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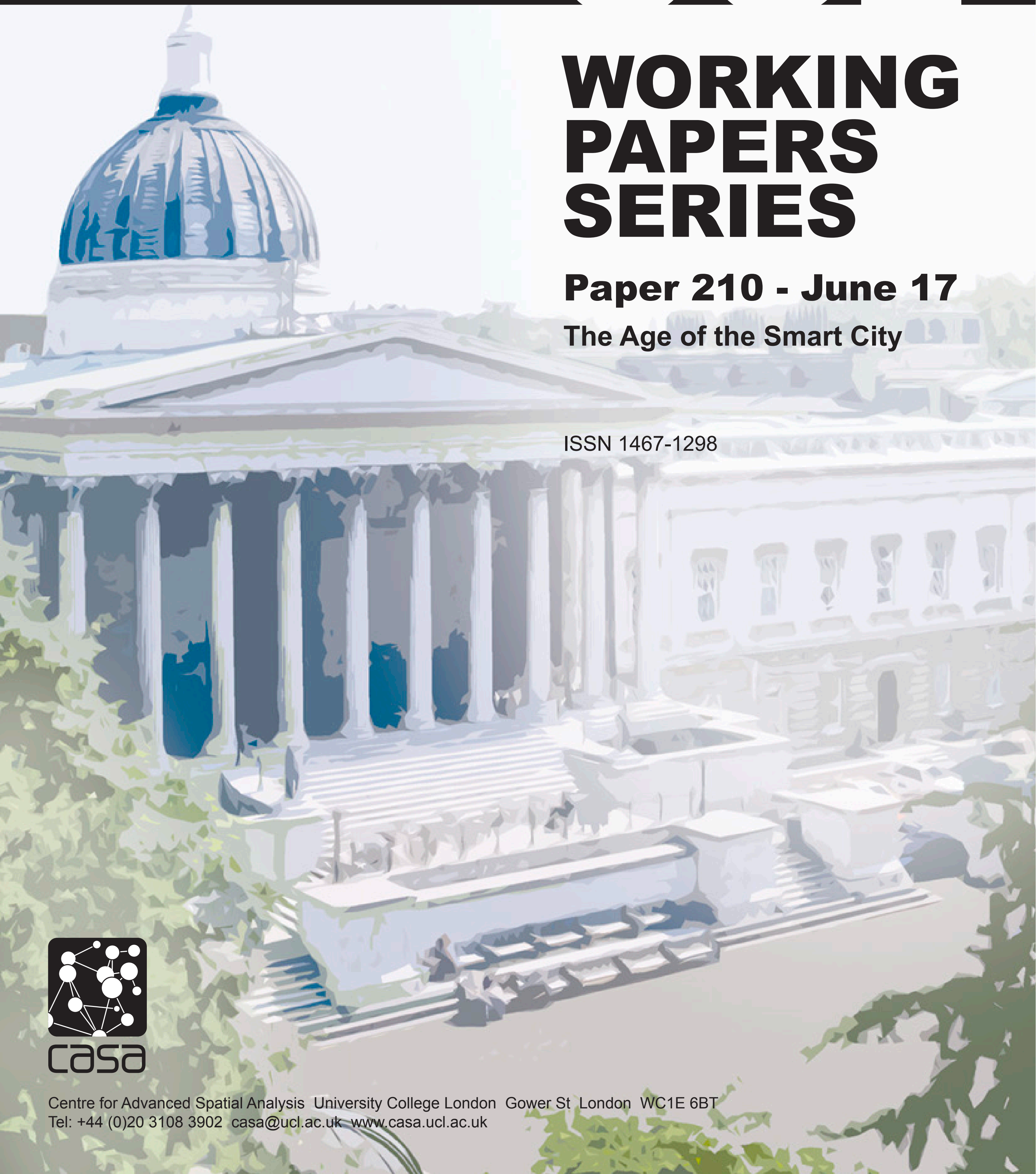

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The Age of the Smart City

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Abstract

The smart cities movement defines a sea change in the way we will live in cities and the way they will function in the 21st century and beyond. Cities are becoming computable and automated at every level of their operation (Batty, 1997) and there is a massive disconnect emerging between their physical form and social process. No one knows where this transition from a world based on energy to one based on information, will end up or when the recent wave of change in economic structure that appeared with the 'big bang' and massive deregulation in the 1980s culminating in the great recession, will work itself out. In this paper, I will sketch the waves that have dominated technological change during the last 250 years, drawing on ideas suggested by Kondratieff and Schumpeter but beginning by focussing on the current wave – the so-called Fifth Kondratieff – which is dominated by the internet. This however is ending and a sixth wave which I call the Age of the Smart City is beginning to encapsulate and underpin everything we do in ways that were first envisaged by the earliest advocates of the universal machine such as Alan Turing (1948) and Vannevar Bush (1945). I will sketch the transition showing how new technologies are being integrated with one another, how the reliance on generating and extracting data, thence information, about the city is changing the way we understand our own spatial behaviours, and how the functions of the future city will be increasingly disconnected from its form. I will then speculate on how relevant the model is to the near and medium term future, and attempt to reconcile Moore's Law and Kurweil's Conjecture about the singularity with a future when we all live in cities and when world population may well lose the growth dynamic that has dominated its history over the last 500 years.

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A Question for Which There is No Answer

In the last fifty years our view of cities has been turned on its head. In the mid 20th century, the predominant analogy was that a city was like a machine, controlled from the top down and functioning in straightforward, ordered terms. Today we consider that cities are more like organisms. Biology has replaced physics as the dominant metaphor. Cities grow from the bottom up, the patterns that we see emerge as the product and outcomes of millions of individually motivated decisions and in so far as there is any top down planning, this is usually short lived, nonetheless designed to solve urban problems at different scales but rarely having lasting continuity. By this we mean that when one looks at a city in its entirety, there are few physical expressions of comprehensive planning that can be seen to manifest themselves physically over long periods of time, decades or centuries. Cities are examples *par excellence* of complexity in the raw involving systems whose forms and functions emerge from the great diversity of activity that characterises them at their most elemental and individual level.

This lack of top down planning has of course been known for a long time. Its association with the problems of rapid growth that industrialisation brought to cities, particularly in the 19th century, was the force that motivated the need for comprehensive institutionalised planning in the first place. But planning added yet another layer to the increasing complexity that has clearly characterised cities since their emergence some 5000 years ago. To an extent through history, cities have become ever more complex. As new technologies are invented and as new forms of our own behaviour often conditioned by increasing wealth, emerge through time, new forms are layered on top of old, disrupting the old but never completely replacing them. The latest wave of these technologies – essentially digital technologies – increasingly enable individuals to engage with one another, to compute and communicate from the bottom up, while becoming instant global citizens with virtual immediate access to the world's resources of data and information.

The focus is thus shifting from a concern primarily with the physical form of cities to questions of how technology is enabling better but less visible communications through automation. This has been occasioned by the rise of the smart cities movement which is really the latest stage in the revolution in information technologies which began with the invention of the digital computer. From its very inception, its founders realised that the computer was a universal machine (Bush, 1945; Turing, 1948). By reducing computation to anything that could be represented in bits (or bytes), computers could be employed to represent some aspect of most phenomena in one form or another, and once they began to converge with the means to communicate such information, computers and computation have spread out everywhere. In one sense, the current manifestation of computers and communications in cities is just the latest phase of a massive diffusion of digital technologies that shows no sign of stopping.

Smart cities essentially enable computers and communications to be embedded in the very fabric of the city[1]. The term smart has long been associated with the fact that computers can be used intelligently for many purposes while the recent wave of devices that enable us to compute as well as remotely access data enables us to demonstrate such smartness through extremely fast access to ever increasing volumes of information. By and large, the kinds of automation that currently characterise the smart city are only intelligent or smart insofar as we, ourselves, use them intelligently. It is ourselves who are potentially smart rather than the devices that we use although there is much speculation that various forms of artificial intelligence combined with our own natural intelligence could augment our behaviours quite dramatically in the near future. It is perhaps soberingly, always in the near future. To date, however, there has been only modest progress, despite the current hype about 'deep learning' and the proliferation of voice-activated devices that enable one to search the web in almost conversational mode.

If we accept the argument that cities are largely built from the bottom up, then the degree to which they might become 'smarter' – as we tend to anthropomorphise their collective behaviour – depends on each and all of us acting intelligently. In this sense, grand plans to make the city smart are no different from any other kinds of grand plan and are likely to be as short-lived. We may not conceive of many of our actions as grand plans but whatever rationality we bring to bear on the city and whatever form we employ it either individually or collectively, ultimately decisions which change the city are rooted in the province of the individual. So our first response to asking the question "what or where is the smartest city?" is that this is a question that has no lasting answer. There may be impressive strategies to automate bits of the city and sometimes these are integrated effectively and carefully: cities such as Barcelona are a case in point. And there are entire new towns which are being built with extensive automation in their various sectors such as Masdar in the UAE or Songdo in South Korea. Yet these are but islands in an encroaching sea of automation. There are also long term strategies for urban automation deeply embedded in national comprehensive planning – Singapore is one of the classic prototypes of such an informated society – but it is the use that is made of such automation that is key to

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[1] Usage of the term smart is peculiarly North American (see Batty et al., 2012). The first reference seems to be some 25 years ago in a book by Gibson, Kozmetsky, and Smilor (1992) ***The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Network***s. Other terms such as intelligent cities, wired cities, virtual cities, information cities, even electric cities have been suggested. In this context, we will use all of these interchangeably to suggest ways of looking at cities where computers are being embedded into their fabric in both hard and soft ways.

working out the extent to which a city is becoming smart. If the essence of urban development is individual action, then a city can only be as smart as its citizens. And in a world where more than half the global population has smart phones, then one might even state that the answer to the question as to the smartest city is the city that has the largest number of smart phones.

It is not possible to answer the question, however, because the very revolution that the smart city movement is part of is a wider diffusion of digital technologies which are increasingly focussed on the individual. As noted above, the smart cities movement is only the latest stage in the all-pervasive revolution in information processing where its most tangible form so far has been the embedding of computer technologies and their control into physical artefacts – buildings, roads and so on. In fact, the miniaturisation of computable devices to the scale of the phone provides a very obvious means of accessing computation remotely while on the move. If most of the smartness that we are associating with the city is accessible and generated by ourselves, then the number of smart phones might superficially seem a good measure of this progress. But to an extent this is a mirage because the devices are mobile. In short, the intelligence shifts around making the smart city even more of a moving target.

Thus the question as to "what and where is the smartest city?" not only has no answer, it is also ill-defined largely because smartness or intelligence is a process not an artefact or product. There may be answers to questions such as "where can one find the greatest concentration of automated public services in cities?", or "where is the most integrated organisational structure for linking different types of energy provision?" or "where is the most effective delivery of online information for transit users?" but these are very specific and even these kinds of achievement depend on local conditions. In some senses, anyone who has access to a smart phone with a web link and has the resources to use it is a member of the smart city, and that will probably mean *"everybody"* by the end of this century. When voice becomes the dominant means of interacting with such technologies, then it is likely that we will no longer speak of the smart city for by then, the smart city will be already firmly woven into the very nature of the information technologies we currently have at our disposal. The nature of the smart city then lies in the very technology that defines it and before we chart any kind of progress, we must diverge to inquire into the nature of that technology and how individualistic it has become.

The Nature of Information Technology

The idea of representing phenomena in elemental either-or chunks such as zero-one, black-white, yes-no, on-off is deeply embedded in our human development. At various points in recorded history, it has surfaced but only since the discovery of electricity has it become central to our means of representation. In fact with the development of mechanical technologies in the first industrial revolution, there were serious attempts at building analogue machines that could manipulate such elemental codings[2], but it was not until the notion that an electrical pulse could be used to represent such distinctions that the prospect of the digital computer appeared. The ability to represent phenomena in the binary code would not have become all pervasive without two key developments. First, the invention of the transistor which lead to the dramatic path to miniaturisation now enshrined in Moore's (1965) Law. For the last 50 years, this law has demonstrated that for the chip, memory and processing power have doubled and speed has halved every 18 months with little sign of slowing, certainly not stopping. Second the convergence of computers with telecommunications has enabled equally dramatic access to information which is computable. Both developments have been essential for the massive proliferation and scaling down of computing devices and their connection to one another, and without any of this, we would be unable to speak of an information society, certainly not of a smart or automated city.

In some respects, the first and second industrial revolutions associated with mechanical power and electric power are essential for the current revolution in information processing. A plausible interpretation of industrial development over the last 250 years (or even as far back as classical times) now seems to suggest that the great divide between the old world and the new is marked by the transition from a world of materials and energy to one of data and information. It is likely then that cities and societies in the new world will be completely unlike those in the old. This is clearly evident in the fact that cities could only grow beyond a million or so people after the internal combustion engine emerged due to the invention of mechanical technologies, and now with emergence of information technologies, physical limits on size are once again being cast in a very different light.

We can summarise these various forces in several clichés which are often referred to in the most casual sense as 'laws'. These are not hard, immutable physical laws for they are clearly dependent on social context but they do provide simple rules for gauging the past and possibly the future impacts of IT on cities and societies. The core of this transition is of course miniaturisation embodied in Moore's Law, first articulated in 1965 from his observations of what had happened at Intel where he worked on the development of the integrated circuit. Moore's Law is crucial to the inexorable rise in not only computer memory but also to the extent of computation. There is little doubt that current developments in artificial intelligence depending on

[2] Babbage's difference and analytical engines constructed from the 1820s but never finished by the time of his death in 1871, are the best known examples of such analogue machines: see https://en.wikipedia.org/wiki/Difference_engine and https://en.wikipedia.org/wiki/Analytical_Engine

continuous iteration of simple rules to extract a degree of intelligence from computation lie at the root of current predictions about massive automation of the workplace, and the disappearance of many middle ranking jobs. This all depends intrinsically on Moore's Law.

The picture would not be complete with an equally important law pertaining to how computers are able to communicate with one another. Metcalfe's Law named after the first developer of the Ethernet at Xerox Parc in 1974, suggests that " … the value of a network is proportional to the square of the number of nodes". In short, as the number of computers increase and are all networked together, the value of the network measured in terms of the amount of information that it can process increases exponentially, at least as the square of the number of computers acting as nodes in the network. This is the form which Gilder (2000) gave to Metcalfe's observations, and notwithstanding that there has been some empirical criticism of its precise form, it still conjures up the notion that a computable society is not simply about computers *per se* but about how they are connected and the economies of scale that emerge from such connections.

There are three other laws that build on network connectivity. Gilder's (2000) own law suggests that the total bandwidth of communication systems triples every twelve months. This is much faster than Moore's Law and it is yet to be fitted precisely as the data is difficult assemble and total bandwidth is a nebulous concept. The second is Sarnoff's Law[3]. This states that the value of a broadcast network is directly proportional to the number of viewers, which might be interpreted as the lower limit of Metcalfe's law, again suggesting that the concept of value needs a clearer definition. All of these laws are, to some extent, 'convenient fictions' and to conclude on an even more fanciful note, there is a fifth: Zuckerberg's Law[4]. The founder of Facebook formalised the hype by stating that " … the information that people share doubles each year". In fact, this is quite important because it moves the argument away from hardware – computers and networks – to people and information and it is this that is so critical to the all-pervasiveness of computers and computation in contemporary and probably all future societies. In fact, this is as much true for past societies as for present, except that information was harder to extract in the past as it was more bound up with material transactions. In Negroponte's (1995) phraseology, bits were then harder to separate out from atoms.

It is now clear that an entirely networked world has almost emerged and in such a context, the kind of computation that takes place across all possible devices and networks will determine its form and function. It thus depends on what is attempted and thence achieved using such devices and this maps directly onto the extent to

[3] http://protocoldigital.com/blog/sarnoffs-law/
[4] https://www.technologyreview.com/s/426438/the-law-of-online-sharing/

which traditional functions are automated, substituted for or complemented by these new devices and how this new digitality generates new functions which do not currently exist. We do not have a very clear idea of the impact of all this, especially when it comes to the physical form and function of the traditional city. Virtually every aspect of the city and of our activities within it are touched in some way by digital technologies and thus many writing and commenting about the smart city resort to hyperbole, coupling lists of everything in sight that might appear to be influenced by new information technologies.

Within the last ten years, roughly from the time when the great recession began, the smart phone has emerged with an increasing number being used for a range of work, home, and entertainment activities as well as multiple routine functions involving storing (banking), generating, and using money, and all kinds of email and social media. Information is now being stored remotely and with voice activation and interaction, there is a rapid transition to a world where information associated with various services and stored in a diverse array of archives is immediately available. Remote servers – part of the ubiquitous cloud – are now the norm even for types of computation which are still strongly place-related. The traditional hardware distinctions between mainframe, supercomputer, mini, desktop and mobile device which represent a sequence of computer technologies emerging over the last 60 years, still exist in various forms but these distinctions are blurring even for scientific computation. The kinds of computation that now characterise contemporary society are also evolving rapidly and the line between computers and sensors is no longer particularly distinct. It is into this world that the smart city has appeared as the current wave of the digital revolution. But before we chart its progress, we need a clear view of what cities are and what aspects of them we need to include in our definition of the smart city. Therefore, we need good robust theory for without theory we have little chance of making sense of an environment entirely dominated by computers, computation and networks. To this we now turn.

Theoretical Perspectives on the Smart City

It is no exaggeration to suggest that there are almost as many perspectives on the nature of the city as there are persons researching their structure, managing their organisation or engaging with their design. Cities admit multiple viewpoints and multiple theories, and it is of little surprise that when a new set of technologies emerge, new perspectives are fashioned to consider how such technologies can be implemented and embedded in the city and how they change human behaviours. In the context of highly scalable computers down to hand-held devices and small scale sensors, there is also a strong force to sell such products and with the universality of such devices, the business ethic is one that is rapidly driving the move to the smart city. This means that the corporate world is often at the forefront of popularising the smart city with the consequence that much of the hype surrounding this involves the most obvious aspects of how the city and its parts might be automated.

If you pick up one of the many reports on smart cities written by municipalities, governments, large ICT companies, consultants and so on, or examine the many conferences that energise discussion on the business of smart cities, you will be struck by the somewhat random nature of the topics discussed. The topics rarely have any strong internal ordering and invariably simply reflect the most obvious components and activities that go on in cities. Moreover this list of topics based on components does not really focus on the processes of automation and how these might alter the way populations behave with respect to urban markets and forms of governance. There is however much speculation about how such technologies might be integrated – in terms of sharing hardware, software and the networking capabilities that serve to tie various data and computation together – and there is even fanciful talk of building entire operating systems for cities. What these might be is anybody's guess for an operating system assumes that there is agreement about what in a city is the focus of operation. The notion of sharing is also writ-large with respect to data and software often arrayed and organised across 'platforms' that serve to tie various systems together. Much that is written about the smart city from these perspectives does not in fact propose anything that is more generic than a will to integrate and coordinate. As the history of large ICT clearly reveals, integrated workable systems are few and far between. What exists so far in terms of the smart city is very largely *ad hoc*, more intention than actual implementation, more heat than light (Saunders and Baeck, 2015).

The sort of areas which are identified by the vast majority of the literature on smart cities largely emanating from the non-academic sector is not based on any distinct theory of how cities function or even how they should be managed or designed. They tend to be based on where sensors and computers and their concomitant networks can be developed (and sold) with mobility and energy as key themes. Services delivered to citizens are also important in this mix but invariably these range from location-based services to municipal delivery of benefits that traditionally the public sector are mandated to deliver. Cybersecurity which involves everything from block-chain to bitcoin has recently appeared as a key function of the smart city, while financial services (fin-tech), retailing involving online shopping, and marketing tend to be somewhere in the frame. Waste, pollution, various kinds of utilities infrastructure and such-like network systems also appear as candidates for automation but there is little focus on how they might be integrated with population demand and infrastructure supply. A concern for data – particularly open data and now 'big data' which is directly related to real-time streaming and operation of automated functions in the city – is also significant. But all of these elements do not add up to a comprehensive picture of how the smart city functions or will function once various automation of the kind implied here comes up to scale. Interacting with the public through various kinds of participatory dialogue and crowdsourcing to elicit everything from opinion, personal innovation, and responses to policy to the collection of new data is also a feature of the kinds of environment that the smart city can bring. This sometimes dominates the debate but all of these perspectives and foci tend to emphasise the current and routine operation of the city rather than the longer term goals for more liveable and equitable environments.

These kinds of discussion tend to be set against an implicit background of continuous economic growth with little discrimination over what might be important, feasible or equitable with respect to functions that might be automated. Most contributions tend to be silent on what are effective organisational structures that might best enable this kind of automation. There is very little discussion about how cities function in terms of the way activities are served by markets and how resources are allocated spatially with respect to transportation. There is absolutely no discussion of the many new networks that have appeared involving information, and it almost as though email, the web, and the myriad of other fixed wire and wireless networks as well as GPS and related technology do not exist in terms of their influence on the smart city. In fact, the smart city is only possible because of them. Academic commentaries on the smart city are equally lacking. Townsend's (2013) book is an excellent discussion of the key issues from the point of view of the citizen, the planner and the industry but this is more of a historical focus than a prolegomena for action.

What the smart city debate has thrown into sharp relief is the focus it has brought to the temporal dynamics of cities. Most approaches to cities in the past have focussed on how cities function and develop over years and decades rather than finer time periods such as minutes, hours or days, although there have always been organisational and management functions that pertain to their routine functioning. It is these that are becoming automated at a rapid rate and thus the smart cities movement has tended to emphasise short term dynamics rather than longer term. Most individual decisions about urban development occur in real time although they may have implications over many different time horizons. It is this mixing of time periods that makes clear the need for much clearer theoretical perspectives on exploring, understanding and predicting the impacts of automation on the city, and this requires a much more complete framework for examining automation than we have developed hitherto. In fact, there has not been a strong emphasis on dynamics in understanding and planning cities hitherto largely because cities have been considered to be in equilibrium and their improvement has been largely phrased in terms of idealised plans without any realistic time horizons for implementation. If there have been time horizons these have been end-states to a future that is far away. Thus the smart cities movement has brought time onto the agenda with a vengeance and this is likely to revolutionise how we plan and what we plan, notwithstanding the largely a-theoretical context into which these ideas are being introduced.

With digital technologies spreading everywhere and all with very different degrees of automation and impact, it is not possible to provide a coherent theory of the smart city that is all embracing. But at least here we can imply a generic approach that focusses on how individuals and groups function in cities in terms of the myriad of networks that tie social groups together in space and time. Cities exist to bring people together and their form is one where these linkages portray networks of many kinds. Most of those prior to the digital age were material in their transport but they are now being augmented, complemented and substituted for by ethereal flows – where information is the new energy, and data is the new oil. What happens in any location within the city depends on networks of people, materials, energy and information that is transmitted to and from these places which act as hubs. In fact, our understanding of cities must be based on unpacking locations into the spokes that ties these hubs together for the changes that are most durable in cities depend on what is flowing into these hubs. All this is fairly obvious and in some sense, the notion that cities can only be understood in terms of their networks is not a new insight; it is an obvious consequence of why cities exist but the idea that we can only understand cities in terms of networks, not simply, locations has taken a long time coming (Batty, 2013).

This network view of cities is based on the central principle that cities evolve from the bottom up. As we implied in the first section of this paper, top down planning is rare compared to the myriad of decisions that are made by individuals acting for their immediate family or group usually in their own self-interest. From this, we can articulate the city as being composed of layer upon layer of networks, between which there are networks linking networks. In the medieval city, these networks were simpler but as new technologies have emerged, new and different forms of network have been invented and constructed. The history of the city is thus one of a fast proliferating set of networks (West, 2017). The network view of the city has always been one primarily of social networks but as soon as mechanical technologies began to proliferate in the early industrial revolution, cities began to grow as the separation of functions made it possible for individuals to carry out new tasks remotely from one other. These networks have become ever more global but until the invention of the computer and before it the telephone and related information devices, the extent to which the world could be easily charted, was quite bounded and coherent. In the last 60 years, all this has changed; in fact, it is probably within the last 30 that information networks have massively proliferated but only in the last decade have large numbers of people become connected to them. We are now facing a world where anyone anywhere with a smart phone and internet connection can access enormous amounts of information globally, and interact with many people who they have never physically met. This of course has dramatic implications for the city. In fact, the smart city is a constellation of networks where real change is coming from the use of these networks. When everyone is connected to everyone else, then what we will see is more and more variants of network layered on top of one another. This kind of complexity is what the smart city is bringing although we barely yet have a science yet to deal with its emergence.

A Paradigm for the Smart City

Before we examine how information technologies will evolve the city into entirely new forms during this century, we will sketch a simple model of the way in which cities are being automated which enables us to contrast the emergent smart city with the city in history. We call this a paradigm to make clear we think this is a more complete way of characterising smart cities than any of the current approaches which tend to be without any theoretical conception of how cities function as complex entities. The paradigm is really quite simple in that we begin by making the obvious distinction between the city as it exists externally to our perceptions, and our understanding of the city that is necessary to make sense of the external reality which is necessary to any interventions we might make to change it. This is the difference, then, between the reality of the city and our theories about it. Our theories can be from any and every perspective but they involve some form of abstraction that makes our models of the city distinct from the city itself.

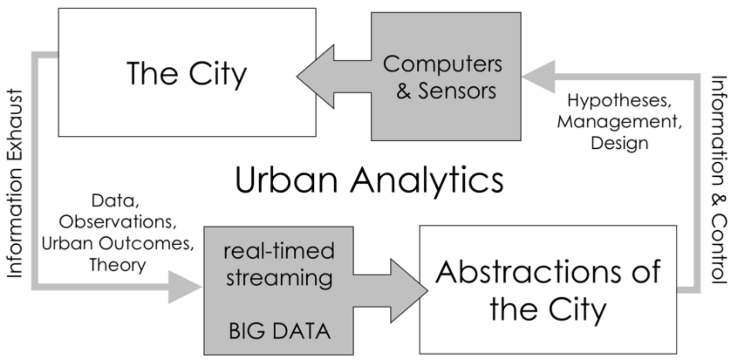

Figure 1: Understanding, Managing, Planning the Smart City

We can picture this distinction in the diagram in Figure 1. There we show the reality and our abstractions from it in a closed loop which suggests that we draw data from the real city and from this form our understanding. In parallel, we exercise control over the real city through management and/or design, thus changing the city which in turns feeds back to change the data that we draw from the city. In this sense, there are at least two loops involved in this circularity: the scientific method in which the city is the object of study with our hypotheses, thence our theories representing our understanding; and the process of management and planning which is how we enable the city to function while at the same time changing its design. In fact, we might separate this second loop into two – that concerned with the functioning of the real-time city and that concerned with its design. The real-time loop is one that usually works with much shorter time horizons than the second. Rather than present three loops in Figure 1, we only show one but we notate them to impress this threefold meaning.

A consequence of our argument here is that it is difficult to date the beginnings of the smart city and if smartness is associated more with ourselves rather than our computers, then no origins are possible. However, reflecting on the world prior to the emergence of the web before the 1990s, computation was largely associated with two sets of functions which impacted the loops in Figure 1; first computers were used almost from their inception to build models of complex social systems such as cities and thus very early on became part of a loosely structured science of cities that was evolved to enable a better understanding of urban problems. Such models were and are highly abstract but focus on key elements that determine how cities function. They have been often used for prediction in plan-making, and indeed this was their original rationale. The second usage has been computer applications in managing complex systems or parts thereof for purposes of control. To a large extent, this involved transactions-processing notwithstanding some early attempts at controlling and optimising urban functions such as emergency services and utilities. To a very limited extent, a third usage of computers in design has emerged but prior to the web, and the rapid increase in computer graphics capabilities which occurred in parallel, such uses were modest and minimal. Only now is computer-aided design writ-large but most of this is not related to city planning *per se*.

Progress in developing computational simulations supporting our understanding, management and design was extremely slow prior to the last two decades. However once computers came to be scaled down to the level at which personal devices could be used for interactive control, and networks of sensors became robust enough to provide control in real time, the embedding of computers into the fabric of the city – rather than computer being used to understand and manage the city – has become a reality. In Figure 1, the two dark grey boxes indicate that once this kind of embedding began to take place as the web developed (Batty, 1997), the entire picture of what is possible in terms of the three functions – understanding through science, management and control, and thence design – is radically changed. First the data that is available from such embedding is available in real time, and if not actually linked to real-time control, is available in a *post hoc* fashion for analysis and design.

This data because of its volume (and variety) is often termed as 'big' in that in principle there is no limit to its volume as it is continuously generated (Batty, 2016).

Big data tends to be associated with the very short term whereas most traditional sources of data that are used to understand (and in the past even control) the city were assembled over years, decades or even longer. Of course big data which is assembled second by second will also pertain to the long term when enough of it has been collected to enable the kinds of long term analysis that is traditionally done to be replicated with these new data sources. We have not quite reached the point where these new sources of data – many pertaining to transit and some to retailing and finance – have been used for longer term analysis and there are potential limits on such data due to confidentiality and ownership, hence access. However, the nature of big data of the real-time streamed variety is very different from traditional data sets that are associated with individuals often collected through periodic censuses. Much big data is of course collected by streaming from mobile devices associated with individuals but there are key problems in using this data. First real-time data is often associated with devices that are not linked to people and even if they are such as fixed sensors that an individual activates, then it is rare for any attribute data to be associated with the individuals involved. If the data is individually identified, then often attribute data is simply not collected and has to be inferred. Quite frequently that data is flawed in that it is difficult to interpret and is highly biased to particular groups or cohorts. Such is the case with social media data.

What Figure 1 does reveal however is that by using computers in real time to control the city and to engage in many traditional functions in new ways adds a new layer of complexity to our traditional approaches. We have not unpacked this diagram with respect to digital versus non-digital operations and functions but the new embedding of computers into the form and function of the city generates new kinds of networks which are based on information rather than materials and people flows. This is where the new urban analytics that we identify in Figure 1 as a contextual backcloth is relevant. The many models, simulations and analytical techniques that we group together under this new label are all under very rapid development at the present time due to the development of new data sources and new ideas about how the city functions in terms of information networks. None of this is yet worked out in any detail but an enormous challenge is to devise new ways of integrating many of these new perspectives and data sources as well as new forms of spatial behaviour with traditional models and simulations. For this we need new theory which embraces what we and others are calling the smart city as well as traditional views and time frames with respect to how cities have been understood, managed and designed hitherto.

The Continuing Evolution of Information Technologies

Digital technologies include related hardware involving networks, switches, and sensors as well as software, data-ware and the organisational structures important to their functioning. A key point arising from our earlier history is that it is difficult to place any of those developed since the beginning of the industrial revolution into a distinct sequence. To an extent, mechanical precede electrical precede digital and these can all be seen as part of the same processes of innovation and application with this kind of continuity clearly continuing. Whether or not anything can follow digital is an open question although other kinds of computing such as quantum and telecommunications involving voice rather than text and numbers do define rather different technologies, at least in terms of accessing computers and data. The issue with digital technologies however is that their development has followed Moore's Law which suggests ever increasing rates of change. This appears counterintuitive to our perceptions that there are distinct phases of technological development.

The idea that development takes place in waves is also deeply ingrained in our perceptions of history, for economic theorising and practical policy-making is dominated by notions of the business, credit and other monetary cycles. These cycles seem to have more resonance than the longer waves that have been proposed for the rise and fall of civilizations while the notion that more specific events such as technological change can be articulated as super-cycles has gained some currency in the last 100 years. It was Kondratieff working in Stalin's civil service in the 1920s who first gave form to the idea that different technologies appeared to have periods of relative dominance of around 50 years. He pointed to the early industrial revolution when the internal combustion engine was invented (from 1870 to around 1820), followed by the age of steel and steam (1820-1870) which led to the age of electricity. This was more or less finishing when Kondratieff (1925) began to theorise about all of this but his work was short-lived. He fell victim to Stalin's purges with his revisionist ideas branding him capitalist and he was thence sent to the Gulag where he died in 1938. Yet his ideas were quickly picked up by Schumpeter (1939) who called them Kondratieff waves (K-waves) and who suggested that once a new technology had been invented, a period of consolidation and application followed, the wave being finally completed with a downswing characterised by falling investment in the technology, only to be superseded by a new technology which heralded the start of a new wave. These long waves were marked, said Schumpeter, by the creative destruction of the existing technology which often appeared perfectly serviceable but was inevitably replaced by newer and shinier and often radically different forms of the same.

It was Kuznets (1953) who gave a clearer form to these waves dividing each into four sequential stages – beginning with *innovation* where new technologies were first exploited (although their invention might have been much earlier), followed by applications usually characterised by rising investment. This was followed by steady *application* in which the profit generated from such inventions declined and this then lead to *depression* where the technology became less attractive and where new technologies became noticeable through their invention. From this emerged a period of *recovery* which would lead to the start of a new wave based on new innovations. In fact, there is no definitive thinking about the length of these long waves or super-cycles, nor is there any real agreement about the precise form of the stages within each cycle. There is clearly rise and fall which is the mark of a wave but in some respects the waves build on each other and in many technologies, the earlier versions continue to be improved and are key to the ones that displace them or rather become the evident representation of the dominant technologies very often used for the same applications as earlier ones.

The fourth and fifth Kondratieff waves have been characterised respectively as associated with the automobile and digital (IT) technologies. In terms of the 50-year cycle, these took place between 1920 and 1970 and from 1970 to the present day. In this characterisation, the sixth Kondratieff nicely fits the age of the smart city but others suggest that this should be an era of biotechnology where health is to the fore. In some senses, this does indeed accord with our earlier sentiments about the fact that the next wave of computing will be the embedding of computers into ourselves so that we might improve our health. However when each of the six waves which cover the time from the beginning of the industrial revolution are compared, they tend to be somewhat unlike one another in that it would appear that the first wave is invention, the next application and so on. On this basis we are coming to the end of a wave of digital inventions and this might herald a wave of applications – in smart cities, in health, in space travel and so on.

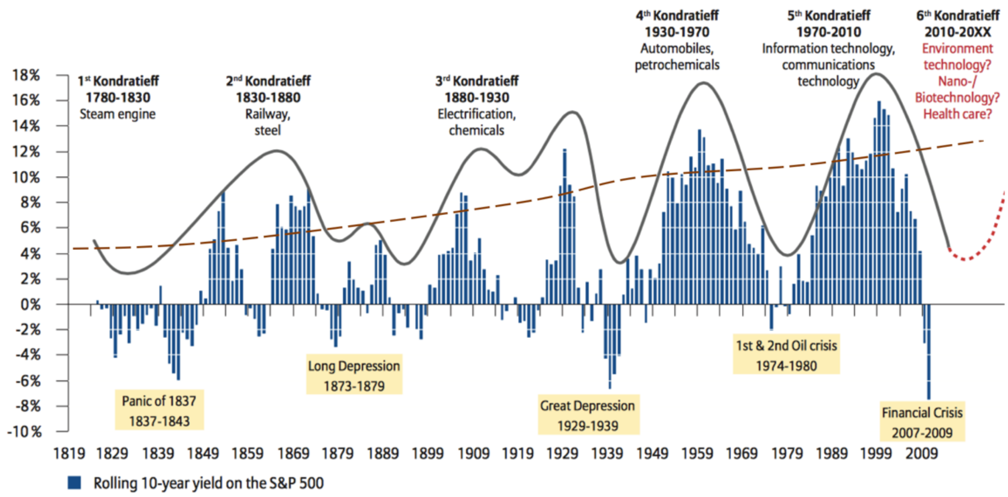

Figure 2: An Interpretation of Kondratieff's Long Waves

A useful interpretation of these waves has been presented by Naumer et al. (2010) who imply that the amplitude of each wave is getting a little greater (and perhaps the periodicity a little shorter) but their picture which we show in Figure 2 is only one of several where the actual timing of the cycles differ. In fact, if these waves are getting shorter and more pronounced, then this appears consistent with rapid developments in information technology which now seem out of step with the general timing suggested a century ago by Kondratieff himself and also by Schumpeter. We have also plotted the mid-points of each cycle in Figure 2 and this suggests that there is a much longer term process at work which we would argue is simply the transition from a non-mechanised, non-automated world to our current digital one. In fact, if the waves get shorter and larger, then they eventually coalesce to produce a singularity, an event horizon of continuous creative destruction. The meaning of such a convergence is hard to fathom and we have no experience of such an event or environment. This is what makes it unlikely (?) but the prospect of continuous invention is certainly possible in a world where everything might be special and individual, something which appears to be occurring in limited contexts, particularly in social media and crowd-sourced activities.

The idea of a singularity is something that I think we should avoid elaborating much further in this paper. The essential notion is that if the rate of change is exponential or more likely super-exponential, then one can predict that in finite time – in this context during this century, the world would become so different and unsustainable that it is simply not useful for informed speculation about the near future, about smart cities. Nearly 60 years ago the rate of change in world population reached its maximum and at that point it looked at though the global population would increase without bound until it reached a crisis – a singularity – in the 2020s (von Foerster et al., 1960). None of this could take account of the fact that in the last two decades it looks as though a turning point has been reached for world population and that this now following the generalised logistic which is associated with the demographic transition. But there are other massive singularities in prospect, particularly in health according to Kurzweil (2005) but also in technology due to machine learning. This is the message preached by Brynjolfsson and McAfee (2011) in their book ***Race Against the Machine*** where they suggest that we are in a race to make sure our machines do not create an artificial intelligence that overwhelms us. The rate of change in this context appears to be speeding up not slowing down as we pass threshold after threshold in what machines can extract from the fire hose of data that is now being fed to them.

Conclusions: The Future City

There is another question that cannot be answered in any definitive way and that is 'what the city will look like in the near, medium or longer term future?'. Our best guess is to look back and to simply examine the superficiality of urban form, not function. Street patterns tend to be quite inert, the growth of big cities which is determined by culture and physiography, and of course communications technology tends to be familiar, and although everything looks quaint and old-fashioned, cities of the past certainly back to 100 years ago still appear similar to those of the present and even those, we might speculate, of the near future. It is functions that change and it is very likely that the disconnect between form and function which became evident in the 1970s will continue full pelt until we become entirely connected digitally and footloose locationally in terms of interacting with any place from any other. In essence, there are plenty of reasons why form will still follow function but the disconnect is a powerful force and it will ultimately play out when most of the functions that we engage in can be operated remotely from places where they were once located.

Add to this all the very obvious automation that is in the pipeline. Many services which are currently unregulated and have emerged because of network communications such as Uber, AirBnB and so on, do not appear to be making much impact on spatial behaviour *per se*. The hype over self-driving cars and related technologies that depend intrinsically on machine learning and massive historical and current data acquisition will have some effect but the complexity of a bottom-up environment is such that this will be more limited than some suggest. There is no doubt that automation in cars and connected vehicles will advance while the substitution of fossil fuels for renewables is likely to proceed quite rapidly. Advances in construction and materials closely related to new digital technologies at all scales will make a difference to the way we design and use buildings, and the prospect of connected buildings like connected cars is on the horizon. In terms of tools that we will use to explore, understand and predict the city, automated physical models of their 3D form are likely to emerge in real time and to these will be linked various functions and flows that can also be captured in real time. Thus the notion of an instant and continuously changing digital picture of the city is in prospect.

This list of futures is a little bit like the list of smart city technologies that we critiqued as being somewhat mindless at the start of this paper, but it simply serves to show that the future is unclear, not necessarily confused but uncertain in its detail. There is no doubt that the proliferation of digital networks all determined by activities, many yet to be invented, all generating data about their functioning but most being hard to relate to individual human attributes other than the fact that individuals operate them in some way, will provide a more complex future than that we have had to grapple with in the past. In this sense, the age of the smart city is one of increasing complexity and variety which has always been the case from the earliest cities. This makes the prospect of generating informed analysis of the future city ever more uncertain. There are some big drivers too that we have not mentioned in this paper such as aging and climate change and these need to be factored in. But what is certain is that as Haldane (1926) said many years ago: "I have no doubt that in reality the future will be vastly more surprising than anything I can imagine". Our inability to predict the form of future cities is largely due to the fact that we are part and parcel of their future creation and design.

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