriented design imagine the urban, control rests on a managed form of analytical fragmentation: objects (e.g. hospitals) which have discrete subcategories (e.g. clinical specialisms); clinical specialisms which have doctors; doctors with certain skills; and so on, until the city is broken down into its most fundamental components. Thinking reality as hierarchically organised 'stack'—a popular way of conceptualizing protocols, data formats and software amongst computer engineers—ensures that each layer handles "the same base information simultaneously, but at different levels of abstraction" (Straube, forthcoming: 9). Extrapolating 'stack thinking' to the city means that, in a highly hierarchical fashion, different urban systems (such as health, transport, energy or waste) are modelled and understood in the same way. But critically, "the stack is not simply an enumeration of different elements that constitute a whole. Instead, each of its layers is an articulation of a specific logic and already encompasses the entire system" (Straube, 2016: 11).

The city as (disconnected) strata, operating as a piloting device, introduces new players and establishes new hierarchies, with the very materiality of IT systems and/or devices figuring as foundational layers. In Figure 2, these are represented by the notions of infrastructure as a service (IaaS), security, data and workflow platforms as a service (PaaS) and software as a service (SaaS). The city is, in essence, subject to a form of modularization and cataloguing according to a set of pre-defined criteria that are then reflected in the nature of the software system. In a way, in order to apply these systems in an urban context, you have to work upon the city through these forms of standardization, modularization and classification. This is a process of breaking down the city into a multiplicity of objects and components. In a hierarchical manner, this unbundling of the city occurs in a way that is predefined by the nature of the software itself: through the data fields, data sets and types of services that are involved in digital systems. Yet, within the IT industry, there is concern that there are no common standards for classifying the components of different urban layers. As companies such as CISCO have pointed out—in a way that compares their city building task to the configuration of scientific knowledge of the Enlightenment—"subjects such as botany have had classification systems for more than 100 years… However, there is no equivalent agreed-upon taxonomy for city information" (CISCO, 2012: 7).

The urban CPU

Smart urbanism is also at the forefront of the formation of new urban ecosystems, playing a critical role in reassembling local connections between the different layers of the city. The Urban OS is a way of organizing interconnections through the development and positioning of new centers, this time in 'rhizomatic' rather than 'stratified' manners (Figure 3). In this reconfiguration, a special class of "operators, or intercalculatory elements, is needed to effect this interlock" (De Landa, 2000: 39). As Figure 3 suggests, these emerging techno-social ecosystems are organized around the obligatory passage point in the middle of the figure—the core, centre or platform around which the wider ecosystem is organized. This archetypical image not only provides the overall system architecture showing the critical role of the Urban OS in assembling connections between software and hardware, but also establishes a form of relation to the internal governance of the city and the virtual and physical networks outside such governing nodes. It suggests a form of interlayering of networks, interfaces, data integration that are assembled together in a new control system that sits across/above/within the layers of the city. Disconnected and separate layers are now potentially linked with new analytic and control functions.

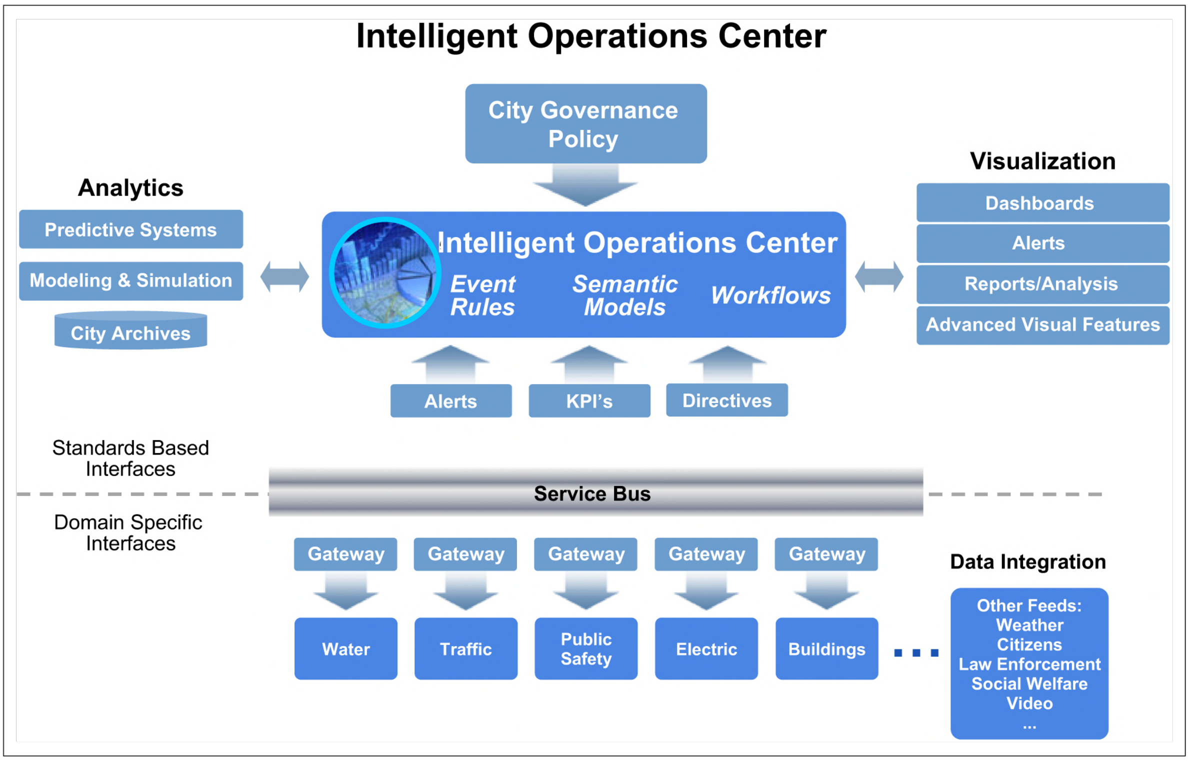

Figure 3 - the urban CPU: "IBM Intelligent Operations Center architecture" (IBM, 2013: 15)

The particular example presented in Figure 3 positions city governance as a form of input into an Urban OS or operations centre. It breaks the city down into a series of event rules, a set of semantic models and workflows that are supported by key performance indicators, directives and alerts. Providing a tangible platform to recent urban big data debates (Kitchin, 2014; Klauser and Albrechtslund, 2014; Townsend, 2015), this characterization of the Urban OS brings together forms of analytics (data analytics, predictive systems, modeling and simulation) that are based on a standardized set of city archives (for example, a municipal open data platform). The analytics generated by such urban big data are then related to a set of visualizations, such as dashboards and alerts (see Kitchin et al., 2015). Such scheme, through a 'service bus' (a term used in software design to refer to communication interfaces between mutually interacting software applications) and digital gateways aimed at data integration, acts upon the city, on buildings, electric networks, public safety, traffic, water, etcetera. It both represents and brings into existence a model for the Urban OS to connect the core operating system to a set of other urban capacities, through specialist software and smaller companies or communities of knowledge with particular expertise in infrastructure. The hardware centric nature of the terminology used in Figure 3 suggests analogies between the city and a computer. A language that emphasizes control nodes, data flows, memories, gateways and interfaces, with key analytical processing centers surrounded by ports and monitors, reframes the urban: like a personal computer, this understanding of the urban is based on visual outcomes and displays (a screen or monitor, or in the case of the smart city, dashboards and alerts) and specifies external memory as well as interfaces, providing boundaries as well as forms of interaction with an outside world.

Urban data flows: circular autarky

Central to Urban OS operations are circular and closed processes of data acquisition, analysis and action (Figure 4). The key premise is the establishment of a single data set—sometimes referred to within the industry as the 'golden record' or the 'single version of the truth' (IBM, 2009)—that feeds the operating system. Through the modularization of layers examined earlier, the Urban OS is able to predefine and standardize inputs and outputs for any urban context and process. The aspiration, referred to in Figure 4 as 'science in action', is the creation of a closed loop of data collection, analytics, insights and action. It is a flow that connects public and private clouds, through city sensors, mobile and desk based computer devices, data management and public data markets. However, it is worth asking, within such tight understanding of data flows and knowledge acquisition, what forms of knowledge and expertise are squeezed out?

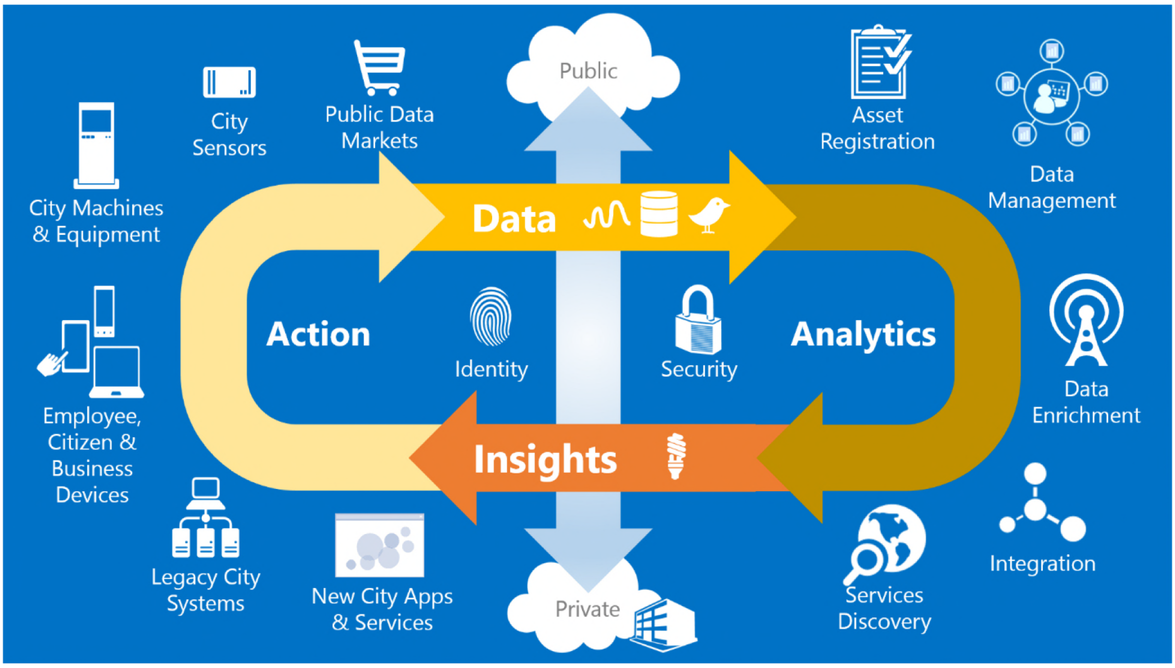

Figure 4 - data flows in the city and circular autarky: "A wealth of city data fuels a continuous cycle of insight and action" (Microsoft, 2013: 7)

The Urban OS presumes a mode of information flows that is inward looking, exclusionary in terms of the social interests involved, and largely depoliticized. The assumptions and presumptions of the Urban OS focus data within the system itself and tend to ignore others forms of knowledge and expertise that lay outside the system, particularly, outside of the formal lexicons of planners and modelers—as such, as city with only limited learning capacities (c.f. McFarlane, 2011). A potential implication of this urban epistemology is to exclude (voices, priorities, stakeholders, viewpoints, etcetera), a process embedded in techniques of automation. Characterized by the primacy of data over other priorities, the Urban OS becomes an internalized and technocratic system that is not open to challenges or other processes of innovation and creativity. This is a closed world, characterized by forms of closure and self-referential behavior shaped by software configurations. Urban processes, agents or stakeholders, in order to be part of *analytics*, *insight* and *action*, have to be inside the presumptions of the software system itself.

Dis- and re-assembling urban circulations

The city, already disassembled in layers and data, is then selectively re-assembled through an attempt to construct a coherent aggregate. These are highly selective processes that dis- and re-assemble on the basis of the categories and presuppositions of the Urban OS. It involves a suggestion that flows and other aspects of urban life can be un- and re-bundled to achieve flexibility, efficiency and optimization. Figure 5 provides a simple but powerful illustration of re-assembly in the Urban OS. It is powerful precisely due to its simplicity, where colored blocks with no particular reference to either the city or the computing world are re-aggregated by a dashed line, recombining towards the fulfillment of a new urban function. Or, as Hitachi puts it, "daily-life services infrastructure can be broken down (disassembled) into the various different services provided by the city… the disassembly and reassembly of the daily-life services infrastructure as one way to create new value for smart cities" (2013: 23).

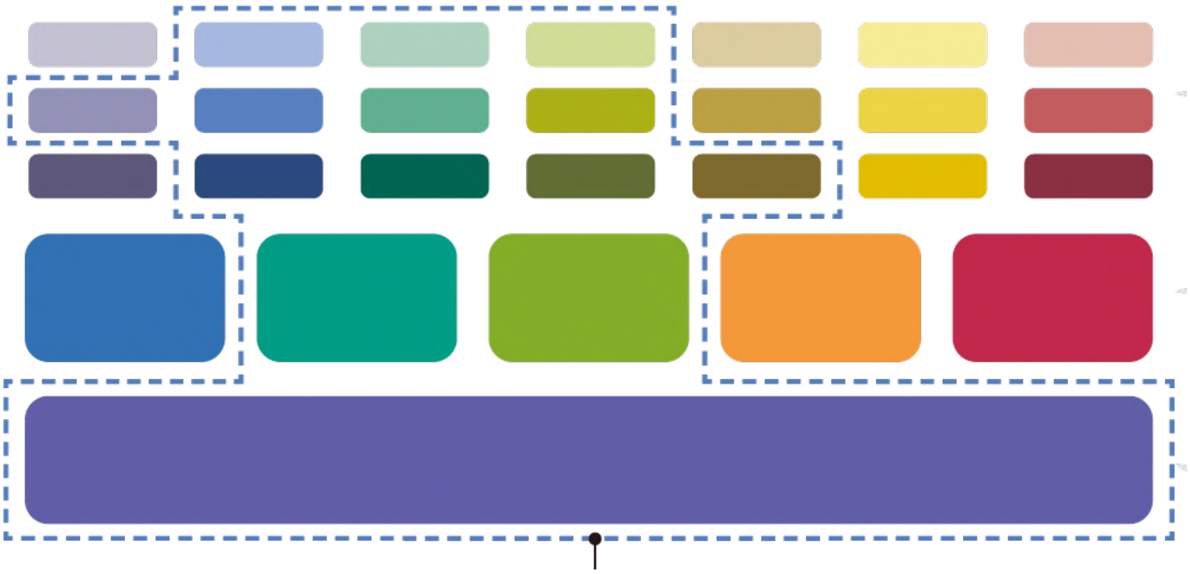

Figure 5 - dis- and re-assembling urban circulations: "Design Framework - Example combination for a particular urban project" (Hitachi, 2013: 21)

Whilst incorporating diversity and the ability to develop relationships, the need for modularity, interoperability and transferability across systems—and cities—revokes specificity. Explicitly referring to processes of un-bundling and re-bundling, the Urban OS relies on techniques of modularization and categorization to claim a unique capacity to reimagine and reconfigure the urban. It is claimed that these 'customized packages of service delivery' can serve the unique circumstances of individual cities. Yet, local particularities can enter the system only in the form of data. By combining data sets, the city can be reconfigured in a multiplicity of ways. The Urban OS, often as a single large-scale off-the-shelf software package (albeit not exclusively), works upon the comprehensive design of items, relations and transactions that can be molded into a management model that could be brought to bear on any organization. This process of disaggregation is made possible by reconfiguring the components of the city into data blocks that can later on be worked with, recombined or reprocessed. The city is laid bare—disassembled into its constituent parts as defined by the categories used by the

Urban OS—and then unproblematically reassembled into new more desirable configurations and flows. Urban processes, now distilled into immaterial data packages, can be reconfigured in a variety of ways. From this perspective, the Urban OS operates through the technique of digitalization. Thus, the development of 'strata' in the Urban OS is largely an abstract process, where converting components into data equates the formation of a common language. It requires an abstracted short hand of the city that is decontextualized from particular contexts.

Conclusions— Governing through Urban OS?

Computational logics have become ubiquitous, pervading every aspect of contemporary life. They are used in every institution, and are involved in every product and service we interact with. We have focused on a particular form of computational product that has been transmuted into the urban context—the Urban Operating Systems (Urban OS). We argue for the need to critically examine the rhetoric and rationalities of emerging urban computation logics, and how these resonate with (and inhibit) established structures of urban control. This has been investigated in two ways. First, by examining production of computational logics, the rationalities underpinning these systems and the claims of the superiority of computation as a form of organizing society. Second, by examining the transmutation of computational logics from the corporate to the urban context, inquiring into the ways in which the Urban OS seeks to dis- and re-assemble the city into new more flexible configurations.

In this article we have foregrounded the critical need to place Urban OS within a longer-term historical context of applying information technologies and computational logics to urban problems. In the US, during the 1960s and 70s, new techniques and technologies of communications, control and computing were explicitly reoriented from the military and defense sectors and applied in multiple urban contexts. This cybernetic turn that viewed the city as a system of systems made comparisons between cities and both technological/communication systems and ecological concepts in order to achieve balance and homeostasis. These initial efforts towards the computational city were relatively short lived, and their failure revealed important limits in the applications of computing technologies and techniques to urban issues. Yet these, largely hidden, historical antecedents of 'smart' and the organizational origins of ERP in the corporate enterprise sector help us understand how Urban OS may reshape the governing of the city. Following the failures to embed communication and computing technologies in cities in the cybernetic turn of the 1960s and 1970s, the IT sector focused on the corporate sector as a context for developing and selling integrated systems. Critical information, organization and management studies provide important insights into the ways in which such packages enforced the simplification of decision making into functional steps and integration through standardized operating procedures of multiple corporate functions to fit the premises and assumptions of the software packages. It is important to place today's shift to 'smart urbanism' in this wider context in order to understand whether the limits and tensions identified in either the failed applications of urban cybernetics or the corporate manifestations of the ERP are still relevant or whether new Urban OS offer different capacities and functionality.

We have also focused on five archetypal framings of how Urban OS envision the city as an object, problem, solution, means of action and reconfigured flow relationships. The Urban OS, the inheritor of earlier—military inspired—waves of urban computing and a product of the interface between corporate, logistics and IT thinking, represents an attempt to construct new rationalities for a regime of control. This emerging regime is based on functional simplification and heterogeneous reintegration mediated through computational ecosystems that embody important presumptions about what constitutes appropriate knowledge and forms of decision-making. The diagrammatic logics of the Urban OS signal towards new ways of imagining the city, establishing urban meaning and opening or closing modes of inclusion. Urban OS frames (and effectively mediates) urban circulations, through the obligatory passage point of computing technology with an emphasis on re-engineering, agility, modularity, flexibility, configurability, security, etc, as urban flows are increasingly viewed as an efficient logistical enterprise.

We have shown how rationalities and presumptions originally developed in the military and defense sectors and then transferred to the corporate sector via ERP systems are embedded in the extensive bricolage of smart urban systems mobilised as Urban OS. Such rationalities, analyzed through five emblematic framings of an emerging computational urbanism, view the city as an experimental site for the transmutation of corporate integrated information systems into an urban context. Our analysis sees an emerging computational urban diagram operating beyond simple representation, playing a role in creating a new type of reality (Deleuze and Guattari, 1988). In this sense the Urban OS as an urban diagram is both a design for the city and a template for its operations. The Urban OS reduces the complexity of the city through simplification alongside both packaging data and data packages, and then selectively reassembles these packages to generate new sets of relationships.

There are three sets of future research challenges that are raised by these developments. First, the need to understand how the city has emerged as a critical site for commercial/societal experimentation through urban test beds (c.f. Evans et al., 2016), drawing attention to a logic of control that powerfully mirrors that of the corporate enterprise and the extent to which this is resisted or modified. Urban OS see the city as an enterprise, analyze and audit it as an enterprise, and develop responses as an enterprise. They highlight the potential of a style of informational diagrammatic of control that is being transmuted from the corporate sector by being revised, developed and tested in different urban contexts through numerous and diverse smart city programmes. Mirroring a business, the city is envisioned as a simplified and integrated space of functionality, capable of constant re-engineering and characterized by modularity and configurability to assess efficiency and achieve optimization. Second, further work is required on how this regime of control accelerates and intensifies existing and multiple subjectivities of self-control and responsibility as active informed citizens. Citizens are using technology to self-govern (e.g. health monitoring; see Wilson, 2011), responding to signals and messages, feeding broader systems with data (Gabrys, 2014) and being entrepreneurial with it (e.g. via hackathons). Policy makers are also required to become 'smart'—respond to signals more quickly, utilise new sources of data, and develop engagement modes to work with ICT players. Finally, there is need for further work to understand how this new diagrammatic reshapes and interfaces with logics of circulatory and resource flow control. For instance what does it mean to apply logic's of control from logistics and corporate enterprises to urban infrastructural networks and urban ecological flows. Is this a logic in which the city, as an audited enterprise, can develop more efficient and cost effective urban services (business reengineering/cuts); respond quickly to emergences (business continuity); develop more reliable and secure infrastructures (logistics/resilience); or identify new areas of profit/return by identifying new synergies and business opportunities (data mining/economic development)?

The critical issue our analysis raises is the extent to which the forms of knowledge and rationalities that underpin the computational logic of the Urban OS also then provide the foundational underpinnings of the wider set of technologies and products that constitute both the smart city and a new form of computational urbanism. Although the IT sector has had many difficulties in selling a total unified and standardized Urban OS package to a single city, the product itself has been broken down into a series of different computational ecosystems as stand-alone products such as dashboards, intelligent control rooms, open data platforms, sensing platforms and predictive analytics systems, amongst others. These ecosystems are extracted from the Urban OS and then reformulated selectively as standalone products, that operate through broader networks of knowledge and technology—civic hackers, app developers, urban technologists, a multiplicity of data sources and other forms of urban knowledge and expertise. Transcending bounded corporate software systems reconfigured towards the urban market (such as ERP, SCADA or other content management systems), the Urban OS is positioned by a multiplicity of stakeholders to function on account of its systemic operationalization of the urban world. This form of smart urbanism rests on the unbundled elements of the unified and idealised Urban OS understood as the totality of the city's systems (somehow represented in the 'urban CPU' and the circular 'data flows in the city' illustrations (Figures 3 and 4)), which then underpins particular smart city applications and processes. It is our view that the Urban OS is being constituted in a multiplicity of ways beyond the simple repurposing of an ERP system towards 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 interact with, complement, build upon, reinterpret and transform smart city systems in ways that can be considered to have broader systemic qualities.

In this sense, the Urban OS is a metropolitan socio-technical process that transcends its makers, shaping the city in systemic ways whilst advancing a particular epistemology of the urban. Using the language of Easterling (2013), the protocols, routines, schedules and choices embedded in smart urban technologies transcend a single software package, shaping the politics of the emerging forms of smart urbanization. We argue therefore that it is critically important to understand the systemic qualities of the forms of computational logic that underpin the Urban OS and the ways in which this, as an emerging computational urbanism, is transmuted and reapplied towards governing a much wider set of urban processes. Beyond simple dichotomies that contrast bottom-up and top-down technological configurations of the city, the progressive potential of the smart city is likely to emerge only through processes that subject its modes of calculation to scrutiny and question the very epistemological underpinnings of computational urbanisms.

References

Amstutz AE. (1968) *City Management - A Problem in Systems Analysis*. Sloan School of Management – MIT, Cambridge, MA.

Batty M (2013) *The New Science of Cities*. Cambridge MA, MIT Press.

Barns S (2016) Mine your data: open data, digital strategies and entrepreneurial governance by code. *Urban Geography* 37(4): 554-571.

BBC (2011) Smart cities get their own operating system [online]. Available from http://www.bbc.co.uk/news/technology-15109403.

Callon M. (1986) Some elements of a sociology of translation. In J. Law (ed) *Power, action and belief: A new sociology of knowledge.* London, Routledge: 196-223.

Callon M. (1987) Society in the making: the study of technology as a tool for sociological analysis. In: Bijker WE, Hughes TP and Pinch T (eds) *The social construction of technological systems.* Cambridge MA, MIT Press, 83-103.

CISCO. (2012) Smart City Framework: A Systematic Process for Enabling Smart+Connected Communities. In: Cisco Internet Business Solutions Group (IBSG) / G. Falconer and S. Mitchell (ed).

Cowan D. (2014) *The Deadly Life of Logistics.* Minneapolis, University of Minnesota Press.

De Landa M. (2000) Deleuze, diagrams, and the genesis of form. *Amerikastudien/American Studies* 45(1): 33-41.

De Waal M. (2011) The Ideas and Ideals in Urban Media. In Foth, M. et al (eds) *From Social Butterfly to Engaged Citizen*, Cambridge MIT Press: 5-17.

Deleuze G. (1988 [2006]) *Foucault,* London: Continuum.

Deleuze G and Guattari F. (1988) *A thousand plateaus: Capitalism and schizophrenia*: Bloomsbury Publishing.

Easterling K. (2014) *Extrastatecraft: The Power of Infrastructure Space*, London: Verso.

Evans J, Karvonen A and Raven R (eds) (2016) *The Experimental City*, London: Routledge.

Farish (2010) *The Contours of America's Cols War*. Minneapolis, University of Minnesota Press.

Forrester JD. (1961). *Industrial Dynamics*. Waltham MA, Pegasus Communications.

Forrester JD. (1969) *Urban Dynamics*. Cambridge MA, The MIT Press.

Forrester JD. (1975) *Collected Papers*. Cambridge MA, Wright-Allen.

Foth M. (2009) Handbook of research on urban informatics the practice and promise of the real-time city. Hershey, PA: Information Science Reference - IGI Global, 470.

Foucault M. (1977 [1995]) *Discipline and Punishment,* New York: Vintage.

Foucault M. (2009) *Security, territory, population : lectures at the Collège de France, 1977-78,* New York: St Martins Press.

Gabrys J. (2014) Programming environments: environmentality and citizen sensing in the smart city. *Environment and Planning D* 32(1): 30-48.

Galloway A. (2004) Intimations of everyday life: Ubiquitous computing and the city. *Cultural Studies* 18: 384-408.

Golumbia, D. (2000) *The Cultural Logic of Computation*, Cambridge, MA. Harvard University Press.

Graham S. (1999) Towards urban cyberspace planning: grounding the global through urban telematics policy and planning. In J. Downey and J. McGuigan (eds) *Technocities. London, Sage*, 9-33.

Graham S. (2004) Postmortem city: Towards an urban geopolitics. *City* 8(2): 165-196.

Graham S and Marvin S. (1996) *Telecommunications and the city,* London: Routledge.

Halpern O. (2014) *Beautiful Data: A History of Vision and Reason since 1945.* Durham NC, Duke University Press.

Halpern O, LeCavalier J, Calvillo N, et al. (2013) Test-Bed Urbanism. *Public Culture* 25: 272-306.

Harris B. (1966) The uses of theory in the simulation of urban phenomena. *Journal of the American Institute of Planners* 32: 258-273.

Hitachi. (2013) *Hitachi's Vision for Smart Cities*. Available at: www.hitachi.com/products/smartcity/download/pdf/whitepaper.pdf.

IBM. (2009) Case Study - The City of Albuquerque: from heterogeneous data sources to public service visionary.

IBM. (2012) *Intelligent Operations Center for Smarter Cities Administration Guide*. Available at: http://www.redbooks.ibm.com/redbooks/pdfs/sg248061.pdf.

Jacobs FR. (2007) Enterprise resource planning (ERP)—A brief history. *Journal of Operations Management* 25(2): 357-363.

Joyce P. (2003) *The rule of freedom: liberalism and the modern city*: Verso Books.

Kallinikos J. (2007) *The Consequences of Information.* Cheltenham: Edward Elgar Publishing.

Kallinikos J. (2011) *Governing Through Technology: Information artefacts and social practice.* Basingstoke: Palgrave Macmillan.

Kitchin R. (2014) The real-time city? Big data and smart urbanism. *GeoJournal* 79: 1-14.

Kitchin R, Laurialt, T and McAardle, G. (2015) Knowing and gverning cities through urban indicators, city benchmarking, and real-time dashboards. *Regional Studies, Regional Science* 2(1): 6-28.

Kitchin R and Dodge M. (2011) *Code/Space,* Cambridge, Massachusetts: MIT Press.

Klauser F, Paasche T and Söderström O. (2014) Michel Foucault and the smart city: power dynamics inherent in contemporary governing through code. *Environment and Planning D* 32(5): 869-885.

Klauser FR and Albrechtslund A. (2014) From self-tracking to smart urban infrastructures: towards an interdisciplinary research agenda on Big Data. *Surveillance & Society* 12(2): 273-286.

Knoespel KJ (2001) Diagrams as Piloting Devices in the Philosophy of Gilles Deleuze. *Théorie – Littérature – Enseignement* 19: 145-165.

Light JS. (2002) Urban security from warfare to welfare. *International Journal of Urban and Regional Research* 26(3): 607-613.

Light JS. (2003) *From warfare to welfare: Defense intellectuals and urban problems in Cold War America*. Baltimore, JHU Press.

Living Plan IT (n.d.) PlanIT UOS [online]. Available at http://www.living-planit.com/ (accessed 1 June 21016).

Luque-Ayala A and Marvin S. (2015) Developing a Critical Understanding of Smart Urbanism? *Urban Studies* 52(12): 2105–2116.

Luque-Ayala A and Marvin S. (2016) The Maintenace of Urban Circulation: An operational logic of infrastructural control. *Environment and Planning D* 34(2): 191–208.

Mabert VA. (2007) The early road to material requirements planning. *Journal of Operations Management* 25: 346-356.

Marvin S, Luque-Ayala A and McFarlane C. (eds) (2016) *Smart Urbanism: Utopian Vision or False Dawn?,* London: Routledge.

McFarlane C. (2011) *Learning the City: Knowledge and Translocal Assemblage,* Oxford: Wiley-Blackwell.

Meier RL. (1962) *A Communications Theory of Urban Growth*. Cambridge MA, MIT Press.

Meier RL and Duke RD. (1966) Gaming Simulation for Urban Planning. *Journal of the American Institute of Planners* 32: 3-17.

Microsoft. (2013) *Microsoft CityNext Technical Reference Model Overview*. Available at: http://www.microsoft.com/en-us/citynext/resources.aspx.

Osborne T and Rose N. (1999) Governing cities: notes on the spatialisation of virtue. *Environment and Planning D* 17(6): 737-760.

Otter C. (2007) Making Liberal Objects: British techno-social relations 1800–1900. *Cultural Studies* 21(4-5): 570-590.

Paroutis S, Bennett M and Heracleous L. (2014) A strategic view on smart city technology: The case of IBM Smarter Cities during a recession. *Technological Forecasting and Social Change* 89: 262-272.

Rabinow P. (1995) *French modern: norms and forms of the social environment*: University of Chicago Press.

Rashid MA, Hossain L and Patrick JD. (2002) The evolution of ERP systems: A historical perspective. In L. Hossain et al. (eds) *Enterprise Resource Planning: Global opportunities & challenges.* London, Idea Group Publishing, 1-16.

Rossiter (2012), Materialities of Software Logistics, Labour, Infrastructure. *Australasian Association for Digital Humanities (Digital Culture and Society conference)*, Australian National University, Canberra, 28-30 March. Available at http://aa-dh.org/conference

Söderström O, Paasche T and Klauser F. (2014) Smart cities as corporate storytelling. *City* 18(3): 307-320.

Straube T (forthcoming) Stacked Spaces: Mapping Digital Infrastructures. *Big Data and Society*.

Taylor PJ. (1988) Technocratic optimism, HT Odum, and the partial transformation of ecological metaphor after World War II. *Journal of the History of Biology* 21: 213-244.

Taylor PJ and Blum AS. (1991) Ecosystem as circuits: diagrams and the limits of physical analogies. *Biology and Philosophy* 6: 275-294.

Townsend AM. (2000) Life in the real-time city: Mobile telephones and urban metabolism. *Journal of Urban Technology* 7(2): 85–104.

Townsend AM. (2015) Cities of Data: Examining the New Urban Science. *Public Culture* 27 (2-76): 201-212.

Transparency Market Research. (2014) *Smart Cities Market 2013 – 2019*. Available at: http://www.transparencymarketresearch.com/smart-cities-market.html.

Vanolo A (2010) Smartmentality: The Smart City as Disciplinary Strategy. *Urban Studies* 51(5): 883-898.

Vanderbilt, T. (2002) *Survival City: Adventures Among the Ruins of Atomic America*. Princeton, NJ, Princeton University Press.

Voutsina K, Kallinikos J and Sorensen C. (2007) Codification and Transferability of IT Knowledge. *15 European Conference on Information Systems.* St. Gallen, Switzerland.

Webber M. (1964) *Explorations into urban structure,* Philadelphia: University of Pennsylvania Press.

Wilson MW. (2011) Data matter (s): legitimacy, coding, and qualifications-of-life. *Environment and Planning D* 29(5): 857-872.