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Big Data in Smart Cities: A Critical Literature Review

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ABSTRACT

Population growth, urbanisation and climate change are some of today's most significant challenges. Deploying big data and technologies to cities can potentially mitigate the countless problems faced by society. However, regardless of the numerous opportunities, concerns are being raised regarding data biases, privacy and the increase in surveillance. This literature review aims to assess the existing research on the topic of big data in smart cities in a critical manner to showcase divergences by scrutinising the topic from various perspectives. First, arguments underpinned by the bounded technical-rational view are outlined, including technical possibilities and best practice examples of smart cities. Attention then turns to socially embedded assumptions, questioning the overall utility of smart city initiatives. In conclusion, this review reveals an area for further research to explore: leveraging big data in smart cities to benefit all stakeholders.

1 Introduction

T Big data in smart cities provokes both utopian and dystopian rhetoric (Boyd and Crawford, 2012; Shin and Choi, 2015). On the one hand, an idealistic, almost hyperbolic, view of big data is being drawn in the literature. The phenomenon, framed as a revolutionary technical tool, leverages data for the generation of novel and unique insights, creating significant opportunities not only for businesses but also for public organisations and entire societies (Boyd and Crawford, 2012; Frith, 2017). Urban researchers extensively outline the possibilities of big data and analytics, drawing a utopian world of data-driven, highly efficient cities (Frith, 2017). On the other hand, several scholars build on the socio-technical school of thought and provide a more nuanced view of big data and smart cities by including political and societal dimensions. Some even present a dystopian view on data-driven cities by highlighting various implications (Kitchin, 2014b; Shin and Choi, 2015).

This review aims to critically assess the current literature on big data in smart cities to identify different points of contention regarding the use of big data in urban environments. Smart cities are predominantly seen as a holistic concept and a socio-technical phenomenon (Albino et al., 2015). This review, therefore, follows the definition by Bakici et al. (2012) describing a smart city as an "high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality" (ibid.). To reveal the utopian and dystopian view of big data in smart cities, the interests of various stakeholders as well as the divergences, the topic is scrutinised from multiple perspectives with their underlying assumptions.

First, the literature underpinned by the bounded technical-rational view is analysed, including its engineering and managerial rationality. The perspectives focus on technological aspects and best practices. Second, the underlying assumptions and arguments made by scholars within the literature of the socially embedded view are examined, including more reflective and questioning stances (Avgerou, 2019). As few scholars have followed a formal-technical rational approach to explore the topic of big data and smart cities, this perspective is only briefly discussed. Finally, the conclusion summarises the different perspectives and highlights relevant research gaps. Because of the interdisciplinarity of the topic, 21st-century, peer-reviewed articles were examined not only in the fields of information systems and management but also in cities, urban technology and government. To identify relevant papers, keywords in conjunction with smart cities* such as big data, Internet of Things, citizen centricity*, social* and privacy were selected to search the LSE Library Database, ABI/INFORM Database and Google Scholar. Articles were classified as relevant if the main topic was related to big data in smart cities and if one or more of the perspectives mentioned above were addressed. For the final selection, research papers not adding variety were rejected.

2 Bounded technical-rational perspectives

Whereas the formal technical-rational approach looks for an optimal solution, the bounded technical-rational view accepts satisfactory results due to various restrictions, such as the limited cognitive abilities of practitioners, information (un)availability, uncertainty and complexity (Avgerou, 2019). In the following section, the underlying assumptions

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within the bounded technical-rational perspective are examined and contrasted.

2.1 Engineering rationality: Leveraging big data to build a smart city

The literature within engineering rationality focuses on the prominent assumption that with sufficient technology, cities' efficiency and the citizens' quality of life can be enhanced (Stone et al., 2018). The academic discourse sees information communication technology (ICT) as a core component and emphasises the importance of big data in smart cities as it is seen as a key enabler for data-driven urban projects. Valuable real-time insights are revealed and provide endless possibilities (Al Nuaimi et al., 2015; Kitchin, 2014b). The emerging literature characterises big data as being high in volume, velocity and variety (Kitchin, 2014b). Scholars enumerate various sources for big data in cities, including the Internet of Things (IoT) and data gleaned from surveillance or provided by citizens. Furthermore, the authors highlight the necessity to connect and integrate data sources to enable data analytics and derive valuable insights (Aguilera et al., 2017; Hashem et al., 2016; Kitchin, 2014b). It is important to note that smart city literature predominantly focuses on leveraging data generated by the IoT.

Some of the core notions underlying the academic discourse on smart cities have changed over the past decade. Specifically, the integration of IoT data and other sources was seen as a prominent technological challenge (Su et al., 2011). However, due to recent technological advances, platforms and cloud-computing now offer solutions to overcome the integration issue (Al Nuaimi et al., 2015; Hashem et al., 2016; Stone et al., 2018). Some researchers even draw a futuristic, utopian picture of cities. By coining the terms 'instrumental rationality' (Mattern, 2013) and 'solutionism' (Morozov, 2013), the academics rather follow a more formal- than bounded-rational approach. The scholars argue that datafication and computation enable the seamless monitoring of a city. In addition, the authors claim that leveraging insights through data analysis would result in a flawlessly functioning city, eliminating all inefficiencies (Mattern, 2013; Morozov, 2013).

However, despite technological advances, most researchers (Degbelo et al., 2016; Frith, 2017; Kitchin, 2014b) continue to recognise significant challenges, opposing the picture drawn by Mattern (2013) and Morozov (2013). Frith (2017) stresses the importance of formatting and analysing data through algorithms; otherwise, data will not reveal valuable insights. The challenge of data management and the harmonisation of various data formats is also addressed by Al Nuaimi et al. (2015) and Hashem et al. (2016). Both researchers claim that advanced algorithms and enormous computational power, which do not yet exist, are required to handle the complexity of data. This view is shared by Kitchin (2014b), who argues that although algorithms may conduct some data analysis, many processes still require human analysts, particularly concerning interpretation. Given these realities, Frith (2017) notes the importance of employing educated professionals, equipped with a sufficient understanding of metadata and database structure, to undertake these tasks. The author highlights that little research has been conducted on how employees interpret data and on which bases decisions are reached.

In conclusion, the literature outlines the available technologies and tools to enhance the efficiency and the quality of life within cities. However, the majority of academics continue to see technical limitations and the need for human involvement, supporting the bounded-rational rather than the formal-rational view of smart cities.

2.2 Managerial rationality: Deriving at best practices

The literature underpinned by a managerial view explores practices and principles that can be followed, defined by rational techniques, to achieve a desirable objective (Avgerou, 2019). The literature includes several case studies of smart city initiatives to derive best practices for city planners, endeavouring to overcome the technological challenges. Frameworks and roadmaps are created, ensuring seamless development and implementation of smart city initiatives with minimal cost involved. However, controversies in the academic discourse arise when scholars criticise best practices developed by corporations. It is claimed that these 'smart-city-in-a-box' solutions fail to prioritise the well-being of residents, suggesting a need for more citizen-centric practices (Aguilera et al., 2017; Kitchin, 2014b). Hereafter, the underlying arguments within the literature of the managerial rationality are outlined and contrasted to provide an overview of this perspective. Several researchers have conducted case studies of smart city projects, funded by corporations to frame best practices (Consoli et al., 2017; Cheng et al., 2015; Lee et al., 2014). Cheng et al. (2015) highlight that various studies have been performed regarding the implementation of sensors and data collection. However, the authors stress the need for flexible data platforms to leverage connected data. Hence, they investigated the platform CiDAP in Santander, Spain, to provide a design example of a data platform. The platform aims to analyse both historical and real-time data produced by over 2000 IoT devices within the city (Braun et al., 2018). Furthermore, best practices are outlined, including the management of multiple data sources and the support of data semantics. Consoli et al. (2017) re-direct the academic discourse towards the challenge of data integration, offering a government data model for smart cities. However, scholars note that the integration of data from heterogeneous sources remains problematic (Cheng et al., 2015; Lee et al., 2014).

In contrast, other researchers have taken a more holistic approach to smart cities, examining them as entire organisms (Ahlers et al., 2016). From this perspective, smart city initiatives conducted by corporations, and partly governments, are criticised as a top-down approach. While corporations often focus on their return on investment, the public sector is driven by increasing cities' attractiveness and economic stance, losing sight of the population's needs

(Alawadhi et al., 2012; Kitchin, 2014a). Ahlers et al. (2016) promote the active involvement of inhabitants within the planning and development process following a bottom-up approach to understand the needs of the wider society. Although scholars agree with the underlying assumption of the importance of user-centricity, many fail to outline how this can be achieved (e.g. Ahlers et al., 2016; Gupta, Chauhan, and Jaiswal, 2019). Aguilera et al. (2017) and Degbelo et al. (2016) are some of the few scholars filling this research gap. The authors suggest practices to build smart cities by combining existing infrastructure and leveraging citizen-produced data. An open data city approach is applied, allowing for easy data access by various stakeholders, therefore serving not only smart city initiators but society as a whole.

Lastly, it is noted that few scholars have developed a strategic roadmap and holistic framework for smart city projects. Al Nuaimi et al. (2015) highlight that planning a smart city goes beyond standalone initiatives and projects. It involves the consideration of social and technological requirements and various stakeholder needs. The researchers offer a roadmap and practices to follow when planning a smart city; however, these remain superficial. In contrast, Lee et al. (2014) develop a more comprehensive framework by studying Seoul and San Francisco, considering both technological and institutional aspects. Overall, academic consensus shows the need for further case studies to create effective, holistic best practices for smart city development (Lee et al. 2014; Scuotto et al. 2016).

3 Socially embedded perspective: Implications for society

Academics focussing on the socially embedded view take a more reflective, philosophical perspective on the broader implications of leveraging data to connect cities. The potential consequences for society are evaluated, and occasionally, academics question smart city movements (Avgerou, 2019; Tierney, 2019). Considering the motivations behind smart city initiatives, the literature underpinned by the socially embedded perspective debates the various consequences and implications for urban residents.

The academic discourse questions the core notion of smart cities resulting in a higher quality of life. It is claimed that urban projects, often funded by multinational corporations, are primarily profit-driven rather than citizen-centric (Braun et al., 2018; Tierney, 2019). Not only is citizen-centricity scrutinised, but the literature furthermore highlights the jeopardy of corporation dependency, with the risk of a technological lock-in effect and the rise of companies' monopolistic power (Hill, 2013; Tierney, 2019). Hill, as cited in Kitchin (2014b), even presents a dystopian view, contending that deploying corporate smart city solutions leads to inefficiencies because the public relies on particular devices and systems. With rapid technological progress, these devices risk becoming outdated due to the fact that corporations in monopolistic positions might not have an incentive to upgrade their technology. By exemplifying the phenomenon of monopolies through Sidewalk Lab's partnership with the City of Toronto, Tierney (2019) extends the academic discourse. The futuristic picture of consistently monitored cities drawn by Mattern (2013) and Morozov (2013), as cited in Kitchin (2014b), is reflected by Tierney (2019). However, the author does not draw upon a utopian vision but instead describes a planned undertaking. The scholar's main concern lies with the transformation of personal and environmental data into an economic resource by Google's subsidiary Sidewalk Labs, the point being that Google aims to monetise the project through the sale of residents' personal information to advertisers. Furthermore, it is feared that data will be analysed to influence people's actions to Google's benefit. With novel insights about citizens, not only can Google sell its products more efficiently, but it can also adjust people's actions to increase their service utilisation (Tierney, 2019). The author raises apprehensions not only regarding the planned surveillance of citizens and privacy invasions but also regarding the implications of data analytics and data biases for society. However, these concerns are not only addressed in recent literature but have also been extensively discussed over the past decade (Boyd & Crawford, 2012; Kitchin, 2014b). Because data and the revealed insights lack objectivity, scholars stress the importance of restrictions and regulations regarding data collection and algorithmic profiling. It is argued that data biases and automated, data-driven decisions could lead to disturbing consequences for society, including discrimination, rising inequality and a dilution of democracy. The scholars fear that cities will be regulated by technology and multinational corporations (Beretta, 2018; Kitchin, 2014b; Tierney, 2019; Van Zoonen, 2016). Furthermore, the academics highlight reservations regarding the constant monitoring of cities, describing the danger of surveillance and a 'Big Brother society'.

The high significance of these matters is underlined by the fact that privacy and security concerns are one of the most contested topics within the socially embedded perspective (Gupta et al., 2019; Kitchin, 2014b). Van Zoonen (2016) criticises the bounded technical-rational approaches of smart city solutions, claiming that residents' privacy concerns are not considered. The author argues that, whereas the collection of impersonal data for service purposes causes hardly any disquiet, resistance is expected when personal data are utilised for surveillance purposes. Meanwhile, Braun et al. (2018) highlight the necessity to address privacy and security concerns, claiming that the benefits of smart cities will diminish if citizens refuse to participate in these initiatives. However, although several scholars emphasise the various challenges and concerns smart cities present for society, the academic discourse lacks solutions and guidance for public institutions to ensure citizens' data protection and safety and to preserve democracy.

4 Conclusion

This critical review explored the topic of big data in smart cities from two main perspectives—the bounded-technical and the socially embedded rationales—revealing the main points of contention. First, the paper outlined the possibilities of leveraging

big data and technology to create efficient cities, tackling today's challenges and improving citizens' lives. The best practices of various initiatives and were outlined, partly drawing a utopian view of cities. Second, the social implications of smart city projects were examined, highlighting concerns regarding the delusion of democratic processes, privacy and security, as well as the rising level of surveillance, provoking dystopian rhetoric. By evaluating the different perspectives, the conflicting aim of balancing the demand for open data and data-driven, connected cities, while maintaining citizens' privacy and preventing a world of surveillance, is highlighted. Experts hold opposing views on smart city initiatives, debating whether these are beneficial or harmful to society. The recent announcement of Google's intention to build a smart city district in Toronto has intensified the discussion. For example, whereas Zuboff calls the plans 'surveillance capitalism', urbanist Florida argues that the Sidewalk Labs initiative could increase Toronto's competitiveness and "propel Toronto into the top ranks of global cities" (Wakefield, 2019).

Whilst various projects on city transformation have arisen worldwide, many open questions and challenges remain. Further, research on the use of data in cities is required to develop smart city strategies serving all stakeholder needs, rather than exclusively accommodating those of multinational corporations or governments. Moreover, the decision-making processes of human interpretation or automated algorithms related to data biases require further investigation to ensure a non-discriminatory and democratic city. Privacy concerns need to be addressed, including ambiguities in data ownership and the use of data. Lastly, it is of importance to further investigate the phenomenon of surveillance, including its containment within regulations, to avoid citizens' resistance to smart city projects.

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