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On big data, artificial intelligence and smart cities

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ABSTRACT

Cities are increasingly turning towards specialized technologies to address issues related to society, ecology, morphology and many others. The emerging concept of Smart Cities highly encourages this prospect by promoting the incorporation of sensors and Big Data through the Internet of Things (IoT). This surge of data brings new possibilities in the design and management of cities just as much as economic prospects. While Big Data processing through Artificial Intelligence (AI) can greatly contribute to the urban fabric, sustainability and liveability dimensions however must not be overlooked in favour of technological ones. This paper reviews the urban potential of AI and proposes a new framework binding AI technology and cities while ensuring the integration of key dimensions of Culture, Metabolism and Governance; which are known to be primordial in the successful integration of Smart Cities for the compliance to the Sustainable Development Goal 11 and the New Urban Agenda. This paper is aimed towards Policy Makers, Data Scientists and Engineers who are looking at enhancing the integration of Artificial Intelligence and Big Data in Smart Cities with an aim to increase the liveability of the urban fabric while boosting economic growth and opportunities.

1. Introduction

Data generation is believed to be possible in almost all sectors of human activity and this promises new ways of understanding our world. This availability of data showcases that Big Data can be useful in optimal usage of resources while making informed decisions (Alam, Sajid, Talib, & Niaz, 2014). The Internet of Things (IoT), Artificial Intelligence (AI) and Machine Learning (Dempsey, Bramley, Power, & Brown, 2009) amongst others (Mayer-Schonberger & Cukie, 2013) can contribute greatly to this process.

Smart Cities have adopted IoT as a means to encourage efficiency and performance of urban fabrics. Bhadani (2016) and Batty (2016) supports that increased connectivity led to an unprecedented amount of data creation, which created the possibility for a platform that allows for gathering, analyzing and distribution of data that is useful in different spheres of life (Evans, 2011). IoT encompasses digitization, which sparked changes in the way numerous entities work; be it governments, organization, businesses or individuals (Miller & Mork, 2013). These changes have resulted into a tremendous growth in generated data. A report by the International Data Corporation (IDC) shares that available data by 2020 will increase to beyond 35 trillion gigabytes (Gu, Li, & Cao, 2014).

However, the perception and description of 'Big Data' keeps evolving. Alam et al. (2014) views Big Data in terms of volume, velocity and variety. On a similar line, Chen, Chiang, and Storey (2012) shares an understanding relating to volume and the analytical method employed by different individuals and organisations. Kitchin & McArdle (2016) added to these characteristics the dimensions of exhaustivity, resolution, indexicality, relationality, extensionality and scalability. As those dimensions bring numerous advantages, it is believed that cities will be amongst the main beneficiaries (Barns, 2016; Bibri, 2018a; Lim, Kim, & Maglio, 2018).

The analysis of Big Data can be done through Artificial Intelligence; which can be interpreted as the way of training computers to mimic thinking patterns and can even be done to simulate human behaviours (Tecuci, 2012). The accuracy of achieved results is understood to increase with more data and processing as machine learning occurs; hence the primordial need for Big Data and the desirability of real time data. As cities are increasingly digitized, the role of Information Communication and Technology (ICT) in urban fabrics have been widely covered (Aguilera, Peña, Belmonte, & López-de-Ipiña, 2017; Allam, 2017a; Allam & Newman, 2018a; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014a), and it has been shown that technologies have allowed governments, municipalities and decision makers to collect data regarding a plethora of issues (Abaker, Hashem, Chang, & Anuar, 2016; Souza, Figueredo, Cacho, Araújo, & Prolo, 2016). It's

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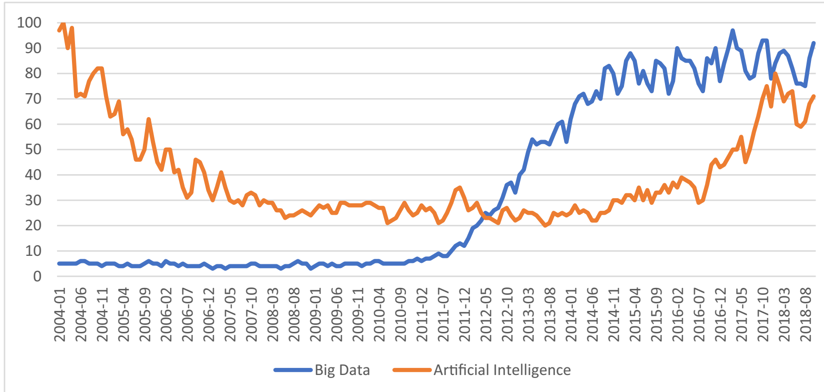

Fig. 1. Popularity of Big Data and AI from 2004 to 2018 (Google Trends, 2018).

processing, and analysis allows for better urban governance as policy makers can make informed decisions and formulate adequate and responsive policies. Such analysis can be performed by Artificial Intelligence.

While AI has been in fashion since the early 1950's (Google Books Ngram Viewer, 2018), its applicability has been slow in adoption. An analysis from Google Trends (Fig. 1) on the popularity of Big Data and AI (Google Trends, 2018) interestingly reveals a peak in Big Data from 2011 to 2014, while a decline in AI is observed from early 2004 to 2008. It can be seen however that the popularity of AI rose from 2014 to 2017 which can be interpreted as a result of Big Data, and even can even be foreseen to lead towards coupling. Interestingly Allam and Newman (2018a), through Fig. 2, shared that the concept of Smart Cities has peaked in almost the same time period, highlighting a key correlation with Big Data and AI.

However, even though the technologies, and the associated benefits of Artificial Intelligence, Big Data and Smart Cities have the potential to render numerous positives to an urban fabric, Allam (2018a) warns against the blind adoption of technology and encourages a further integration to the societal fabric. In this regard, the author recommends that careful calibration and contextualisation is key to building truly sustainable cities that are in turn resilient just as much as intelligent. This paper further explores the opportunities and challenges of ICT through Big Data and AI in relation to cities and explores and generates a framework with the potentiality of building more sustainable, safe, inclusive and resilient cities as highlighted by the Sustainable Goal 11.

2. Big data and cities

Numerous researchers support that the processing and interpretation of data is an essential step towards enriching the urban fabric (Bernabé et al., 2015; Bibri, 2018b; Cheng et al., 2018; Li et al., 2016; Neirotti et al., 2014a; Rolf, Pauleit, & Wiggering, 2018). Data can now be sourced from numerous neighborhoods to gain a better holistic understanding of the urban fabric. This allows planners and policy makers to shift from closed systems; where different urban elements such as land plots, open spaces, physical buildings and streets are inter-linked to what Levy (1999) calls 'open fragmented peri-urban fabric'. These have tangible impacts on different aspects of the urban fabric including density, fragmentation, cohesion, compactness and other variances as expressed by Li et al. (2016). A better management of the various dimensions and components of the urban fabric is thus crucial.

This is becoming increasingly possible as cities around the world are becoming digitized through the installation of sensors, computational cores and different telecommunication systems (Alvalez, 2017), as promoted by the contemporary concept of Smart Cities (Allam & Newman, 2018a). These digital concepts are tied to Artificial Intelligence and machine learning technologies, which are making it possible for the collection of near real-time data; providing a deeper understanding of how cities evolve, adapt and respond to various conditions. Allam and Newman (2018a) support that data analysis can allow cities to support socio economic dimensions while ensuring the implementation of sustainability features; including liveability components.

The processing of data through AI can ensure the better provision of liveability dimensions; through cleanliness, health and conducive environments for people to live and work without the urban challenges of pollution and congestion. It is further believed that, through this technology, the built environment can digitally support intelligent and responsive services both conveniently and in real time. In addition, cities are seen to leverage Big Data from AI to attract higher economic returns since their enabling infrastructures such as connectivity, energy and computing capabilities, amongst others, allow them to support globally competitive jobs (Davenport & Ronanki, 2018; Hoske, 2013;

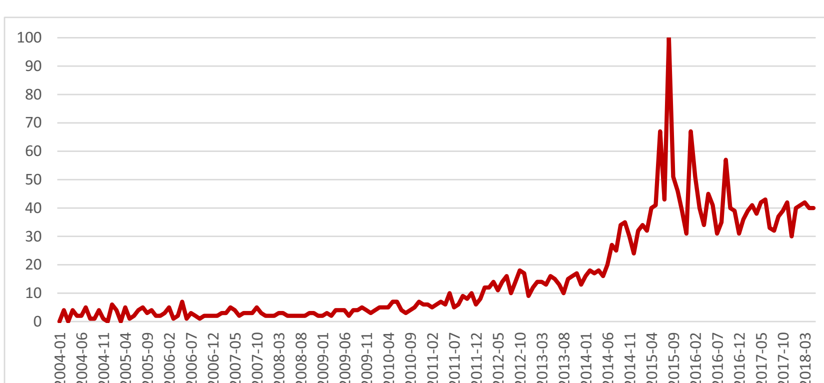

Fig. 2. Popularity of Smart Cities from 2004 to 2018 (Allam & Newman, 2018a).

Kaplan, 2017; Wilson, Daugherty, & Morini-Bianzino, 2017).

However Big Data can add to the complexity of data reliance (Bari, 2017; Fan, Han, & Liu, 2014; Tole, 2013). For Bari (2017) the availability of Big Data poses challenges such as scaling, spanning, preparation, analysis and storage bottleneck. Fan et al. (2014) contends that Big Data call for large sample size; hence, the problems of noise accumulation, spurious correlation, measurement errors and incidental endogeneity, which can delay or impact results. On the other hand, there are advanced analytical trends that supports Big Data discovery; hence, quality analysis and interpretation. Even though that there are notable challenges, the primary advantage of AI in Big Data analysis is that it supports the heterogeneity and commonality principles that are part of the Big Data analysis.

Through the urban fabric, AI could capture hidden structures of urban cells and components and provide a deeper understanding of common features. Some of these hidden structures are warranted by dynamics and complexities that modern cities are facing due to application of technologies in most of their fabrics (Koenig, Miao, Knecht, Bus, & Mei-Chih, 2017). The adoption of AI, as the source of Big Data analysis, in cities is encouraged since it allows for cognitive computing integration; hence, aid in urban design, planning processes and governance.

3. Urban governance in the digital era

Urban governance increases in complexity due to the evolving dynamics of policy. In the forefront of these dynamics is the concept of urbanization coupled with digitization. In the recent past, the 'New Public Management' concept was the blueprint adopted by major cities for urban governance (Andersson & Liff, 2012). This is now deemed unfit to accommodate numerous institutional and policy complexities; hence, cater for social urban problems (Dunleavy, Margetts, Bastow, & Tinkler, 2005). For this reason, citizens, especially in developed countries are seen to have leveraged on technology to solutions to emerging urban challenges. This triggered the concept of urban digitalization, which has seen a widespread adoption in most cities, and ultimately changing the ways they operate and governed (Kernaghan, 2000). However, according to Lynn (2000), the digitization can be a challenging endeavor as older trends continues to play out, and are still active in developed and underdeveloped countries. In developed countries, any trend that does not align with the digitization is seen as disruptive and only help in delaying the full adoption of digitization. This can thus be expected to impact on urban efficiency and performance.

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. Various authors (Allam, 2017a; Allam, 2018b; Allam, Dhunny, Siew, & Jones, 2018a; Allam & Jones, 2018a; Allam & Newman, 2018a; Allam & Newman, 2018b) postulate on the need for increased governance models in regards to Smart Cities, and more so with the idea that data can be incremental in enhancing a city's efficiency by rendering it more intelligent. In this regard, data allows for knowledge mobilization which in turn aid in planning decisions and designs. Buying from Barns, Cosgrave, Acuto, and Mcneill (2016) research, the only way to govern the modern cities that are so interlinked and connected is by relying on data 'built between cutting edge research and technological innovation'. The researchers acknowledge one area where data played a significant role; that is the digitization of urban infrastructure, which, in turn has made it possible for information processed from these sources to be integrated into the urban fabric. Moreover, governance from data sourced from areas like weather forecast, traffic departments and security sources would improve transparency in areas like the procurement and structuring of the education sector to benefit an urban population (Ubaldi, 2013). A related example is the case of the cholera epidemics that impacted on London in the mid-19th century. Data on the location of each diseased victim was collected and an analysis showed that high mortality rate in areas supplied by water from contaminated systems. With this finding, the city management was able to address the problem and adopt even better measures like insulation of pipes amongst others (Barkham, Bokhari, & Saiz, 2018).

With the means of interconnectivity of systems through IoT and the resulting emergence of Big Data, AI can help greatly in facilitating this process and providing faster data analysis to identify current, emerging, or even future urban issues.

To complement Big Data, AI and Machine Learning technologies, novel approaches like the Blockchain technology can contribute greatly to cities (PwC, 2016). The technology is described as a distributed, replicated and secure digital ledger that allows contracting parties to see one system of records that are immutable (Swan, 2015). Urban governance entails a myriad of transaction that ranges from financial and contractual ones and involve a sizeable number of parties. Due to government bureaucracies and policy complexities, transactions tend to lag and sometimes are expensive and uncertain. To facilitate this process the services of a third party is often warranted, which causes additional issues of privacy. Studies (Mik, 2017; Savelyev, 2017; Zyskind, Nathan, & Pentland, 2015) showcase that these mishaps can be overcome by the use of smart contracts through the Blockchain technology (Reyna, Martín, Chen, Soler, & Díaz, 2018). Tapscott and Tapscott (Tapscott & Tapscott, 2015) shares that smart contracts are self-executing computer programs that are triggered to allow for transfer of digital assets automatically (Al-Saqaf & Seidler, 2017; Hammi, Hammi, Bellot, & Serhrouchni, 2018). The nature of immutability, where contracts cannot be altered or manipulated once they are initiated (Christidis & Devetsikiotis, 2016), is an interesting characteristic for cities. Voto (2017) supports that the Blockchain technology can significantly contribute to city management since it allows for enhanced governance and supports the establishment of new services built on collaboration between machines, Big Data and humans (Muzammal, Qu, & Nasrulin, 2019; Zyskind et al., 2015). With Blockchain, Big Data generated by the city stakeholders could be kept permanently and made accessible across networks of computer; thus, allowing access to citizens to contribute views on urban issues and governance.

The key is the use of trustable data that provides a clear overview of how different urban fabrics relate. Big Data and AI alone cannot guarantee the quality of data due threats like hacking and human mistakes and tempering (Maria-Lluïsa & Marsal-Llacuna, 2018; Ølnesa, Ubacht, & Janssen, 2017). However, the integrating of these technologies with Blockchain technology can enhance trust in data since the technology is encrypted and secure. This is enabled by instant verification and distribution of every transaction that is made available for use instantly across the network. A PWC report (PWC, 2018) on Blockchain technology coupled with Big Data, AI and Machine Learning, supports this and affirms that the governance of cities will be significantly enhanced. The report projects that in the near future, cities will be characterized by prosperity, stronger and interconnected communities, healthier people, positive growths and unprecedented social mobility. These will be catalyzed by rapid urbanization, demographic and social change, advanced technological breakthroughs, increased economic opportunities and sustainability drives (Allam, 2012).

4. Urban social comfort and big brother

Technology has enabled transformation in different spheres of life and interconnectedness of people and urban systems have changed how people live and interact. As technology has allowed collection, analysis, interpretation and storage of data in various forms, there have been many notable benefits for the urban fabric.

Urban centers have witnessed numerous transformations, geared with an increasing demand in land and resources (Al-Kodmany, 2018). The social fabric morphed to respond to increasing demands while creating more opportunities for jobs, better health care, quality education, quality living standards and security services. This has also given rise to economic opportunities (Siew & Allam, 2017; Allam et al., 2018a; Allam & Jones, 2018a; Allam & Newman, 2018b). These factors, coupled with an increasing population further attract people, seeking better and more attractive opportunities, to urban areas. With an enhanced economic dimension, the need for liveability standards becomes a necessity to ensure the survival of the economic ecosystem.

While technology can greatly increase liveability, numerous challenges emerge such as insecurity, moral decadency and privacy breach, amongst others. The ability to gather, analyze, and share information in real-time using different devices adds to the difficult of maintaining privacy, compromising on social and psychological comfort that urban dweller seeks (Davey & Tatnall, 2015; Power, 2016). Hildebrandt & Gutwirth (2008) posit that through different technological platforms, individuals can unlawfully access personal data of others and could use it in a way that compromise their privacy. Similarly, with the emergence of social platforms, the availability of personal data surges in both popularity and quantity; hence, exposing new personal threats (Santanen, 2019; Zimet & Jacob, 2001). What is interesting is that personal data is not sought by individuals, but by businesses and government agencies.

Access to data must thus be carefully sought as privacy is considered a fundamental human right in many democracies, and protected legally and constitutionally (Diggelmann & Cleis, 2014). Hough (2009) supports that everyone is entitled to privacy in all its facets: solitude, intimacy, anonymity and reserve. This argument is further compounded by the legislations regarding data protection in different countries (House of Lords, 2009). Legislation notwithstanding, it is increasingly difficult to contain these infringements especially those not directly related to surveillance. For instance, the case of high rise overlooking lower buildings (Moore, 2010) or through the use of drones (Pomeroy, 2015).

The issue with privacy concerns in relation to technological advancement is that they do not include the speed of technological change (Sweeney, 2002). Concepts such as Smart Cities and technologies like IoT, Blockchain, AI and Machine Learning are still in the offing and are anticipated to evolve even more as their application gains in popularity and in adoption. However Braun, Fung, Iqbal, and Shar (2018) warns that the advancement of these technologies may also mean new opportunities for privacy invaders. Therefore, efforts geared towards safeguarding the privacy of urban dwellers should anticipate technological change and should be at the forefront of concerns for digital scientists and planners. The primary key towards this goal is the safeguard of data; hence, collection, interpretation, sharing and storage. Incidentally, Rinaldi, Peerenboom, and Kelly (2001) propose strictness in identifying, understanding and analyzing the interconnectedness of the different components that makes up the city. Similarly, Blockchain technologies will have taken shape and will complement the data safety strategies (Ølnesa et al., 2017; PWC, 2018).

Autonomous devices advocated in Smart Cities such as self-driven motor vehicles, smart buildings and other smart devices, adds to the complexity of data storage, sharing and communication. An intricate array of devices is expected to operate and transfer exclusive personal information to various service providers. Data leakage in one node may prove detrimental to individuals or even the entire system, thus posing additional risks to the further adoption of Smart City concepts. Therefore, part of the task related to data transfer and processing should relate to improvement of security and strengthening of networks altogether (Coaffe & Fussey, 2015; Karabulut, Aras, & Altinel, 2017). Braun et al. (2018) share that AI and other supportive technologies can greatly improve data processing collected through various devices across service providers but at the same time, there is a need for human oversight. Zoonen (2016) contends that such strategies would speed up the uptake of smart city technologies since the greatest hindrance to its adoption is the lack of trust demonstrated by citizens.

However, the question of trust is only one amongst many concerns regarding the application of AI in cities. Other questions arise such as: Who owns and controls data? Who controls the urban economy? Are smart services inclusive? Are urban decisions geared towards humans or machines? Is there political goodwill for the inclusive adoption of smart technologies?

In respect to the latter, there is a spirited effort in different parts of the world by the political class and the governments to boost the concept of Smart Cities. Allam, Dhunny, Siew, and Jones (2018b) supports that the concept is gaining in popularity and various means may be utilized to further encourage its integration. Barns et al. (2016) support this by showing how the wide range adoption of Smart Cities by the Australian Government.

However, even though there has been a rapid adoption, those are believed to be geared towards economic pursuits disconnected to the collective good of urban fabrics (Allam & Newman, 2018b). In addition, the failure to address the questions raised above could further pose threats to the efforts of digitalization of cities. AI, Big Data and Smart Cities technologies have not been fully understood by many, thus, qualifying the fear of data ownership and the motivation behind these advancements (Montjoye, Farzanehfar, Hendrickx, & Rocher, 2017). There are notable fear that automation and digitization of services within the city would cause unemployment; thus, compromise individual economic status. Pavaloiu and Kose (2017) argued that automation of services would lead to employment shift, economic disparity and skewed wealth distribution. The issues relating to of privacy infringement are also present, which is increased with the implementation of AI technologies (Wallach, 2014). In addition, there are fears that smart services will only benefit the digitally savvy and is meant to segregate and disadvantage groups that are digitally disconnected (Bonnefon, Shariff, & Rahwan, 2016). Pavaloiu & Kose (2017), claimed that these can be addressed by public educating on the need for smart services and the potential gains from its benefits. Confidence and trust could be further accrued with public participation where citizens can share comments on desired urban management models and impact on policy decisions. Participatory models are thus seen to be key in the devising of inclusive neighborhoods, and this can be enhanced using technology. To add to the line of thought of urban inclusivity, urban comfort can be equally shaped using technology through the components of sustainability, which is key to increase both liveability and economic dimensions.

5. Sustainability and technology

The impacts of Climate change on cities have been greatly covered in literature, and urban leaders, policy makers, and other stakeholders are driven to strategize on to mitigate those impacts (OECD, 2014). Cutter, Emrich, Gall, and Reeves (2018) highlights that one the most prevalent impact of climate change is that of flooding, that tend to occur in cities that were previously relatively deemed as safe. Besides flooding, there are increased incidences of bushfires which are impacting on the liveability of cities as shelters are at risk, and even rendering entire urban areas as uninhabitable (Hales et al., 2007; McDonald, 2017), thus forcing people to leave their homes. In certain instances, further accentuates the sad phenomenon of 'climate refugees'. For cities in developing countries where the local governments are financially constrained; hence unable to offer alternative lands, infrastructure repairs, or housing subsidies, a portion of the population ultimately ends up homeless and this leads to the creation of an informal economy; which are even more vulnerable to the impacts of climate change (UN Habitat, 2015). Emilsson and Sang (2017) further shares how cities are seen to experience higher temperatures, especially in form of heat waves which result to loss of lives, and in some cities it drives a higher energy demand for mechanical cooling (Allam, 2014). Furthermore, unlike before, cities are now experiencing shortage of food supplies as climate change has also affected the agricultural sector due to the unpredictability of climate from conventional farming techniques (Burton et al., 2013).

Doherty, Klima, and Hellman (2016) and Allam (2012) support that finding solutions to these impacts will be key to the survival of cities and that mitigation strategies, potent with sustainability consciousness in mind, must be sought at various levels of policy making. They peg their argument on results from other researchers (Hughes & Sarzynski, 2015; OECD, 2014) that established that cities contribute greatly in aggravating climate change. On the same line, many city managements have started to fashion policies in such a way so as to have as little as negative impacts as possible to prevent the compromise of the environment and available resources (George, Schillebeeckx, & Liak, 2015; Silva, Khan, & Han, 2018). In this front, many cities have managed to leverage on the available advanced technologies such as AI, Big data, IoT, Blockchain, amongst others to render sustainable solutions to both city planning and management (Allam, 2018b; Allam & Jones, 2018b; Allam & Newman, 2018a; Lim et al., 2018; Pioletti, Fox, & Goodfellow, 2016).

Barns et al. (2016) highlights that one such area where technology has been helpful is the implementation of the Smart Cities concept, which can be key in helping cities achieve resilience and sustainability. Koenig et al. (2017) and Beatley (2011), amongst others, argue that analysis, through AI enabled devices and systems, of data from IoT; that Smart Cities prone, have allowed the customization of different urban fabrics such that they optimize on the available resources. For instance, Smart Cities have catalyzed the introduction of autonomous vehicles, and even encouraged sustainability passive methods through the creation of bicycle lanes and walking paths; hence, contributing to the reduction in fossil fuel consumption (Barns et al., 2016). These technologies have encouraged the adoption of construction tools in the building sector that can possibly integrate low power and water consumption, allow for green spaces and also accommodate green walls and roofs and have smart waste management systems (Allam & Jones, 2018a; Conke & Ferreira, 2015). These types of constructions also allow for increased conservation of land as there is reduced sprawl; hence, the land can be used for other purposes like agriculture, open space and forest reserve, amongst other uses that can benefit the local population and users of the urban fabric (Gaigné, Riou, & Thisse, 2012).

Dengel (2013) succinctly shares how, through AI and big data, the agricultural sector is enhanced since information on issues like weather patterns, soil types and the best crops to plant at particular areas are readily available and this provides informed decisions as to crop management; which leads to higher yields and related proportional economic growth. The same approach in other sectors, especially in developing countries, through domains such as health, business, transport, services, amongst others, can render economic benefits while catering for sustainability outcomes by saving resources from these sectors (Barns et al., 2016; Beatley, 2011). The same can be used for climate change mitigation projects, and benefit cities, countries and regions that need it the most; like Small Island Developing States and Low-Income Economies that are on the front line of the impacts of Climate Change.

6. A review of current applications of artificial intelligence

A review of existing applications of AI pertaining to the Urban Fabric has proved limited, but this is expanding through the increased adoption rate of Smart Cities; which boasts the application of the Internet of Things (IoT) which generates Big Data, on which AI sustains. Through this limited characteristic, an expanded search to other domains revealed an extended focus on 12 fields that brings a direct applicability to Cities. The works of various authors bring a valuable contribution to those domains, and this is showcased in Table 1 below.

The undertaken review of literature and identified applications of AI in various domains, as shown through Table 1 above, showcases that the energy sector bomed with the advent of technology and industrialisation of the society, which in turns called for a higher energy supply to meet with growing demand. The use of AI provides accurate estimates for generating energy maps which can be used for energy modelling and planning purposes (Suganthi et al., 2015). A mix of renewable energy sources can effectively act as a replacement for fossil fuels to meet up with the growing energy demand (Aljicevic et al., 2016; Lakshmanan & Pandian, 2012), in a sustainable and efficient fashion. The harvest of renewable energy however shows some concern in view of the setting up of infrastructures in most suitable locations. Borah et al. (2013), Lakshmanan and Pandian (2012) and Aljicevic et al. (2016) made use of the Artificial Intelligence tools through the concept of Fuzzy Logic to test the claim of Suganthi et al. (2015) and successfully contributed to the identification of energy farms for an optimal outputs. As the energy sector is gaining in energy adoption, its increased efficiency through AI is helping in the rising adoption rate of renewable energy sources, which is in turn helping in mitigating the impacts of climate change.

Climate Change has been affecting cities, countries and regions and directly impacting on the livelihoods of people and the economy; which leads to increased political and geopolitical agendas to sustain both economy and the environment. Numerous researchers (Borah et al., 2013; Cook et al., 2009; Lakshmanan & Pandian, 2012; Suganthi et al., 2015; Zhou et al., 2009) showcased how the technical applications of AI can effectively render more sustainable environments. However, in line with the above, it was noted that the education sector needs to be refined to generate more specific and appropriate tools in the shaping of minds and creativity. With Data and AI, this renders a unique benefit of providing training in current challenges as they unfold (Baker, 2000; McArthur et al., 2005; Santana-Mancilla et al., 2013). However, as those benefits directly impact on economy, the efficiency of current financial models set to accommodate and catalyse generated economic benefits from various sectors, were themselves deemed as obsolete by being slow and cumbersome. New recommendations and models making the use of AI were developed to address those concerns (Bahrammirzaee, 2010; Fethi & Pasiouras, 2010; Salchenberger et al., 1992).

The same is being observed for health sector which has been adopting Artificial intelligence (Miller, 1986; Patel et al., 2009; Ramesh et al., 2004). Health professionals are set to be assisted in: diagnostics (Alkım et al., 2012; Amato et al., 2013); probability estimation of diseases (Fryback, 1986); monitoring of illness (Coiera, 1993); critical care medicine (Hanson & Marshall, 2001; Holt et al., 2006); dyslexia (Reggia & Berndt, 1986); planning treatments and finding better solutions for patients (Hanson & Marshall, 2001). As those contribute to better livelihoods, the technology used in its assistance is gaining adoption in its application in Mobility (Alam et al., 2018; Alazawi et al., 2011; Arfat et al., 2017; Arfat et al., 2018; Büscher et al., 2009; Mehmood et al., 2017; Mehmood & Graham, 2015; Schlingensiepen et al., 2016), Information Technology (IT) and Internet of Things sectors (IoT). Those have given rise to multidisciplinary solutions such as smart logistics and transportation systems by ensuring that sustainability principles are brought forward from the combination of IT and IoT (Ahmad & Mehmood, 2016; Schlingensiepen et al., 2016). The emergence of data provided numerous benefits but also highlighted a limitation in current models of storage; which is now being addressed through cloud computing (Tawalbeh, Bakheder, & Song, 2016a). Data through IoT is further being used through mobile applications through two way streams in retrieving and transmitting information at a much faster rate (Arfat et al., 2017). Progress in this domain further contributes to more efficiency and increased performance, but the standardisation of processes need to be supported by appropriate policies.

As such, to ensure the rapid, and effective, integration of AI in various domains, and to ensure its coherent cohabitation with current models in use, numerous authors dwell in the policy design, implementation and monitoring by underlining the increased benefits of AI in those various stages.

Even though the authors, as compiled in Table 1, may not have

Table 1
A summary of current applications of AI by various researchers.

Authors	Domains											
	Education	Environment	Energy	Health care	Policy	Financial	IT	Smart cities	Mobility	Sustainability	Big data and computing	IoT
Borah, Roy, and Harinarayana (2013)		X	X		X		X					
Tawalbeh, Bakheder, and Song (2016a)				X				X			X	
Arfat et al. (2017)								X	X		X	
Zanella, Bui, Castellani, Vangelista, and Zorzi (2014)								X				X
Tawalbeh, Bakheder, and Song (2016a)				X				X			X	
Alam, Mehmood, Katib, Albogami, and Albeshri (2017)											X	X
Alazawi, Altowaijri, Mehmood, and Abdljabar (2011)								X	X			
Alam, Mehmood, Katib, and Albeshri (2016)												X
Lakshmanan and Pandian (2012)		X	X		X		X					
Muhammed, Mehmood, Albeshri, and Katib (2018a)				X				X			X	X
Aljicevic, Kostic, Dautbašić, and Karli (2016)			X		X		X					
Muhammed, Mehmood, and Albeshri (2018b)												X
Suganthi, Iniyan, and Samuel (2015)		X	X		X		X					
Baker (2000)	X				X		X					
McArthur, Lewis, and Bishary (2005)	X						X					
Bahrammirzaee (2010)						X	X					
Fethi and Pasiouras (2010)						X	X					
Patil, Adibi, and Shoemaker (1996)				X			X					
Salchenberger, Cinar, and Lash (1992)					X	X						
Ekman (2005)							X					
Cook, Augusto, and Jakkula (2009)		X			X		X					
Santana-Mancilla, Echeverría, Santos, Castellanos, and Díaz (2013)	X											
Coiera (1993)				X								
Miller (1986)				X	X							
Holt, Bichindaritz, Schmidt, and Perner (2006)				X			X					
Horvitz, Breese, and Henrion (1988)					X							
Amato et al. (2013)				X	X							
Alkım, Gürbüz, and Kılıç (2012)				X			X					
Fryback (1986)				X			X					
Reggia and Berndt (1986)				X	X		X					
Patel et al. (2009)				X	X							
Hanson and Marshall (2001)				X	X							
Usman, Mehmood, and Katib (2018)											X	
Alam, Mehmood, and Katib (2018)				X				X	X			
Alamoudi, Mehmood, Albeshri, and Gojobori (2018)				X								
Khanum, Alvi, and Mehmood (2018)								X				
Al-Dhubhani, Mehmood, Katib, and Algarni (2018)								X				
Ramesh, Kambhampati, Monson, and Drew (2004)				X	X							
Chassignol, Khoroshavin, Klimova, and Bilyatdinova (2018)	X											
Klimova, Bilyatdinova, and Karsakov (2018)	X						X					
Tawalbeh, Basalamah, Mehmood, and Tawalbeh (2016b)							X	X				
Ahmad and Mehmood (2015)							X	X		X		
Ahmad and Mehmood (2016)							X	X		X		
Büscher et al. (2009)					X				X			
Schlingensiepen, Nemtanu, Mehmood, and McCluskey (2016)				X				X	X	X		
Shaykhislamov and Voevodin (2018)					X		X					
Zhou, Yin, and Hu (2009)		X			X							
Melville (2010)		X			X							
Mehmood and Graham (2015)				X				X	X		X	
Arfat, Mehmood, and Albeshri (2018)								X	X		X	
Mehmood, Meriton, Graham, Hennelly, and Kumar (2017)				X				X	X		X	
Alsulami and Mehmood (2018)	X							X			X	
Suma, Mehmood, Albugami, Katib, and Albeshri (2017)								X	X		X	

(*continued on next page*)

Table 1 (*continued*)

Authors	Domains											
	Education	Environment	Energy	Health care	Policy	Financial	IT	Smart cities	Mobility	Sustainability	Big data and computing	IoT
Suma, Mehmood, and Albeshri (2018)								X	X		X	
Alotaibi and Mehmood (2018)				X					X		X	
Aqib, Mehmood, Albeshri, and Alzahrani (2018)	X								X		X	
Alyahya, Mehmood, and Katib (2018)											X	

made mention to direct applications to Smart Cities, those solutions ultimately generate enhanced setups that contribute to the intelligence of networks and systems; which is critical and primordial in the development of Smart Systems. However, those need to be calibrated to support human life and not with the aim to integrate technology for economic benefits. As such, the inclusion of the liveability dimension in Smart Cities is paramount of the generation of healthy, safe and sustainable urban setups.

7. Urban liveability and smart cities

An extensive literature on Smart Cities was conveyed by Allam and Newman (2018a), where the authors revealed key dimensions (Table 2) that current Smart City Frameworks support.

While those frameworks have been known to work, and is set to accentuate technological output, Allam and Newman (2018a) argue that the liveability dimension was being overlooked. To ensure an inclusive framework, the authors support that Smart Cities must encourage technology, but the overarched dimensions must be focussed towards people; hence aimed towards improving urban liveability. In this regard, the authors proposed three key dimensions: Culture, Metabolism and Governance. The Smart City Model as presented by Allam and Newman (2018a) is represented in Fig. 3 below.

The authors also highlighted that an overemphasis on technological dimensions may pose a threat to liveability and sustainability levels of cities; thus, the model overlooks the dimensions of technology altogether and propose that policy makers dwell into the three key dimensions of Culture, Governance and Metabolism first and foremost prior to the integration of technology. The present authors thus propose the integration of the same principles in a new framework, which looks at how to effectively integrate technology in Smart Cities while aligning with the governing principles as laid out by Allam and Newman (2018a).

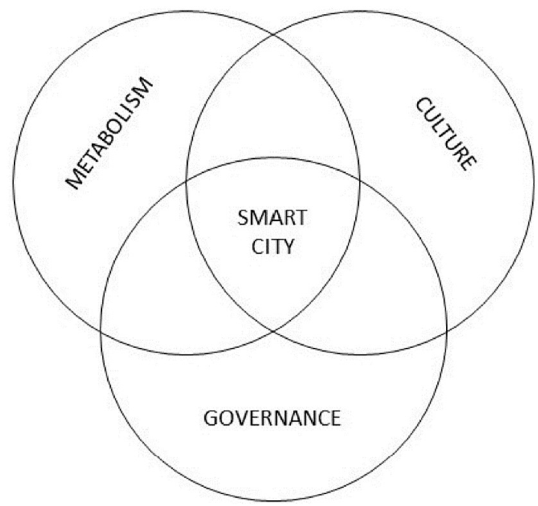

Fig. 3. Sustainable and inclusive smart city model as presented by Allam and Newman (2018a).

8. A proposed framework

The proposed framework by the present authors looks at how to effectively integrate the use of technology while encouraging the input of Big Data and Artificial Intelligence at the core of Smart Cities. By using the careful calibration by the three key dimensions of Culture, Metabolism and Governance, as prescribed by Allam and Newman (2018a), the proposed model is aimed to ensure that societal liveability is preserved by encouraging the pursuit of technological input. The proposed framework is illustrated in Fig. 4.

A salient feature in the proposed framework is that it does not cater for technology as its own dimension. The authors rather propose that technology is to be a fundamental core of Smart Cities where Big Data can emerge through IoT through various domains Artificial Intelligence is then proposed as an underlying feature which can process, analyze and interpret the generated data. The fundamental dimensions of Culture, Metabolism and Governance, as prescribed, are ensured in this framework to ensure that the inclusion of Big Data and Artificial Intelligence is geared towards human liveability rather than the sole

Table 2
Key dimensions from smart city frameworks. Adopted from Allam and Newman (2018a).

Indicator	Petrolo, Loscrì, and Mitton (2015)	Nam and Pardo (2011)	Chourabi et al. (2012)	Washburn et al. (2009)	Dameri (2012)	Neirotti, De Marco, Cagliano, Mangano, and Scorrano (2014b)	Balakrishna (2012)	Mosannenzadeh and Vettorato (2014)
Smart governance	X	X	X	X	X	X	X	X
Smart people	X	X	X		X	X	X	X
Smart economy	X		X			X	X	X
Smart living/livability	X			X	X	X	X	
Smart environment	X		X		X	X	X	X
Smart mobility	X			X		X	X	X
Smart infrastructure	X	X	X	X		X	X	X
Smart education				X		X		
Smart healthcare				X		X		
Public safety				X		X		
Culture						X		

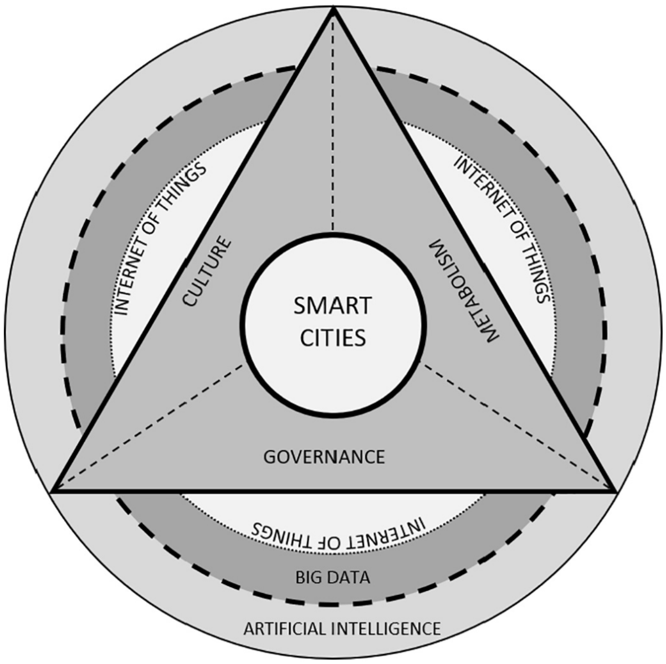

Fig. 4. A proposed framework for the integration of AI and big data in smart cities to ensure liveability.

purpose of technological integration for economic pursuits by corporations alone. The following section discusses the implementation of the proposed model and its benefits.

9. Discussion

Cities have undergone various changes caused by the emergence and adoption of numerous concepts such as sustainable cities, inclusive cities, resilient cities, amongst others. In the current knowledge economy, the focus is on Smart and Intelligent Cities. These changes have been prompted by numerous factors ranging from population increase, advancement in education, increase in demand for city services and products, and above all, technological advancement. Transition from traditional to high tech urban centers brought about numerous changes in the way cities are governed. Intelligent, or Smart, cities have shown improvements in transport infrastructures, health care services, security, communications and, amongst others, access to quality social amenities and services. They have also been serving as hubs for job opportunities and centers for vibrant economic development. The rapid adoption of Smart Cities is thus understood as there is a direct correlation with higher economic outputs and urban performance.

Despite these positive outsets, urban dwellers still face a myriad of challenges characterized by modern urban environments: traffic congestion, environmental degradation, insecurity, infringement of privacy, inadequate housing, trafficking, urban sprawl and inefficient service delivery, just to name a few. The proposal of a new framework thus looks at how to integrate the emerging concept of Smart Cities towards a more livable and inclusive fabric.

This paper showcases that technologies such as Artificial Intelligence are gaining traction and its integration in city management is promising. The proposed model then supports the use of AI, as through this dimension, it is now possible to gather data sourced from different urban components in one central location. This is possible due to the interconnectedness of different services warranted by availability of numerous smart devices. With this Big Data, city managers, governments, businesses and other stakeholders have the possibility to customize services appropriately (Parkes & Wellman, 2015; van de Gevel, 2013). This is moreover pursued by intelligent marketing campaigns led by big Information Communication Technology (ICT) corporations that earn profits from Smart City products, including IoT Solutions (Allam, 2018b).

As such, IoT is taunted as the core technologies in transforming cities to 'Smart' Cities through the intelligent IoT devices, Smart sensing devices and Big Data mining riding on AI. These devices allows for the interlinkage of different urban fabrics through the sharing of data (Barns et al., 2016). Through technology, data yielded from a myriad of devices are intelligently analyzed, interpreted and distributed in real-time, such that appropriate actions are taken efficiently and timely (Guo, Lu, Gao, & Cao, 2018). Besides data gathered from smart devices, AI coupled with the IoT has allowed for collection of data from virtual objects such as human behavioral data that influences economic decisions (Gil, Ferrández, Moramora, & Peral, 2016; He, Wang, Huang, & Liu, 2018). Li et al. (2016) support that computational methods can increase this capability and Mulgan (2018) further believes that exponential gains are to be foreseen if the coupling of human and machine intelligence is achieved, and particularly in the harnessing of group intelligence. This type of data supporting group intelligence can be achieved through IoT by making use of sensors in urban areas; where data sourced from various domains can be made to communicate between each other. However, there is a careful calibration to be done as to ensure that the pursuit of technology is done at the detriment of liveability levels, which is discussed later in this section. Even more so, the calibration to local context and economies are equally important (Allam, 2018a).

This type of model may seem farfetched as the technology that needs to support it may be in embryonic stage, but this is far from the truth. Today, city managers are leveraging advanced in Big Data technologies as decision making tools in improving the city infrastructure (Barns, 2016), which is impacting heavily on the urban economy and having positive impacts on an even larger, national and regional level. Blanco, Fuchs, Parsons, and Ribeirinho (2018), of McKinsey, contended that AI has become an integral part of the engineering and construction sector which has helped stakeholders in costs reduction, overcoming challenges of schedule overruns and addressing safety concerns ubiquitous with city dwellers. The utilization of AI in the built industry will greatly assist in addressing the housing challenges common in cities. When this domain is fully linked with others in the infrastructure realm, high costs associated with properties will be moderated; hence, allowing more young professions to comfortably reside in cities (Allam et al., 2018b), and thus reducing on commuting times. In line with this, AI, Big Data and associated technologies are said to be aiding in automation, thus, allowing residents to experience quality, efficient and timely services (Boenig-Liptsin, 2017).

This model thus supports those types of approaches through a decentralised fashion, thus not only profiting large ICT corporations, but also Small Medium Enterprises (SMEs); which are often the primary users of the city. This model thus promotes the creation of economic resilience and a more sustainable and healthy urban economy through the empowering of the local population, and the creation of wealth locally; rather than its export to foreign agencies and corporations. Thus, by ensuring that both Big Data and Artificial Intelligence are considered as core elements of Smart Cities, the analysis and exchange of data from various fields can thus be greatly enhanced. Schneeweiss (Schneeweiss, 2018) shares that, in the health sector, there is an unprecedented reliance on nonrandomized database and advance technologies such AI, Big Data and Machine Learning can automatically optimize methodologies and procedures. With the data output, service providers, for example in the health sector, are able to predict health outbreaks and thus enforce required mitigation strategies (Pham, Tran, Phung, & Venkatesh, 2017), or predict emerging patterns that can render better economic opportunities (Davenport & Ronanki, 2018; Parkes & Wellman, 2015). This is further enforced by data that encourage both better management and financial spending (Capone et al., 2016).

Numerous models, including the one of Allam and Newman (2018a), warn against the use of technology in the primary applications of sustainable urban theories. However, AI and its related technologies such as Machine Learning can allow scientists to develop Artificial Neural Networks (ANN) and algorithms that help in amplifying human cognitive functions (Bini, 2018), which can lead to more intelligent urban fabrics. When the concept of AI is integrated within Smart Cities, residents' well-being is bound to improve as explained by Obinikpo and Kantarci (2017). These technologies also allow for a better governance since data obtained could be used during planning and designing stages and supply chains could be aligned to run seamlessly in between related services (Miller & Mork, 2013; Wahl, Cossy-Gantner, Germann, & Schwalbe, 2018). On the same note, when all these sectors are integrated, there is optimal use of resources and spirited effort to conserve the environment; which contributes to increasing liveability levels for city dwellers. This model is thus geared to support the key dimensions of sustainability, as those technologies can be tailored to better response to climate change to reduce its impacts on urban life, as well as early on in the urban planning stage.

Moreover, the liveability aspect of cities is also directly influenced by the security and safety therein. Technology has proven vital in ensuring security improvement and the safety of residents, business, visitors and infrastructures of the city. Through AI, advanced surveillance technologies and devices are in use to combat numerous security threats confronted in cities worldwide. An emerging approach is the use of drones and other unmanned devices. Besides these, AI has facilitated numerous ways through which governments and its agencies are monitoring and gathering information concerning different forms of security threats such as terrorism, different forms of trafficking and organized crimes et cetera. Even though there have been concerns of privacy and data security, enhanced technology, can increased the quality of basic urban infrastructures such as health care products and services, water, internet, waste management and disposal, amongst others can be greatly influenced (Allam, 2017b; Allam, 2018c; Allam & Jones, 2018a). Data must thus be seen as tool that can greatly increase the process of urbanism, instead of a threat. Of course, this also creates the demand for new networks, protocols, and systems for increased security; as is the practice in any other sector. From a macro level perspective, the use of Big Data, collectively, from personal, government, businesses and media coupled with AI technologies can help to address numerous of urban services and further encourage the safety of urban residents just as much as expensive urban infrastructures that are vital at safeguarding the liveability of cities (Bini, 2018; Blanco et al., 2018; Wahl et al., 2018). Through this means, the key dimensions essential to supporting urban life, as prescribed by Allam and Newman (2018a), in the form of Culture, Metabolism and Governance, can be greatly enhanced and have a natural productive growth through Business and Economy by the help of SMEs at the local level (Siew & Allam, 2017; Allam & Jones, 2018b; Allam & Newman, 2018a).

By ensuring a focus of Liveability through the dimensions of Culture, Metabolism and Governance, the proposed framework provides a more inclusive outset on how to encourage smarter and healthier cities from both economic and social levels. However, to ensure that the proper integration of AI in Smart Cities, there is a number of issues that requires attention. Jia et al. (2017) shared that Big Data analytics are geared towards business intelligence, machine learning, bio-informatics and ad hoc analysis. To ensure that these processes contribute significantly to the economics of cities, both large amounts of energy and higher processing power (Coronel, Morris, & Rob, 2013; Saravanan, 2018; Wang, Zhan, Shi, & Liang, 2012). Similarly, highly specialized labor is required to oversee the complex processes of digitization.

Notwithstanding, the role of technology must be hailed to improve the urban life in terms of performance and efficiency. To do so, factors intricately linked to the support of a flourishing environment, which supports life in all its forms, must be enforced in cities; as without which, the liveability levels would be comprised, which in turn would negatively impact on the urban economy.

10. Conclusion

An extensive review of literature was performed in this paper, and the present authors showcase numerous applications of Artificial Intelligence through the emergence of Big Data from various service providers in Smart Cities. Even though this emergence of data brings rise to a range of concerns in line with issues regarding confidentiality and ethics, the implementation of AI can substantially aid in urban governance and urban economic growth. As the world is witnessing a rapid adoption of Smart Cities, the technological factor needs to be weighted in respect to societal integration. As such, the component of Big Data, promoted through the Internet of Things, which is popular in Smart Cities, highlights concerns that need to be addressed to ensure an increased popularity and adoption rate of the emerging concept. This is shown to be possible through the adoption of technology, through the essential dimensions of Culture, Governance and Metabolism; which is known to form the basis of liveable Smart Cities. A new Smart City framework was introduced that supports the additional use of Big Data and Artificial Intelligence with a primary focus on urban sustainability and liveability; which are essential to building more inclusive and safe environments as supported by the Sustainable Development Goal 11. The models thus ensures that, even though technological pursuit can bring numerous benefits, human dimensions are not overlooked in the process of integration of Smart City concepts in existing urban fabrics, or in greenfields.

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