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Self-monitoring, analysis and reporting technologies

Smart cities and real-time data

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Introduction

Approaching 25 years ago, Putz (1994) in his paper 'Interactive Information Services Using World Wide Web Hypertext' noted that although most World Wide Web (WWW) servers were designed primarily as hypertext file servers, there was an increasing trend towards more dynamic information services where custom documents could be assembled and delivered to a user on request. Since then, the internet has of course transformed into such a system with myriad feeds and data streams from a once largely passive medium for delivering information to one that is interactive in which the user can query, construct and manipulate information on the fly. This level of development can be seen in the emerging fields of smart cities. Networks are beginning to shape themselves into the fabric of cities and in this chapter, we will consider the term 'smart city' to refer to the whole set of opportunities that networked computers offer to cities in terms of their enrichment for greater efficiency and a better quality of life. The smart city is beginning to form into a dynamic information service, but currently, most of the hardware and software which define such elements of the city are based on stand-alone units, not connected to wider networks or linked together in any meaningful way (Hudson-Smith 2014). This is beginning to change but the development is looking to be longer term than the development that Putz (1994) talks about in terms of information services; cities take time to develop and the smart city is one that will develop over the coming decades – these networks are only beginning to form.

The term 'smart' has many other definitions and public perceptions, it has been widely criticised as a meaningless catch-all phrase, as a marketing and public relations ploy, often captured by commercial interests (GLA 2013), indeed as Söderström et al. (2014) note the term can be seen merely as deconstruction of a communication strategy. Therefore, it needs to be defined in context, or it becomes all too easily subject to accusations of marketing and buzzword fodder. Here we use a very self-conscious definition that combines a series of basic functions embracing Self-Monitoring, Analysis and Reporting Technologies (which define the term SMART), and this focuses on our definition of the technologies that are being rolled out to make cities computable in a routine sense. This term originally came from the functions employed in hard disks as a way to internally monitor their own health and performance. Most implementations of SMART, in terms of disk drives, allow users to perform self-tests on the disk and to monitor a number of performance and reliability attributes (Allen 2004). The ability to self-monitor, analyse and report performance and reliability measures is, we argue, a closer definition of how a 'smart city' might function than other looser and wider definitions and one upon which we build in this chapter. We are well aware that many smart city concepts depend on more explicitly social and economic processes, institutions and agencies. We will not review these here for there are some excellent reviews to this area of smart cities work already available (Chin et al. 2011; Debnath et al. 2014). Any complete assessment of smart cities, the technical focus that we have adopted here must be blended with the institutional and organizational and the success of the smart cities movement will depend on a much wider set of forces than those that we describe here (Giffinger et al. 2010).

Such was the momentum 20 years ago when the WWW was first constructed on the back of two generations of networked technologies that Batty (1997) predicted that by the year 2050 everything around us would be some form of computer. In 2019, computerised highways are in prospect, driverless cars and smart buildings which monitor their performance in terms of energy and materials are almost upon us. In 1965, Gordon Moore envisioned in the paper that introduced his famous law 'Cramming More Components onto Integrated Circuits' that integrated circuits would eventually lead to such wonders as home computers – or at least terminals connected to central computers, automatic controls for automobiles and personal communications equipment (Moore 1965). These circuits are increasingly weaving themselves into the city and the fabric of urban form and arguably the prediction by Batty, defined under his term 'Computable City', (Batty 1995) is becoming a reality.

Places and spaces are increasingly becoming internet-connected with mobile communications, and the size of the market for such routine technologies has an addressable market value in terms of transport, utilities and intelligent buildings predicted to amount to some US$70 billion by 2020 (GSMA 2012). The term smart city has become synonymous with how well a city is performing in the current climate of mobile applications (apps), data streams and social networks. As Caragliu et al. (2009) state, it has been introduced as a strategic device to encompass modern urban production factors in a common framework and to highlight the growing importance of information and communication technologies (ICTs) which have become the social and environmental capital in profiling the competitiveness of cities. Yet the smart city is wider than this, for at its heart is a definition of place and space which allows a view from the micro individual up to the macro collective of how a city operates. Indeed even the term smart city itself is perhaps being surpassed as wider contexts develop – the city as a digital twin, for example is becoming a popular term of reference often based on the assumption we are creating a digital duplicate of the physical entity (Datta 2017).

We argue that although phases come and go, the concept of self-monitoring, analysis and reporting technologies is key to the longer-term development. Digital twins can be viewed as a digital representation of the physical world, with the addition of data, collected from anything from building systems through to social and environmental feeds that can be viewed and acted upon. They are like looking at a mirror of our world, a mirror that not only reflects the environment but also displays the invisible: the flows of data (Hudson-Smith et al. 2019). As such they reflect the smart city in mixing the physicality and the flows of data; in this sense the smart city can be viewed as an 'urban hard drive' in which the data can be mined, visualised and modelled for self-monitoring, analysis and reporting which implies a joined-up technology where integration and coordination are key. The challenge of the smart city then is to provide and define the conditions under which this is possible – what is happening now is merely a beginning. We explore challenges that are data stores, data feeds and data visualitions in the following sections, building on work developed at the Bartlett Centre for Advanced Spatial Analysis (CASA), University College London. The Centre has a focus on usability and communication of city-based data with a core around real-time analysis and visualisation.

Data dashboards and data stores

Central to our conception of the smart city is data. Every day, humankind creates over 2.5 quintillion bytes of data – so much that more than 90% of the data in the world today has been created in the last two years alone. These data come from everywhere: sensors used to gather climate information, posts to social media sites, digital pictures and videos, purchases and transaction records, cell phone signals, to name a few (IBM 2013). An increasing amount of this data stream is geo-located, from check-ins via social networking sites like Foursquare, through to tweets and searches via Google Now. The data that cities and individuals emit can be collected and viewed to make it visible, thus aiding our understanding not only of how urban systems operate but opening up the possibility of continuous real-time viewing of the city at large (Hudson-Smith 2014). Cities across the world are at various stages of both releasing and utilising such datasets as both producers and consumers of urban information. It is part of our realisation that smart cities are no longer places where city government acts as the top-down driver of development, but instead, they act as a broker in a much wider ecosystem of data and information (Department for Business Innovation and Skills 2013), though it should be noted that this opening up can itself give rise to interrelated complexities relating to usability, power and marketisation (Kitchin 2013).

Case study: London city data strategy

A key role a city government plays in this emerging ecosystem is as a provider and aggregator of data. The London Data Store in UK is a prime example of how such a system can provide an impetus to the creation of services and added value from data. Developed by the Greater London Authority (GLA), the Data Store has stimulated over 70 mobile applications linking to almost 650 datasets from a combination of the 77 real-time live traffic and transport data feeds it provides. In 2019, the GLA began to actively refine its data strategy, setting out its aims and reasoning in a comprehensive policy document in terms of a roadmap. The roadmap, which is a non-statutory document, builds on the first Smart London Plan, published in 2013. It provides a new approach based on collaborative missions and calls for the city's 33 local authorities and various public services to work and collaborate better with the aid of data and digital technologies (GLA 2019). Recognising that the provision and availability of open data is merely the first step, and drawing upon its expertise and success in this area, the GLA proposes to support the creation of a 'City Data Market'. It hopes this will engage companies who have traditionally viewed data as proprietary and closed to participate in an ecosystem of mixed-permission data products, opening data in order to create demand, and perhaps even trading data with other providers and application developers, in exchange for access or expertise. In so doing, it seeks to promote a sharing culture which can encompass both free and proprietary data. Furthermore, the GLA recognises that it need not provide the repository for these data itself. The availability of mature, well-tested open platforms such as CKAN (a web-based open-source management system for the storage and distribution of open data) which in fact powers the London Data Store, a variety of federation (that is, sharing and harvesting data) modes are available 'out of the box' as it were. This allows datasets to replicate and propagate across heterogeneous data stores both within the city and beyond, according to granular, well-defined rules. It is expected that this blended approach to 'market making' for data will lead to the simple and wide availability of data from a variety of providers and will facilitate analysis.

We argue that while this is a welcome step forward, it is also not enough; a data 'market' is not a data 'commons', i.e. resources considered public goods, meaning that they are accessible to the public, and also rivalrous, meaning that their use by one precludes their use by another (Beckwith et al. 2019). There are barriers, both obvious and subtle, to participating in this data market, and this necessarily influences the nature of data that will be available within it. Certain contributors of data will be seen as less valuable than others, and some contributions will be less welcome than others. This raises questions as to who participates or contributes to the data market. How, for instance, will the contribution of data from citizen science projects be dealt with? Will there be efforts on the part of the marketplace as a whole to encourage participation from demographics who have been historically underserved by the advent of new urban technologies? While the London city data strategy is comprehensive, it fails to note the lack of success of previous attempts to create marketplaces of this kind, such as BuzzData or Freebase to name but two (Dodds 2016). A pilot, currently underway, combines these ideas of a 'hosted' data repository, a market and more nuanced, urgent considerations about the accumulation and use of personal data in a so-called 'data trust' (Wylie and McDonald 2018). Though the precise definition of a data trust has not yet been agreed upon (Hardinges 2018), most trusts conform to one or more of the features distinguished by Hardinges, arguably the most interesting being some form of public oversight of data access.

London data dashboard

Through the application programming interface (API) provided by the London Data Store, our centre – CASA – has created a city dashboard as a means of viewing a key number of live data feeds. This essentially is a simple interface to the visualisation of these data streams that are updated in real time and is available on the web.[1] In London, the dashboard collates and simplifies over 20 live feeds from air pollution through to energy demand, river flow, the FTSE 100, the number of buses in service, the status of the subway networks and so on, which we illustrate in Figure 26.1.

The London data dashboard is an early example of collating and visualising data feeds to provide a citizen focused view of the city. Not limited to London, the dashboard has also been built for Birmingham, Brighton, Cardiff, Edinburgh, Glasgow, Leeds and Manchester, with a version for Venice also under development. But in these different cities, the types of streaming data can be a little different, for the dashboard highlights the variability in the availability of data feeds from city to city. London, at the present time, is the location for a majority of data feeds, with their number updated on a second by second basis. The majority of these data are either collected via an API which is an interface, usually through the web via http(s), where a user can query the status of the system with the live data being delivered to the user (or its

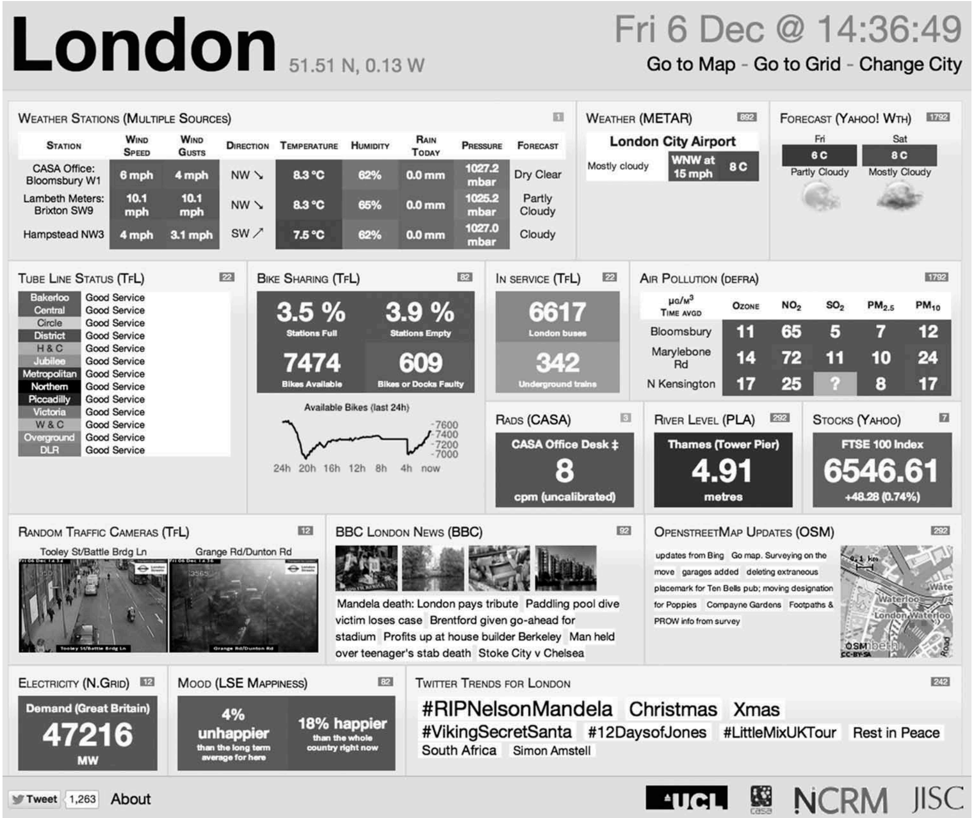

Figure 26.1 Live data feeds into a web-based data dashboard
Source: http://citydashboard.org/london/. Screenshot by chapter author(s)

client) or the data mined in accordance with a data provider's terms and conditions. The ability to tap into these APIs allow the city dashboard to provide a view of the particular city at a glance, with the use of simple colour coding to indicate the positive or negative connotations of the current state of the data. A custom-made version of the London dashboard has been developed for internal use by the London Mayor's Policy Office at the GLA. Designed around 12 iPads and mounted into a single system, the board allows each iPad to display historic and live data relating the city, as we show in Figure 26.2.

The historic nature of the iPad wall version of the dashboard requires an element of data graphing to examine trends in the feeds, and this has led to the next stage of the development of the city dashboard, moving towards an archive system for city data. At its initial conception, the city dashboard was created as a simple viewer for city-related data feeds.

London Data Store

The publishing of data and streams via systems, such as the London Data Store, is creating a new landscape in data availability and arguably the development of a new kind of city-wide information system. The ability to refine and redistribute feeds is perhaps the next step

Figure 26.2 An iPad wall data dashboard to view live streamed city data in London
Source: Chapter author(s)

to their wider use. While we have focused on the distribution of feeds, it should be noted that it is, however, possible to view these streams as a new data archive and plug them directly into systems for building various kinds of urban models ranging from simple 2D and 3D physical visualisations to mathematical abstractions of urban functions such as traffic, rental values, house prices and so on. Such data have the potential to enable the development of a series of indicators which measure the performance of the city in both the short and near term. Indicators covering aspects of the city from urban flow, such as transport and pedestrian movement, through to a city's economic flows and onwards to more social inputs such as wellbeing and happiness, are on the horizon.

The mining and use of APIs from social network data are central to this wider view of city datasets. One of the most popular current social networks is Twitter. First created in 2006, the network now has one billion registered users with over 6000 tweets sent every second (Sayce 2019). Twitter allows users to send a message up to 280 characters in length and a tweet can contain links to other web-based content, user name and a user location. There are a number of emerging 'city toolkits' being developed around collecting a variety of social network feeds with links to geographic location, allowing the data to be understood and mapped at a city scale. One such system is CASA's own Big Data Toolkit[2] which allows the systematic mining of tweets and other social media feeds within a set radius of a location. This allows CASA to map not only the density of tweets but also to collect the text for sentiment analysis, described by Wilson et al. (2005) as the task of identifying positive and negative opinions, emotions and evaluations (Figure 26.3).

Data mining techniques, even via dedicated toolkits, are often limited in terms of the data they can analyse. The 'Twitter Streaming API' is a capability provided by Twitter that allows anyone to retrieve at most a 1% sample of all the data by providing some parameters on the nature of the tweets captured (Morstatter et al. 2013). The Big Data Toolkit used to create the Twitter map was developed to run on multiple cloud-based servers, increasing the percentage of tweets collected. These can be viewed as a sample of the so-called 'twitter-sphere' and thus potentially usable for analysis of the city. Hill (2008) notes in his article on

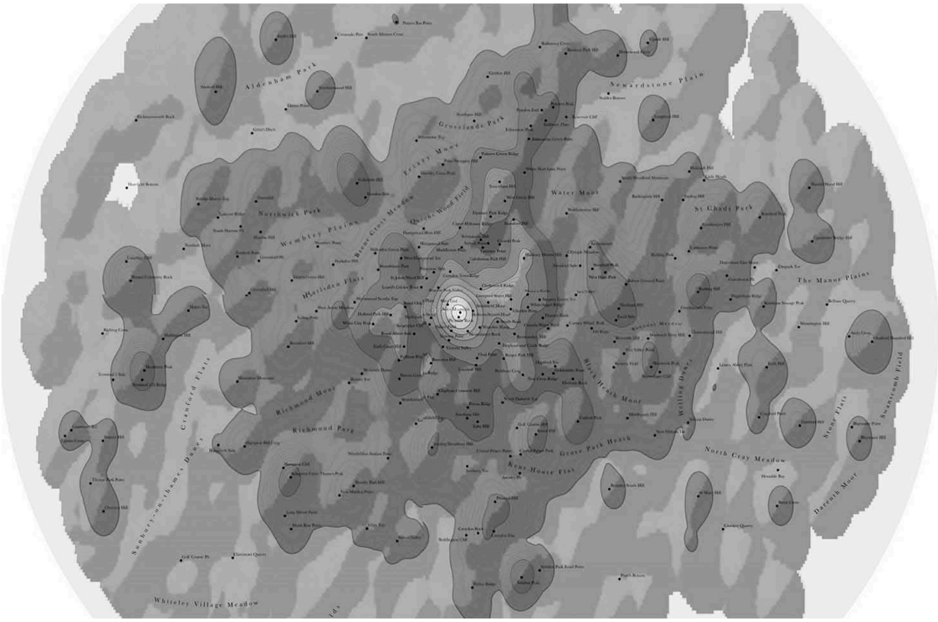

Figure 26.3 Mapping the density of tweets in Central London
Source: www.urbantick.org/

'The Street as a Platform' that we can see how the street is immersed in a twitching, pulsing cloud of data. This is over and above the other well-established sources of data: electromagnetic radiation, crackles of static, radio waves conveying radio and television broadcasts in digital and analogue forms, police voice traffic and so on, which represent the background behavioural data that characterise the city.

This is a new kind of data: both collective and individual, aggregated and discrete, open and closed, constantly logging impossibly detailed patterns of behaviour. The rise of social networks and our ability to communicate via mobile devices is resulting in an ever-growing amount of data being tagged with location. This enables a move towards a real-time view of the city, which at street level in Hill's (2008) view is that 'pulsing cloud of data' travelling outwards to the wider urban datascape or dataverse. Collecting not only more traditional datasets (such as transport, air pollution and building energy use) but also personal data is moving us toward a new view of the city from the urban scale down to the level of the citizen, the group and the crowd. At the present time, crowd-sourced data are arguably more accessible via data mining techniques than more traditional dataset sources. For example, in many cities transport data are still owned by private companies and closed off from public use, which means it is not constituting a part of any public data store or live feed. A similar position exists for energy usage, general utilities and wider city logistics data systems. Public data are increasingly being opened up, but private companies are for logistical or commercial reasons slower to open up feeds and share data. However, the wider public, mainly via mobile technology, are tagging and sharing data to such an extent that participatory sensing allows crowd-sourced datasets to begin to supplement and complement some of the traditional city-based information sources.

Data APIs

The idea of the city dashboard is an integral, but still emergent, part of the shift of the city from the idea of a server of data to a dynamic information system. Today's city dashboards are primarily aggregators of pre-existing data streams e.g. public transport, weather and environmental data, geo-tagged social media data and so on. As we have discussed, in the example of GLA's data market approach, dashboards can lead to a view of this data as merely a resource to be monetised, which as Mattern points out, can and often does impose a particular vision – that of the top-down, technocratic 'management' of city data (Mattern 2015).

Data dashboards are currently designed as 'glanceable' interfaces – ambient, comprehensible screens which quickly convey key information about the city. However, we argue that this concept of the dashboard does not offer the most promising and compelling opportunity for the connected and smart city. Instead it is the rather abstract concept which sees the city as a data server, as we introduced it earlier in the example of retrieving and querying data from a source such as Twitter through its API. This opens up a way for virtual location services, embedded devices (such as urban sensors) and even whole buildings and neighbourhoods to communicate with one another, using ever more elaborate sets of defined actions and messages. In practice, most of these APIs use various http protocols and the representational state transfer (REST) architectural approach (Severance 2015), both of which underlie much of the modern internet's functionality. When you take a photograph with your phone using the Instagram application for example, and a link to the picture can then appear in your Facebook timeline, a series of 'calls' to various APIs have by then been made: your phone makes an http request to the Instagram API, informing it that it wishes to upload a photo and the API responds with a 'go ahead' response. The image is then serialised and uploaded, and an 'OK' response is sent to the app. Conceptually, RESTful APIs can be seen as the lingua franca of today's internet; they are useful abstractions connecting disparate services and applications in a reliable and familiar way. In essence, urban sensor platforms are an attempt to extend the abstraction of an API to the physical world. APIs are not restricted to software; most consumer-grade urban sensors which have become available over the past decade have been capable of communicating with a remote API. It is these APIs which are opening the field of urban analytics within the domain of smart cities.

Visualising and utilising APIs: towards real-time urban analytics

We have highlighted this concept of 'smart' through the use of computers and computation which operate across wide spatial and temporal domains; that is many spatial and temporal scales but from the finest upwards. The focus on moving towards a self-monitoring, analysing and reporting city is on joining up or integrating operations and services and also disseminating the information associated with these activities to users through a variety of computable devices from regular PCs to smartphones. In this, ways of making sense of urban data are key and in the next section we will briefly illustrate the role of visualisation in this process. In addition, these systems, through their embedding into the built environment and their routine use by populations through hand-held devices ranging from smart cards to phones, are delivering large quantities of data about the way cities function. These have the ability to be streamed and archived in real time to either Cloud or local-based storage and analysis systems, thus providing a detailed spatio-temporal record of all that goes on in the functions that are being automated.

In all of this, artificial intelligence, expert systems, routine data mining and the construction of procedures which are automatically invoked are central to developing the concept of the smart city. In the past, many urban services, particularly those dealing with emergencies, have been automated. But now the focus is much more on aiding individuals in the population to make informed decisions with respect to the conditions they encounter, such as those involving the use of energy, transport and the routine purchase of goods. We have not quite reached a world where there is instant access to the internet wherever we are, but this is fast emerging as wireless systems begin to spread out, and phones and other devices are being adapted to searching out such access as the individual moves around the city.

This emergence of a range of advanced and easily accessible digital tools has enabled the realisation of such ideas which are no longer addressed exclusively to the professional, but with a focus on bringing routine information about the city, planning and urbanism closer to the public itself. Characteristic examples include Google Maps, urban themed games (such as Cities: Skylines[3]) and specialised 3D modelling platforms (such as ESRI's CityEngine[4]). These new software applications have facilitated the use of digital environments for testing the consequences of physical planning policies on the future form of cities and are rapidly becoming powerful tools for distributing and communicating spatial information worldwide (Batty, Steadman and Xie 2004).

In the next section we will discuss some examples exploring the use of digital tools and methods which, based on live feeds and open information, will expand city dashboards into a form of dynamic 3D urban analytics. Visualisation lies at the essence of this activity and one thing we examine here is many of the new functions of geographic information systems. One such example is the variability of such information in a 3D spatial context and increasingly these are likely to become available to the non-expert citizens and in the not too distant future digital twins. Finally, we will outline how these systems could be used for understanding the possibilities, problems and consequences of exploring different scenarios relating to the actual form of the future city, thus paving the way for new forms of real-time public participation.

Real-time urban analytics: digital twins

Currently, there are several methods for introducing mined or crowd-sourced data into 3D visual modelling applications. Data, often collected through the use of an API, can be fed into a variety of applications for visualisation purposes, analysis and further editing. As a general requirement, these systems need to have extended editing capabilities such as scripting consoles and specialised libraries. One such example builds on the previously illustrated Twitter map in Figure 26.3 and its visualisation in 3D using CityEngine (Parish and Muller 2001) in order to create a digital twin. This takes the concept of collecting geolocated tweets and placing them into a 3D procedural system for creating data visualisation algorithmically as opposed to manually (Figure 26.4). Tweet City,[5] as the project is known, was developed to create a new 3D urban landscape utilising the Twitter API (Hügel and Roumpani 2013). It allows the user not only to develop different visualisations by editing simple rules but also to develop more sophisticated types of analysis based around city data feeds.

The key advantage of moving city data feeds into a procedural geographic information system is the ability to introduce more advanced spatial analysis functions within real-time data mining. The project aims to include multiple data feeds, such as air quality readings through tracking down enough air quality sensors to form accurate, pinpoint pollution

Figure 26.4 Live Twitter feeds (2015) in London visualised as building heights
Source: Chapter author(s)

estimates. The system operates online and, linked to a 3D representation of the city, it extends the concept of a city dashboard towards one integrating wider data feeds into a 3D model visualisation. The real-time data from the city can be visualised on a city-wide or hyper-local urban scale through the 3D interface. The move to a more 'urban' view of the data and its placement in a geolocated reference frame, whilst still maintaining real-time reporting, further develops the concept of a digital twin for London. It is, therefore, possible to produce fully dynamic 3D city scenes, which can be instantly edited from data feeds (as in the case of Tweet City). The interface can offer generic procedures for developing rules that mirror how cities work in terms of their patterns, movement and location.

Next steps: smarter cities, digital twins

These proofs of concept, the London data dashboard and Tweet City, demonstrate the real-time visualisation of urban data, with the latter providing a method for the development of simulations directly in a virtual 3D urban environment. Moreover, they explore the ways in which new means of visualisation and interactivity can aid in the better understanding of the complexity of spatial interaction, flows and patterns of information in cities via what we have defined as self-monitoring, analysis and reporting technologies. In this sense, we view them as being a core part of the emerging smart city. They provide a method in which they facilitate the development of models and introduction of data feeds within urban environments, defining the advantages, limitations and possibilities of the use of models. In relation to planning scenarios, these tools as ways of interacting and visualising data feeds can be used to test the decision-making consequences of urban planning actions on the fly and in real time. This is leading to the introduction of more complex data feeds which will provide a deeper insight into issues such as identifying possible solutions for optimising systems for the allocation of new social infrastructures. These types of method create an intelligent data analytic toolkit: the combination of city dashboard style feeds and the data streams linked to such 3D data models have potential to not only enhance the current state of the city reporting but also self-monitoring.

We are at the beginning of a new era in our understanding of the city, with a shift in the role of government and the citizen in creating, sharing and understanding data which are fed to a variety of stakeholders in real time. It is perhaps also a shift towards the development of a true 'smart city', one that is not only able to self-monitor, analyse and report but also respond. It is a city that ultimately will become self-aware in data terms of its own operations, mirrored via the creation of a digital twin and one that can adapt its infrastructure and services accordingly to be truly 'smart' – or any term it has since been replaced with.

Notes

1 www.citydashboard.org.
2 http://bigdatatoolkit.org.
3 www.paradoxplaza.com/cities-skylines/CSCS00GSK-MASTER.html.
4 www.esri.com/en-us/arcgis/products/esri-cityengine/overview.
5 Tweet City is available for download and online experimentation http://urschrei.github.io/CityEngine-Twitter/.

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