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Research Article

Taking the Advancement of Sustainable Smart Cities (SCs) Seriously: The Implications of Emerging Technologies

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Abstract: The concept of the Smart City (SC) is currently drawing widespread attention in both theory and practice thus stimulating serious academic discourse especially on the applicability of the concept. Smart Cities (SCs) have the main goal of improving the performance of cities with a vision that not only includes the citizens' prosperity but also the sustainability of cities environmentally, socially and economically by using emerging technologies to integrate the key elements or the sub-systems of a city for effective and efficient interactions. This paper reviews the current literature on emerging technologies for SC developments in the context of smart innovation and Big Data analytics and analyses the diverse proposed architectures for SCs, such as Service Oriented Architecture (SOA), Event Driven Architecture (EDA), the Internet of Things (IoT) Architecture as well as the Internet of Everything (IoE) Architecture. It then proposes an improvement from the perspective of real-time Big Data analytics that characterizes SCs initiatives. The literature review is conducted in the form of a typological investigation which allows searching for useful insights into a clear-cut understanding of existing architectures for SCs and suggests areas of improvement to meet the current challenges of data-driven city systems. In highlighting the implications and the influence of emerging technologies on future cities, the paper also discusses opportunities in the real-time monitoring and analysis of streaming data from SC infrastructures using emerging technologies for Big Data analytics. Finally, the paper highlights the importance of keeping a strong focus on spatial awareness in SCs to fully address matters of sustainability.

Keywords: Smart City Evolution; Big Data; Emerging Technologies; Smart City Architectures; Innovation; Real-time Monitoring; Sustainability

INTRODUCTION

1. Introduction

In recent years, the rapid urbanisation process has become a worldwide phenomenon (UN, 2014). This global trend of urban development coincides with a unique era of computing paradigms, in which emerging technologies or advanced information and communication technologies (ICT) have become more pervasive with a remarkable influence on social, economic, organisational and other key sectors (particularly in the complex systems of city management world-wide). Thus, globalisation and urbanisation processes are promoting modern economies through an increase in standard of the living by using knowledge as the driving force of globalisation expressed in the form of knowledge-driven economies in which cities are at the centre of virtually all the activities. The concept of the Smart City (SC), therefore, brings about an evolution of urban development wherein advancement in ICT and new technologies play key roles through innovation and globalisation processes because the overall strategy of the SC concept is to apply smart technologies to improve the overall competitiveness of cities while dealing with urban development challenges (Wenge et al., 2014).

Höjer and Wangel (2015) viewed sustainable Smart Cities (SCs) as a combination of sustainable development and smart technologies. In this regard, sustainable SC is achieved only when smart technologies are used to make a city more sustainable. Emerging technologies, therefore, are at the heart of the global knowledge-driven economy, creating formidable platforms for knowledge sharing in building sustainable economic growth. According to Neirotti, De Marco et al., (2014), the concept of SC is gaining widespread support in the agenda of policy makers and has been given particular attention by the European Union and other members of the Organisation for Economic Co-operation and Development (OECD) (Paskaleva, 2011).

This paper addresses the development of sustainable SCs from the perspective of the critical roles that emerging technologies will play with regard to the huge volume, variety and veracity of data that characterises the SC environment with the use of IoT devices such as sensors and RFID devices. Fully aware of the diverse viewpoints in the literature on the existing architectures as proposed by different authors, the study analyses the most popularly utilized architectures. It finds the multi-layered architecture proposed by Wenge et al. (2014) useful in view of the data intensive requirement of SCs and suggests areas of improvement in order to meet the challenges of real-time analytics of sensor- and human-processed data in the knowledge-based environment of cities.

The remaining part of the paper is structured as follows: section 2 discusses the background and related work; section 3 discusses the sustainability issues in SCs; section 4 analyses the role of emerging technologies; section 5 analyses the proposed architectures and suggests areas of improvement; section 6 presents a discussion and, finally, section 7 draws the conclusions and presents potential future work.

2. Background and Related Work

SCs represent an emerging area of research that is currently gaining a lot of attention. A number of definitions have been proposed and one notable definition has been presented by

Forrester (cited by Washburn et al., 2009) who defined SC as "the use of smart computing technologies to make the critical infrastructure components and services of a city – which includes city administration, education, healthcare, public safety, real estate, transportation, and utilities – more intelligent, interconnected, and efficient". Similarly, IBM's definition (presented from an industry point of view) sees an SC as an environment that uses technology to transform its core systems in order to optimize resources' utilization. According to IBM (ITU, 2014), at the highest level of maturity, SC is a knowledge-based system that provides real-time insights to various stakeholders, therefore, enabling decision-makers to proactively and effectively manage a city's sub-systems. In this view, effective information management is at the heart of this capability, and integration and analytics are seen as the key enablers.

In addition, as cited in Chourabi et al., (2012), considered SC as "the city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city". Batty et al., (2012) acknowledged that SCs are simply instruments for improving competitiveness in such a way that communities and the quality of life are enhanced. The International Telecommunications Union (ITU) during its focused group analysis (ITU 2014) and in an effort to come up with a standardized definition for Smart and Sustainable Cities, analysed over 100 publications and listed different definitions of SCs. From ITU's analysis, the over 100 definitions of 'SC' kept revolving around 50 keywords such as quality of life, ICT, technology, innovations, management, systems, integrate, intelligent, etc. The instance of about 726 of the keywords were analysed to measure or compare the importance of those words within the subject matter.

According to Gartner, as cited by Lee et al. (2014), an SC is based on the intelligent exchange of information that streams across a city's subsystems. The information exchange is analysed for the benefit of the citizen and the commercial services. Gartner emphasized that SCs act on this information flow to make their wider ecosystem more resource-efficient and sustainable. It is imperative to emphasize that this information exchange needs to be based on a smart governance operating framework designed for sustainability. Lee et al. (2014) posited that SC is a concept that derives its definition from a combination of definitions such as those for the information city, the knowledge city, the intelligent city, the ubiquitous city, and the digital city. After a critical evaluation of the different characteristics of the SC concept, their analysis conclude that Smarter Cities create better, more sustainable cities, where the quality of life is higher, the environment more livable and economic prospects stronger for the citizens.

In summary, the issues of improved services and quality of life are considered imperative in a SC. Thus, the concept of SC has the central objective of improving the quality of life in today's densely populated cities around the globe as well as promoting social, political, cultural, economic equality and access. Hence, it is crucial for SCs to create and transfer knowledge and to improve social innovation and a host of other services using the emerging technologies in Cloud Computing and Big Data Analytics as a platform for solving the environmental, ecological, social, and sustainability problems facing the ever expanding cities of today.

3. Smart Cities' Sustainability Issues

Rising environmental problems and their related concerns have brought the issue of sustainability to the forefront in discourse on the SC agenda among the stakeholders. In order to address the issue of sustainability, stakeholders are now adopting creative, intelligent and innovative solutions within global efforts for sustainable development for cities. Given the economic and social challenges faced by cities globally, advanced cities (especially in Europe) are developing strategies for the adoption of new innovation approaches that can be leveraged for the socio-economic development of urban areas (Komninos et al., 2013).

According to the United Nations (UN) Department of Economic and Social Affairs (2014), Africa and Asia are taking the lead in the global urbanization trend with a projection showing Africa attaining 56% urbanization by 2050 while Asia is expected to reach 64% by the same period. The Department for Business Innovations and Skills in the UK (DBIS 2013), in its recent publication, further posited that 80% of the current global GDP is generated in cities of which 50% was recorded from 380 cities in the developed economies of the world especially in Europe and America. In its analysis, the report estimated a growth pattern that will shift to the east by the year 2025 with China playing a major role in the upward trend of urbanisation with an unprecedented rise in its urban population. Saunders and Baeck (2015) posit that national governments, city planners and technology solution providers across the world are currently evolving strategies for addressing the challenges of mobility around cities, the provision of utilities (especially energy) and, most importantly, the safety of humans and the environment. However, Arup (2011) revealed that cities are being overwhelmed, as 50% of the current global population reside in cities. According to this author, this percentage generates 75% of the carbon emissions which are now complicating the challenges of climate change as the demand for resource utilisation continues to increase.

As presented by Saunders and Baeck (2015), China and India alone are currently planning about 300 SC pilot projects in addition to other various efforts in the developing world. It is an indication that the entire world is developing to a stage where governments are now investing heavily in one form of an SC project or another. For instance, APA (2015) posited that city planners, engineers and other stakeholders are now being challenged to cope with the responsibility of articulating a clear-cut vision with robust data collected and analysed for measuring performance. This also suggests the need to monitor how plans are improving the standard of living in cities while keeping the planners current with the evolving elements of the city.

The globalization of environmental problems has raised more awareness of the need for reconsideration of the means by which the development and management of cities (as well as the application of new technologies) are being undertaken in respect of sustainability concerns. Addressing the sustainability issues in SC deployment will require dealing with a number of challenges such as a strategic assessment to identify the required solutions; mitigating measures to manage the negative impacts of development; adopting the right approach (top-down or bottom-up) on competency by bridging the skills' gap between city administrators and the solutions providers, and also dealing with the issue of governance (Höjer and Wangel, 2015).

MATERIALS AND METHODS

1. Emerging Technologies and SC Deployment

Ubiquitous technologies have changed economic systems by the growing power of knowledge. Thus, innovation is expected to remain the key factor of technological advancement in relation to the development of societies and knowledge distribution. New technologies are gradually being integrated into virtually every facet of the activities in cities resulting in streams of available data (Bell, 2009). Emerging technologies have simplified real-time data collection greatly through IoT and Internet Connection Devices (ICD) devices such as RFID, sensors, cameras and smart phones. Current estimates suggest that the IoT evolution could increase internet connectivity to about 50 billion devices by the year 2020 (Thoma et al., 2015). The "super connected world" as described by this author has introduced innovative technologies that are now capable of assisting in the integration of cities' subsystems and in simplifying decision-making processes.

Cloud Computing as the Driver of Innovation for SC Deployment

The convergence of Cloud Computing and the Internet of Things (Schootman et al., 2016) for the realisation of a ubiquitous communications' vision is critical to the focus of this research. For instance, Suciu et al., (2013) analysed the suitability of Cloud Computing and the IoT for SC deployment in the context of an open sensor network and a decentralized cloud-based platform. In this work, a conceptual interoperable framework that integrates the characteristics of Cloud Computing and IoT for an SC service middleware platform is proposed. The integration of emerging technologies for the realistic applications of SC according to Suciu et al., (2013) should be in a highly distributed environment with support for real-time Big Data management. As noted in the previous study above, the suitability of this model, especially in an emerging environment and when testing it in core SC services (e.g. a Smart Grid) still requires critical investigation.

Similarly, Mitton et al., (2012) posited that the realisation of any envisioned Smarter Cities will depend largely on the critical role of sensor networks and the future internet. In this work, Mitton et al., (2012) believe that SCs will deploy smarter sensor devices (with high processing powers and other capabilities) to capture, analyse, and manage sensitive data such as security data, traffic data, the monitoring and management of water gaze, pollution related data, etc. The study, therefore, proposes a new architecture that will allow cloud sensors and actuators to be dynamically provisioned as services through the platform of the IoT. The previous studies mentioned point to the possibilities in a plethora of tools and techniques for managing smart innovations but advancing these services for data filtering in real-time in a specific SC is yet to be experimented upon. As emphasized by Suciu et al. (2013), the suitability of Cloud Computing and the IoT for SC deployment still requires further research.

Big Data Analytics, Cloud Computing, and SC Evolution

Big Data is defined by the Mckinsey Global Institute (Hu et al., 2014) as datasets whose size is beyond the ability of typical database management software tools to capture, store, manage and analyse within a reasonable time period. Leveraging the opportunities in Big Data analytics within data intensive technologies which can be deployed for future cities will ease the processes of making available the right information to the right user at the right time. The development would have a tremendous influence on how cities are instrumental in driving innovations and creativity in entrepreneurial developments. According to Kitchen (2013), the evolution of Big Data enables real-time analysis of city life and introduces a new form of urban governance while providing an enabling environment for running transparent cities that will be more efficient, sustainable and competitive.

Concerns have emerged about Big Data analytics in the context of knowledge management and innovation in SCs but the trend of development in this area suggests that it is a new research direction. For instance, Townsend (2013) viewed the emerging trend (SC and Big Data) as being technocratic in nature. There is a fear of technological luck-in on the ground that the promotion of SC and the various SC solutions are heavily pushed by technological experts (vendors i.e. IBM, CISCO, Microsoft, etc.) rather than being city government driven. On the other hand, Batty (2013) in principle is of the view that Big Data has the potential to provide an understanding of how city sub-systems function and its management to the extent that "Big Data will become a source of information about every time horizon". Kitchin (2014) further posited that many city governments now use real-time analytics to manage regulatory and other functions within a city in key sectors like security, transportation, environment and a host of surveillance systems. The implications of these developments require more investigation in order to evaluate possible adoption (and even the level of awareness) in both developed and emerging economies.

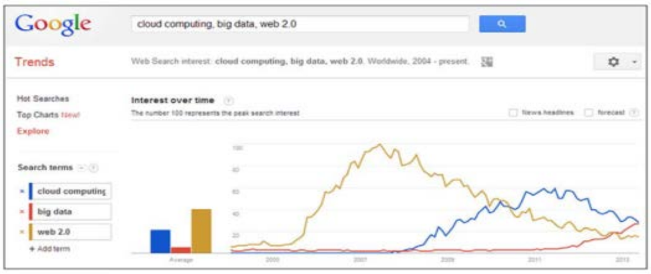

Figure 1: The rise of Web 2.0 Cloud Computing and Big Data from 2004 to 2013
(**Source:** Batty 2013)

It is envisaged that the challenges of complex data collection/capturing (especially in real-time), storage, querying, and analysing that will be required in future city environments will require serious attention, in particular: Volume (terabytes and petabytes of data), Velocity (datasets come in batches and in real-time), Variety (heterogeneity of data – structured, semi-structured and unstructured), Veracity (trust in and integrity of the data) and Value (how much value can be derived from such data). The emergence of Big Data tools and their associated technologies provides rich and diverse research opportunities in knowledge management which can help to provide solutions to some of the pressing urban challenges. This will be more realistic now that most of the SC projects/efforts are virtually at the experimental level.

Innovative solutions in social media and crowdsourcing appear to offer excellent opportunities for a wide range of applications in the critical aspects of city services such as health, education, transportation, professional services, etc. Crowdsourcing is noted to have high accuracy thus it can be used as “a base-map for other social media data” useful in geo-location and mobility management (Batty et al., 2012). With seamless integration of people and systems through the concept of the “web of everything”, emerging technologies are empowering citizen participation via interaction with key actors, thereby promoting territorial proximities and providing opportunities for social and economic development. Thoma et al., (2015) have provided a use-case scenario of a human-centric system of integration for different services such as the Smart Santander initiative in Spain.

2. Smart City Architectures

Recent research in SC development has dwelt heavily on the technologies and architectures of SC and divergent views have been presented. Hence, different SC architectures exist in the literature but to date no generally accepted architecture has been adopted (Wenge et al., 2014) giving an indication that this key aspect of the SC concept is still evolving. SC architectures are being designed from different perspectives of technological knowledge to address the sustainability challenges of future cities by building efficiency and effectiveness into the sub-systems of cities. A significant number of service oriented architectures (SOA), event driven architectures (EDA), Internet of Things (IoT) architectures, and Internet of Everything (EoT) architectures are being proposed while, in many cases, some authors have suggested a combination of different technologies Schootman et al., 2016). However, many of the proposed architectures are not very different from the traditional enterprise architectures being adopted to solve urban development challenges (Mulligan and Olsson, 2013). This section briefly discusses the SC architectures put forward in the literature with a view to suggesting a research direction in this area (see for instance, figure 2).

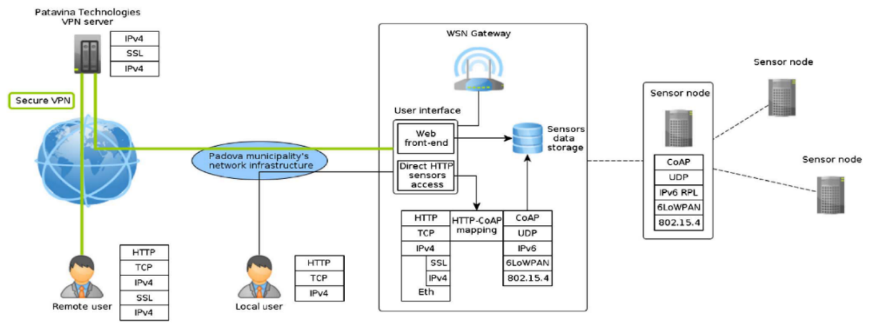

Figure 2: System Architecture of Padova SC (Source: Zanella, Bui et al., 2014)

SOA-based Architectures

From the perspective of Service Oriented Architecture (SOA), some authors have proposed SC architectures in this area to address the flexibility and scalability requirements of managing heterogeneous data in SC technologies. In this context, Anthopoulos and Fitsilis (2010) have proposed an enterprise architecture to strengthen the organisation and technical evolution of SCs. Anthopoulos and Fitsilis have presented a layered architecture with sustainability components to deliver multiple applications and services within urban areas. Andreini et al., (2011) also proposed an SC architecture based on SOA for the efficient orchestration of different components in a re-usable manner. Recognising the importance of scalability, Andreini et al. (2012) suggested the use of a Distributed Hash Table (DHT) protocol applying the concept of geo-localisation to the IoT for easy access to services.

Although these architectures were proposed as effective solutions (in some cases with use-case scenarios) service oriented architectures are prone to the challenges of archival and dirty/unified data (Xiong et al., 2014). These challenges limit the effectiveness of architectures built with a deep emphasis on SOA without the integration of more technologies because the future cities are expected to be data-driven.

EDA-based Architectures

A good number of architectures have also been developed based on Event Driven Architecture (EDA) to manage changes in SC systems. Filipponi et al. (2010) proposed an EDA based architecture that is enabled by Smart Objects for Intelligent Applications (SOFIA– infrastructure) to enhance communication as well as detect abnormal events using sensors. The architecture is designed with an Interoperability Open Platform (IOP) to ease the integration of heterogeneous sensors and sub-systems in managing spatial development. Filipponi et al. (2010) further divided the architecture into a Semantic Information Broker (SIB) and a Knowledge Processor (KP) as the main components for data storage and access respectively. Wan et al. (2012) introduced the concept of the IoT with sensor networks to EDA in order to maximise the efficiency of services in SC through the management and cooperation of machine-to- machine (M2M) components. According to Wan et al., the M2M SC architecture was introduced to manage mission-critical wireless messages that are capable of playing an important role in critical services such as smart grids, public safety, intelligent transport, energy management, etc. Again, EDA architecture has limitations because of the higher semantics of heterogeneous events.

IoT-based Architectures

Looking at a different perspective, developments in technologies and innovation for SC deployment are shifting their focus to the Internet of Things (Schootman et al., 2016) in recent years. Many industry players and academics are vigorously pursuing research topics that will contribute immensely to the IoT adoption for sustainable SC development. The IoT represents a computing paradigm that enables every physical object or heterogeneous device with virtual components with the ability to produce and, at the same time consume, services. The IoT has been described as a convergence of radio frequency identification (RFID) with Cloud Computing (internet), sensor technologies, and smart objects (Singh et al., 2014). In this area, a number of novel architectures for SC deployment based on the IoT (see, for instance, Attwood et al., 2011; Distefano et al., 2013; Horng et al. 2015; Schaffers et al., 2011) have been proposed with different viewpoints in addressing the technical challenges in SC.

One of the most interesting IoT architectures proposed by Zanella et al., (2014) was validated with a use case in “Padova SC”. The proposed architecture was based on an urban IoT system with proof-of-concept deployment covering different areas such as waste management, air quality monitoring, energy consumption, traffic congestion, smart parking, etc. Although Zanella et al., (2014) concluded that the enabling technologies for the realisation of IoT solutions in SC have reached maturity, the impact of noise on humidity and temperature measurements as acknowledged by Zanella et al., (2014) (based on this small scale implementation) requires further insights. IoT architecture, like other architectures discussed earlier, has drawbacks in terms of data security and privacy issues (Roman et al., 2011). In the IoT, everything becomes virtual “anywhere, anything, anytime”, hence, there is need for the integration of more technologies.

IoE-based Architectures

Finally, to uncover new information, enable fast communications and decision-making, as well as automating connections, the Internet of Everything (IoE) has emerged in the SC discourse as a technology that will overcome the challenges of the IoT in connecting people, processes, data and things with the same objective of improving the livability of cities. IDC Government Insights (2013) summarises the implications of the IoE in a SC (architecture) of the future based on the IoE technologies via Big Data and analytics, social media, mobility and Cloud Computing as the foundation for addressing future development challenges in cities (Clarke, 2013). Similarly, Jara et al. (2013) proposed full integration of internet protocol (IPv6) technologies into the IoT architecture in order to realize the IoE potential for SCs. Jara et al. (2013) present an architecture for leveraging connectivity and reliability, for support for heterogeneity, security and mobility in IPv6 interaction by offering an Internet of Everything to enhance the potential of the IoT applications in eHealth/mHealth as well as for SCs. It is important to note that the IoE still exploits the internet infrastructure and network connectivity in order to transport or communicate with every object through innovative management systems.

Towards an Integrated Architecture for Smart Cities

Emerging technologies and innovative solutions for managing new challenges confronting urban development goals in SCs will no doubt require comprehensive integration of diverse techniques, perspectives, and knowledge for sustainability. Research findings in this field have shown a development trend in which the SC architectures are evolving towards integrating different technologies to achieve a heterogeneous architecture for handling the emerging challenges of SCs and the future perspective of the IoE (Kyriazopoulou, 2015). Authors such as Wenge et al., (2014) have contributed immensely to the idea of integrating more than one technology in order to handle the new challenges of SCs through a layered architecture, for instance, their architecture addresses data management issues through the support service layer that integrates cloud computing and data technologies in the form of the Internet of Things (Schootman et al., 2016).

Interestingly, the work ofWenge et al. suggests the fact that data should be gathered, analysed, stored and kept secure. The proposed architecture recognises the fact that traditional data management systems can no longer cope with the challenges of the data intensive requirements of future cities. The new technologies generate Big Data characterised by heavy Volume (running into petabytes) and Variety (coming from various sources) in terms of applications, and the IoT devices' data outputs are heterogeneous - structured and unstructured including semi-structured. Above all, they have Velocity (streaming data) as described in the previous section. As depicted in figure 3, the multi-layered architecture emphasizes the relevance of data integration from heterogeneous sources as the key feature of SCs. The data acquisition layer in this scenario captures data from different sources such as sensors, RFIDs and so forth. As shown in the data acquisition layer to the upper-most application layer (Event-Driven), the architecture depicts a comprehensive integration of SOA, EDA and the IoT capabilities necessary for data fusion from different objects especially with the cloud platforms and visualization technologies.

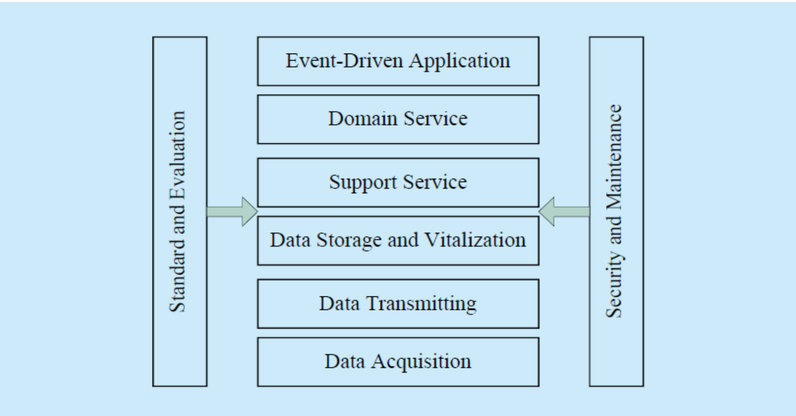

Fig. 3: Data Oriented SC Architecture

(**Source:** Wenge et al., 2014)

Although ease of administration (as depicted in the simple layered architecture), standards, and security in terms of data vitalisation, transmission, and sensorship were considered the critical success factors of the proposed architecture, in view of the new challenges of real-time Big Data analytics and the emerging IoE, a comprehensive integration of technologies that addresses issues along the line of the IoE to create cross-domain solutions for handling real-time Big Data analytics management challenges due to sensor systems may be desired in order to gain further insight. The importance of this has been echoed in the work of Kitchin (2014) which revealed that city administrators across the globe are now using real-time analytics in regulatory functions as well as in the management of some aspects of cities' performance. Furthermore, a data vitalization layer for managing incoming data from sensors can be useful in pushing analytics' results back to different actors in the city (users) through smart devices using SOA techniques to give stakeholders real-time access to information for timely decision-making.

RESULTS AND DISCUSSION

1. Discussion

This paper discusses the role of emerging technologies and the proposed architectures for SCs in the literature as it has been presented in the different sections above. Cities are easy locations where the world's creative and innovative activities are shaping the nature of global economies using technology. As highlighted in the sustainability issues raised by the United Nations (UN) Department of Economic and Social Affairs, because of the global urbanization trend expected in developing economies, the estimated 75% of carbon emissions that will be generated in cities, and the unprecedented and continuous rise in urban population, the role of emerging technologies in building sustainable SCs has become critical.

The Cloud Computing perspective presents tremendous opportunities for developing service models for managing challenges with new technologies. As highlighted in the review, further insights in critical areas such as the potential of Big Data analytics for real-time information about entire city sub-systems, decentralized cloud-based platforms for SCs, and testing a number of these smart solutions in core sectors of the city. With innovative solutions in the web of things, the IoT, social media, and crowdsourcing, emerging technologies are now playing critical roles in a wide range of applications in the critical aspects of SC services such as health, education, transportation, professional services, etc. The use case scenario of a human-centric system of integration for different services similar to the Smart Santander initiative analysed by Thoma et al. is considered relevant in this area in order to improve spatial awareness from social and ecological perspectives in view of the multitude of data requirements.

Emerging technologies are now assisting in crime management. For instance, New York City Police Department (NYPD) utilises feeds from all the city's cameras and uses this information to fight crime. Washburn et al., (2009) cited an example of a 911 real-time dashboard providing information on emergency needs that has helped New York City to reduce the crime rate by 27% with the aid of closed circuit television (CCTV) and video analytics. Enabling citizens to know how their utility consumption compares with their neighbours (through feed-back usage patterns for utilities in communities) is still a critical challenge. The role of emerging technologies in this regard will be to use systems that monitor social behaviours and correlate them to consumption patterns in real-time (smart grid) to predict power consumption patterns in order to provide an early warning.

In terms of the proposed architectures for SC deployment, this research recognises various contributions from different perspectives in this area. It is important to acknowledge that a good number of authors have recognised internet technologies - especially the IoT - as the critical component in the various designs which have included sensor networks and cloud computing.

Although some of the authors approached the issue of architecture for SCs in a particular pattern based on technologies for SOA, EDA, the IoT and the IoE, a few architectures referenced in the literature have adopted the techniques of combining more technologies for managing advanced applications. For instance, Wenge et al. (2014) have designed a simple layered architecture that integrates the functionalities of the IoT, SOA and EDA for the better management of data intensive technologies in SCs.

In view of some the weaknesses noted with respect to many of the discussed technologies, a comprehensive integration of technologies and architectures for SOA, EDA, the IoT and the emerging IoE will create cross-domain solutions for handling the data processing challenges of future cities especially with respect to sensor systems and cloud of things.

CONCLUSIONS

1. Conclusion

In this paper, the issues of sustainability and the implications of emerging technologies in building sustainable SCs were discussed. In highlighting the research interest generated in this area in recent years, the researcher cited specific examples of Cloud Computing innovations, social media, and Big Data analytics' concepts deployed for managing the new challenges presented by cities. Lastly, the study analysed selected architectures (based on underpinning technologies) as proposed in the literature for SC deployment.

The findings from this review and analysis suggest that emerging technologies such as Wireless Sensor Networks (MSN), vehicular networking and machine-to-machine communications (M2M) will play a critical role in the SC agenda, moving governance and the management of city sub-systems gradually towards utilising Big Data analytics. Big Data analytics will, no doubt, leverage cloud computing to provide "unlimited" computing and storage infrastructure to cope with the huge data coming from a SC. The analysis would run both predictive and prescriptive data mining on the extracted data. Such an analysis is already helping in the real-time monitoring of high traffic volume routes in order to facilitate traffic flow as well as assisting law enforcement agencies around the globe notably in crime management.

In the area of architecture, a plethora of SC architectures exist in the literature presented from different perspectives such as SOA, EDA, the IoT, and the IoE respectively. Based on the number of published works that are in the literature, the IoT based architectures dominate the recommended SC architectures and present many use case implementations. A few of the proposed architectures adopt the integration of technologies of further architectures in order to cope with the service requirements of future cities. The most interesting part of the whole analysis are the new challenges thrown up by the emergence of the new Internet of Everything (IoE). From this research's findings, it is suggested that many of the proposed SC architectures did not envisage the arrival of the IoE era where virtually everything and every process can communicate, automatically generating high volumes of Big Data from which extensive insights can be gained through real-time analytics.

Although this is still an ongoing research work, the building of a sustainable SC needs to focus on fundamental issues such as improving spatial awareness. Hence, the integration of the various forms of technologies in SOA, EDA, the IoT and the IoE architectures will improve the capability for converting the vast amount of raw data (Big Data) continuously generated in SCs (as a result of smart innovation) into useful knowledge which is needed for effective and efficient decision-making processes. In the future, efforts will be made to propose an SC architecture that will be more information-centric taking into account the new challenges arising from the IoE technologies.

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