Supplementary Data

Table S1. Summary of definitions of the Internet of Things (IofT), Big (Urban) Data and Urban Informatics/Analytics.

Internet of Things (IoT)	Big (Urban) Data	Urban Informatics/Analytics
…"has six elements"… "identification, sensing, communication technologies, computation, services and semantics"[3]	"…refers to structured and unstructured data generated naturally as part of a transactional, operational, planning and social activities, or the linkage of such data to purposefully designed data." [14]	" …the exploration and understanding of urban systems resource management, knowledge discovery of patterns and dynamics, urban engagement and civic participation, and planning and policy analysis." [14]
"…a drive to incorporate networked computation into the fabric and furniture of daily life…" [4]	"…structured and unstructured data generated naturally as part of transactional, operational planning and social activities, or the linkage of such data to purposefully designed data." [15]	"…the exploration and understanding of urban patterns and processes…" involving "…analyzing, visualizing, understanding and interpreting structured and unstructured urban big data…" for " 1. Dynamic resource management; 2. Knowledge discovery and understanding; 3. Urban engagement and participations; and 4. Urban planning and policy analysis…" [14]
"…cloud computing is an attempt to consolidate computational capacity in a small number of centralised sites, then the IofTs is an attempt to decentralise it once more and distribute it through myriad devices in every home, In every room and at every opportunity." [4]	"…a huge amount of data collected from the subjects and objects, including people, companies and other urban facilities." [3]	"…the study of urban patterns using novel sources of urban big data that is undertaken from both a theory-driven empirical perspective as well as a data-driven perspective for the purpose of urban resource management, knowledge discovery and understanding, urban engagement and civic participation, and planning and policy implementation." [14]
"…a large and growing amalgamation of devices and sensors connected to the Internet, is actively monitoring many aspects of our lives and environment…" [5]	"…the three dimensions of big data: volume, variety and velocity …[3Vs] …"have been accepted as a widespread big data concept." [3] which is a view other echo [16] To this others add "variability" and "value" [17]	"…the study, design and practice of urban experience across different urban contexts that are created by new opportunities for real-time, ubiquitous technology and the augmentation that mediates the physical and digital layers of people, network and urban infrastructures." [28]
"…or as some prefer – the Internet of Everything, consists of billions and billions of devices and sensors connected to the Internet, but also to each other in an intricately networked fashion…" [6]	"…is a rapidly expanding research area spanning the fields of computer science and data science and has become a ubiquitous term in understanding and solving complex problems in different disciplinary fields..." [7]	…the scientific use of data and technology to study the status, needs, challenges and opportunities for cities…" [29]

"…refers to a computationally augmented everyday environment where the physical world (everyday objects) and informational world are integrated within ever-growing Internet infrastructure via a wide range of active and smart sensing devices…" "…as an intriguing construct that is evolving into more and more sophisticated network of (sensor) devices and physical objects…" including "….people, roads, railways, bridges, streets, buildings, water systems, electrical networks, vehicles, appliances, goods, machines, animals, plants, soil and air…" [7]	"…to describe the growth, proliferation, heterogeneity, complexity, availability, temporality, changeability and utilization of data across many application domains…" [7]	"…the exploration and understanding of urban patterns and processes which involves analyzing, visualizing, understanding and interpreting structured and unstructured urban big data." [30]
"…is closely related to the concepts of Machine-to-Machine (M2M) communications and Wireless Sensor Networks (WSN) on the connectivity side, and to Big Data in terms of the content outcomes produced…" "…also comprises the data produced and transmitted between machines (M2M), as well as between machines and people (M2P). Key elements include machine-produced data (e.g., from sensors), and the communication of that data (via connectivity technologies)." [8]	"…is now generally defined in terms of four core dimensions: volume, velocity, variety and veracity – colloquially referred to as the '4Vs'…" [45]	"…The study, design, and practice of urban experiences across different urban contexts that are created by new opportunities of real-time, ubiquitous technology and the augmentation that mediates the physical and digital layers of people networks and urban infrastructures…" [31] "…constitutes 'the collection, classification, storage, retrieval, and dissemination of recorded knowledge' both in and of the city…" [32] "…emerged to respond to this increasingly mobile, pervasive nature of computing, ready to claim as its subject the everyday urban conditions of ubiquitous computing…" [32]
"…a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving technologies…" "…clearly includes M2M (referring specifically to communication directly between devices, and used in a vast array of applications and for a variety of purposes, but broader definitions of IofT technologies also include	"…is fast moving …" …heterogeneous in formats…"…messy with varying levels of fidelity and reliability…" [5]	"…Big data…requires a very different set of techniques and methods…urban analytics – to make sense of it…" [33]

ambient intelligence and smart environments." [8]		
"…(comprising connected devices and connected environments, such as M2M and M2P) and Big Data are separate, but related concepts." [8]	"…everything captured or recorded digitally by information and communication technologies like networked sensors, 'smart' devices, the web and social media." [18]	"… to any vast amount of data that has the potential to be collected, stored, retrieved, integrated, selected, pre-processed, transformed, analysed, and interpreted for discovering new or extracting useful knowledge…" [21]
"…is characterized by using smart and self-configuring objects that can interact with each other via global network infrastructure." [9]	"…is a form of data that exceeds the processing capabilities of traditional database infrastructure… … or engines…" [17]	"…deals with the processing of information particularly via network technologies." [31]
"…wherein sensors and actuators blend seamlessly with the environment around us, and the information is shared across platforms in order to develop a common operating picture (COP)." [10]	"…massive amounts of recently created digital data…" [19]	"… two main stages: data management and data analytics. Data management is to collect and store the data as well a clean and retrieve the data for the analysis preparation. The other process is data analytics, which deals with extracting insights from the data. It involves modelling, analysis and interpretation. [9]
"… can be realized in three paradigms – Internet-oriented (middleware), things oriented (sensors) and semantic-oriented (knowledge). [10]	"…refer not only to data, but also to the tools and practices for analysing, processing and managing these massive, complex and rapidly evolving data sets…"…terms big data and big data analytics…" are"…interchangeable…" [19]	"…seek to gain insights 'born from data'." [22]
"…Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework." [10]	"…not in terms of a lot of data but complex data that can reveal patterns useful to understand, that aren't evident without analysing the data…" "…as a variety of data, put together from various sources to come together in a meaningful way…" "…any human activity that leaves digital traces, which does not have immediate meaning, but when combined together give some meaningful pattern…" [16]	"...offering the possibility of studies shifting from: data-scarce to data-rich; static snapshots to dynamic unfoldings; coarse aggregation to high resolution; relatively simple hypotheses and models to more complex, sophisticated simulations and theories." [34]
"…in which everyday objects and devices are connected to the network technologies." [11]	"…are distributed databases that have a specific focus on data analysis and analytics – as opposed to transactions…" [20]	"…that utilize machine learning techniques designed to process and analyse enormous datasets, such as data mining and pattern recognition, data visualization and visual analytics, statistical analysis, and prediction, simulation and optimization modelling." [35]
"…includes four main components: 1) sensors, 2)	"…is used to describe the growth, proliferation, heterogeneity,	"…the study of urban phenomena through a data

processing networks, 3) data analysis data, and 4) system monitoring," [12]	complexity, availability, temporality, changeability, and utilization of data across many application domains." [7]	science framework of urban sensing, data mining and integration, modelling and analysis, and visualization to generate new insights that simultaneously advance methods in computational science and address domain-specific urban challenges. It is focused on urban computing and computer science techniques to explore, describe, predict, and to a lesser extent, explain urban phenomena with the intent of applying new knowledge that can be used by domain experts to solve problems."…"…brings together aspects of computer science, physics, operations research, management science, decision sciences, and urban planning." [36]
"…consists of a vast number of different devices that are connected with each other and transmit huge amounts of data." [12]	"…has been classified according to five fundamental elements, which are volume (size of data), variety (different types of data from several sources), velocity (data collected in real time), veracity (uncertainty of data) and value (benefits to various industrial and academic fields)." …."additional characteristics beyond the 5V's model such as: validity (correct processing of the data), variability (context of data), viscosity (latency data transmission between the source and destination), virality (speed of the data sent and received from various sources) and visualization (interpretation of data and identification of the most relevant information for the users)…" have been added. [9]	"…the combination of different scientific fields that uses data mining, machine learning, and other techniques to find patterns and new insights from data." [12]
"…networked sensors and devices, cameras, smartphones, social media, and diverse interactions and transactions across networked systems." [13]	"…is huge in volume, consisting of terabytes or petabytes of data; high in velocity, being created in or near real-time; diverse in variety, being structured and unstructured in nature; exhaustive in scope striving to capture entire populations or systems (n=all);" [22, p. 1]	"…is the emerging set of tools and methods to manage and analyse this explosive growth of digital information. It includes data science methods such as machine learning, predictive analytics and visualization." [24]
	"…consists of massive, dynamic, varied, detailed, inter-related, low cost datasets that can be connected and utilised in diverse way," [30]	"…refers to the entire processes and tools required for knowledge discovery including data extraction, transformation, loading and analysis; specific tools, techniques, and methods;

		and how to successfully provide results to decision makers.” [25]
	“…generally refers to large and complex sets of data that represent digital traces of human activities and may be defined in terms of scale or volume, analysis methods.” [23]	“…the practice of using new forms of data in combination with computational approaches to gain insight into urban processes.” [37]
	“…is defined as high-volume, high-velocity, and high variety data that demands cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation.” [12]	“…provides the tools, technologies and processes for this new data-intensive science of cities.“ [37]
	“…is an umbrella term used to describe the constantly increasing flows of data emitted from connected individuals and things, as well as a new generation of approaches being used to deliver insight and value from these data flows.” [24]	
	“…is a natural crop of the advanced digital artefacts and their applications. Mobiles, sensors and Social Media Networks are examples of modern digital technologies that have permeated our daily lives.” [25]	
	“…is commonly characterised by four Vs characteristics: Volume, Velocity, Variety and Veracity.” [25]	
	“…is a massive amount of dynamic and static data generated from the subjects and objects including various urban facilities, organizations, and individuals, which have been being collected and collated by city governments, public institutions, enterprises, and individuals using new generation information technologies.” (26]	
	“…is a fantasy concept around the world.” [27]	

Figure S1. Big (Urban) Data Word Cloud generated by the Wordle App.

Figure S2. Urban Informatics/Analytics Word Cloud generated by the Wordle App.

Table S2. Overview of the Hype and Challenges around Big Data and Urban Informatics/Analytics.

Hype (claims)	Challenges
"…major potential of urban informatics research and applications is in 4 areas (1) Improved strategies for dynamic urban resource management; (2) theoretical insights and knowledge discovery of urban patterns and processes; (3) strategies for	"…caution the potential of serious methodological costs and call on efforts to find ways of integrating these data sources, which have different qualities that make them valuable to understand cities." [41]

urban engagement and civic participation, and (4) innovations in urban management and planning and policy analysis." [14]	
"…Big data: a revolution that will transform how we live, work, and think." [15]	"…the difficulty in controlling the quality and quantity of the data, and privacy issues." [41]
"…the joining of access and data, will enable cities to become "smarter' and even more interconnected. In addition, the rise of automation, greater real-time data collection, and predictive analytic capabilities, are significantly modifying who are making and decisions and how decisions are being made." [28]	"…the use of Big Data for Urban Informatics are: (1) technological; (2) methodological; (3) theoretical and epistemological; and (4) due to political economy that arises from accessing and using the data." [14]
"… Big Data has the potential, especially for metropolis to get valuable insights from huge amounts of data which is collected from a variety of sources." [3]	"…technological challenges arise due to the need to generate, capture, manage, process, disseminate and discover urban information." [14]
"…Big data analytics and context aware computing provide a very rich nexus of possibilities in terms of providing support to citizens and urban entities in their activities…" [7]	"…Big Data…tends to be fragmented, messy and sometimes unstructured. Particularly for data linkage, when one goes beyond structured, rectangular databases to streaming data through APIs leading to text, image and other unstructured data formats, the diversity and fragmentation can pose significant problems." [14]
"…Furthermore, there is a variety potential uses of big data to address problems directly from the source as well as analytics for deeper insights through data analytics, data intelligence and data mining." [17]	"…Given the vast and dispersed sources of Big Data, resource discovery mechanisms to explore and understand data are critical." [14]
"…In general a smart city will improve governance, enhance the economic standing of the city, improve the quality of life of its citizens, and help create an environmentally friendly and sustainable infrastructures." [17]	"…methodological aspects of Big Data such as information retrieval, linkage and curation or the political economy of Big Data including data access, governance, privacy, and trust management may have IT requirements that could limit the availability of data for urban research," [14
"…Urban governance decisions emerging from the reading of data and modern technologies has been proven more efficient, citizen-oriented and sustainable. This is because data is now available in almost near real-time; hence, facilitating timely and quality decisions." [38]	"…There is a need for greater and more general understanding of how Big Data sets are constructed." [15]
"…With this Big Data, city managers, governments, businesses and other stakeholders have the possibility to customise services appropriately." [38]	"…Big Data is not yet transparent and most Big Data is proprietary and commercially controlled, and the methods employed to analyze these data are seldom described in a manner that would facilitate replication." [15]
"…The "low-hanging fruit" of urban big data still lies in the innumerable opportunities for the improvement of municipal services." [38]	"…We are witnessing a shift in data ownership where private companies are collecting, managing and analysing urban data." [28]
"…As such, the IofT and related big data applications can play a key role in catalysing and improving the process of environmentally sustainable development." [21]	"…overemphasis on technologies and its ability to solve urban challenges becomes more problematic in emerging economies. Developing countries lack infrastructure and significant resources for investing in technologies to transform cities." [28]
"…more research in the related big data applications is imperative, and once this novel technology has successfully been implemented in terms of its big data	"…blindly investing in technologies will not result in transforming cities that are liveable, sustainable and resilient." [28]

applications, the benefits and opportunities will be tremendous in the context of smart sustainable cities of the future." [21]	
"…Huge new opportunities are now opening up through improved access to and use of Big Data techniques, which offer learning opportunities to improve real-world processes and enhance decision-making over the short-, medium- and long-term in healthcare, education, emergency services and disaster response, among a variety of other application areas." [8]	"…Lack of data science skills in organizations, organizational cultures that are not leading to data driven operations or data driven decision making are another barrier." [3]
"…When all stakeholders are included in active dialogue, the IofT represents a promising opportunity for more coherent policy-making and implementation." [8]	"…most challenges are associated with the designing, developing and deploying big data…" [42]
"…The fusion of Big Data and IofT technologies has created opportunities for the development of services for many complex systems like Smart Cities." [9, p. 602]	"…these are related to accessible big data tools, real-time analytics, precision, illustration, cost and accessibility." [42]
"…At the same time, Big Data and technologies have opened new application opportunities for industry and academia to develop new IoT solutions." [9]	"…data and information sharing amongst various cities and departments is a big challenge." [42]
"…In recent years, big data and smart cities have become buzzwords for the use of new data methods to provide robust, empirical evidence for urban policy-making." [39]	"…it is a big challenge…to secure movement of data across multiple sources." [42]
"…The "big data" revolution will fundamentally change urban science. Big data turns a cross section of space into living data, offering a broader finer picture of urban life than has ever been available before. Moreover, in combination with predictive algorithms, big data may allow us to extrapolate outcome variables to previously unmeasured parts of the population." [40]	"…Lacking data skills can be the obstacle for the effective utilization of big data…The management and analysis of huge data sets and the development of insights for making effective policies needs skills which are not always available in the public sector." [42]
"…Fuelled by the recent adaptation of a variety of enabling wireless technologies such as RFID tags and embedded sensor and actuator nodes, the IoT has stepped out of its infancy and is the next revolutionary technology in transforming the Internet into a fully integrated Future Internet." [10]	"…Challenges are mostly scientific, computational, and analytical in nature. They include: constraints of design science and engineering; data management and analysis; database integration across urban domains; privacy and security; data growth and sharing; data uncertainty and incompleteness; data quality; intelligence functions and simulation models; modelling and management of contextual information in large-scale distributed pervasive applications in an open and dynamic pervasive environments…" [7]
"…Big data offers the potential for the city to obtain valuable insights from a considerable amount of data collected through various sources." (11, p. 748)	"…the scale, heterogeneity, and velocity of urban data makes it difficult to manage, integrate, process, analyze, evaluate and deploy…" [7]
"…Big data can achieve its goals and can advance the services in smart cities using the right tools and methods for efficient and effective data analysis. [11]	"…larger datasets tend to be more convoluted, computationally intensive and difficult to manage, analyze and document than smaller datasets, which contributes to a range of issues related to data curation,

	data sharing, data quality assurance, data processing and manipulation and analysis…" [5]
"…Real-time interaction and communication with IoT technologies, big data applications, and the huge amount of stakeholder's information can be used resiliently and sustainably, thereby allowing them to reach their full potential." [11]	"…A greater challenge than data capture itself appears to be understanding the best utilization of often huge and unwieldly datasets from multiple and disparate sources to answer new question." [18]
"…Such data, smart city advocates argue enables real-time analysis of city life, new modes of urban governance, and provides the raw material for envisioning and enacting more efficient, sustainable, competitive, productive, open and transparent cities." [34]	"Big data …the sheer amount of it can make analysis quite difficult." [18]
"…For city officials, national governments and supra-national states such as the European Union, smart cities offer the enticing potential of social-economic progress – more liveable, secure, functional, competitive and sustainable cities, and the renewal of urban hubs of innovation and work." [34]	"…Existing information technology systems and traditional data analysis techniques are not designed to clean, measure, mine, manage or maintain big data sets…lack of infrastructure at city levels to analyze community-wide data …local governments and their planning departments may not have the resources to integrate findings into useful outcomes…utilizing big data to better understand urban functions is an increasing need in local governance and often appears inaccessible outside a lab setting." [18]
"…The hype and hope of big data is a transformation in the knowledge and governance of cities through the creation of a data deluge that seeks to provide much more sophisticated, wide-scale, fine-grained, real-time understanding and control of urbanity." [34]	"…challenge becomes organizing the existing data points in a meaningful way to allow comparisons and analysis of multiple data within cities and regions." [18]
	"…Those who make urban policies – e.g. urban planners and policy makers – are not often equipped with the tools and education needed to translate complex scientific outcomes into policies." [43]
	"…Interoperability, harmony of data from one system with another, is a potential in the way of IoT expansion. [44]
	"…Just trying to encompass these different attributes of big data generates very complex models and approaches and make it hard to manage." [17]
	"…Sharing data and information among different city departments is another challenge." [17]
	"…These barriers include outdated IT infrastructure, the inherent complexity and messiness of big data, the lack of data science skills within organizations, privacy concerns, organizational cultures that are not conducive to data-driven operations or data-driven decision making." [4]
	"…These barriers range from developing new employee skills and upgrading IT infrastructure, to instilling new management practices or a new organizational culture across the entire organization." [19]
	"…Currently, the lack of employees with big data or general analytics skills is one of the major challenges facing organizations seeking to embrace bit data." [19]
	"…fully unleashing the power of data analytics will require better coordination across government agencies,

	standardization of data and software, and moving along the learning curve with regard to which applications are cost effective." [16]
	"…most municipal governments will not have the capability to move toward full smart city concepts." [16]
	"…Once enthusiastic proponents of urban informatics have cautioned against the co-optation of platform technologies by corporate power, particularly in relation to the smart city." [32]
	"…It is however the difficulties over integrating big data with other big or small data sets that is the key limitation." [33]
	"…The key challenge is to enable us to direct big data onto key problems of appropriate urban representational analysis so that we can use it to inform and extend our conditional predictive abilities and to focus it on methods for informing urban designers and planners seeking to generate alternative urban futures." [33]
	"..big data analytics broadly speaking suffers from inflated hype and expectation." [20]
	"…These challenges are mostly scientific, computational, and analytical in nature...: constraints of design science and engineering; data analysis and evaluation; management of IofT data produced in dynamic and volatile environments; database integration across urban domains; privacy and security; establishing context (e.g. geolocation and time); data growth and sharing; data uncertainty and incompleteness; data accuracy/quality and veracity; intelligence functions and simulation models; fault tolerance and scalability; data storage and processing." [21]
	"…challenges of big data analytics …the scale, heterogeneity, and velocity of urban data makes it difficult to manage, integrate, process, analyze, and evaluate in order to deploy the resulting knowledge." [21]
	"…Adding to these primarily technical challenges are the financial, organizational, institutional, regulatory, and ethical ones, which are associated with the implementation, retention, and dissemination of bit data across the domains and entities of smart sustainable cities." [21]
	"…These challenges are of computational, analytical, and technological kinds." [21]
	"…organizations are developing smart city systems that are not compatible with those of the municipality or other stakeholders, limiting their use." (39, p. 947]
	"…In its current form, data collection and analysis is at an early stage." [39]
	"…There are still various kinds of difficulties of big data application in urban studies and planning practices, such as the difficulty of data acquisition, privacy protection and correlation not reflecting causality." [45]
	"…data integration within the smart city is one of the important challenges to be addressed." [11]
	"…When the capacity of the data set increases, the effectiveness, efficiency, and robustness of the computational intelligence algorithms normally diminish, thereby making them inappropriate for exploring

	knowledge in big data generated from the smart city." [11]
	"…The challenge of analysing Big Data is coping with abundance, exhaustivity and variety, timeliness and dynamism, messiness and uncertainty, high relationality, and the fact that much of what is generated has no specific question in mind or is a by-product of another activity." [22]
	"…challenges posed by urban big data: (1) how to handle and make sense of millions or billions of observations that are being generated on a dynamic basis and (ii) how to translate the insight derived into new urban theory (fundamental knowledge) and actionable outcomes (applied knowledge)" [35]
	"…new data analytics …techniques are largely in their infancy given that traditional statistical methods were designed to perform data-scarce science; that is, identify significant relationships from small, clean sample sizes with known properties." [35]
	"…Most cities lack the fundamental computing and database infrastructure to support big data analytics." [36]
	"…The abstraction of IofT data is low; that is, the data that comes from different resources in IofT consists mostly of raw data, and not sufficient for analysis." (12]
	"…Analytics alone cannot create better cities." [24]
	"…However, the integration of multiple smart components is not an easy task, in other words integration could be the most challenging task when deploying a real world smart city." [46]
	"…However, big data complexities comprise non-trivial challenges for the processes of big data analytics." [25]
	"…data integration …security…technological…lack of sustainability…skills shortage." [26]
	"…However, such a heterogeneous field of application makes the identification of solutions capable of satisfying the requirements of all possible application scenarios a formidable challenge." [47]
	"…with database quality, linkage and preservation of anonymity." [48]
	"…data (un)availability remains the key limiting factor preventing the widespread use of more rigorous approaches." [48]

Figure S3. Hype around Urban Informatics/Analytics Word Cloud generated by the Wordle app.

Figure S4. Challenges around Urban Informatics/Analytics Word Cloud generated by the Wordle app.