

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**ASSESSING SMART CITY THEORIES AND MODELS
BASED ON THE UTILIZATION OF BIG DATA IN CITIES**



M.Sc. THESIS

Makbule YILDIRIM

Department of Informatics

Architectural Design Computing Programme

JUNE 2018

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**ASSESSING SMART CITY THEORIES AND MODELS
BASED ON THE UTILIZATION OF BIG DATA IN CITIES**



M.Sc. THESIS

**Makbule YILDIRIM
(710051006)**

Department of Informatics

Architectural Design Computing Programme

Thesis Advisor: Prof. Dr. Meryem Birgöl ÇOLAKOĞLU

JUNE 2018

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**KENTLERDE BÜYÜK VERİ KULLANIMI DOĞRULTUSUNDA
AKILLI KENT TEORİ VE MODELLERİNİN İNCELENMESİ**

YÜKSEK LİSANS TEZİ

**Makbule YILDIRIM
(710051006)**

Bilişim Anabilim Dalı

Mimari Tasarımda Bilişim Programı

Tez Danışmanı: Prof. Dr. Meryem Birgül ÇOLAKOĞLU

HAZİRAN 2018

Makbule YILDIRIM, a **M.Sc.** student of ITU Graduate School of Science Engineering and Technology student ID **710051006**, successfully defended the thesis entitled “**ASSESSING SMART CITY THEORIES AND MODELS BASED ON THE UTILIZATION OF BIG DATA IN CITIES**”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Meryem Birgül ÇOLAKOĞLU**
Istanbul Technical University

Jury Members : **Doç. Dr. Ozan Önder ÖZENER**
Istanbul Technical University

Doç. Dr. Bora YERLİYURT
Yıldız Technical University

Date of Submission : 2 May 2018
Date of Defense : 7 June 2018





To my family,



FOREWORD

I would like to express my deepest gratitude to my advisor Prof. Dr. Meryem Birgöl ÇOLAKOĞLU for her support and guidance over the course of my M.Sc. study. I would also like to thank my thesis committee members Doç. Dr. Ozan Önder Özener and Doç. Dr. Bora Yerliyurt for their valuable comments that helped me to shape this dissertation.

I would like to thank to my husband Eren Erman Özgüven for his invaluable support, patience, generosity and love without whom I could not have survived the process.

Last but not the least, words alone cannot express the gratitude I owe to my mother, and my father specifically, as well as my brother, my sister-in-law and my dear nephews Ada and Aras for their love, encouragement and endless support.

June 2018

Makbule YILDIRIM
(Architect)

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xiii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
SUMMARY	xix
ÖZET	xxiii
1. INTRODUCTION	1
1.1 Problem Definition	3
1.2 Research Objectives and Questions	4
1.3 Thesis Contribution	5
1.4 Thesis Outline	6
2. SMART CITIES AND BIG DATA	9
2.1 The Historical Evolution of Smart Cities	9
2.2 The Historical Evolution of Big Data	20
2.3 Big Data in Smart Cities	27
2.3.1 Urban big data	27
2.3.2 Sensing the urban big data	34
3. APPLICATIONS OF BIG DATA TECHNOLOGIES IN SMART CITIES	37
3.1 From Networks to Big Data in Cities	37
3.2 Managing Smart Cities with Big Data	41
3.3 Selected Current Data-driven Smart City Practices	49
3.3.1 The City of Chicago, IL, United States	49
3.3.2 The City of Singapore, Southeast Asia	52
3.3.3 The City of Amsterdam, Europe	53
3.3.4 Masdar City in Abu Dhabi, United Arab Emirates	55
3.3.5 Songdo City, Songdo International Business District, South Korea	57
3.4 Key Findings	60
4. CONCLUSIONS	67
REFERENCES	79
CURRICULUM VITAE	85



ABBREVIATIONS

AoT	: Array of Things
BiT	: Bilgi ve İletişim Teknolojileri
CAV	: Connected and Automated Vehicles
ICT	: Information and Communication Technologies
IDC	: International Data Corporation
IoE	: Internet of Everything
IoT	: Internet of Things
ITU	: International Telecommunication Union
LAN	: Local Area Network
MAN	: Metropolitan Area Network
MAN	: Personal Computers
SSC	: Smart Sustainable City
WAN	: Wide Area Network
WWW	: World Wide Web



LIST OF TABLES

	<u>Page</u>
Table 2.1 : Different descriptions for the cities.....	10
Table 2.2 : Types of urban big data and illustrative user communities (Thakuriah et al., 2015).....	33
Table 3.1 : Summarized key findings for selected current smart city initiatives (re- designed existing cities).....	61
Table 3.2 : Summarized key findings for selected smart city initiatives (cities designed from scratch).....	62
Table 4.1 : Smart city principles through the usage of urban (big) data.	70
Table 4.2 : Various classifications for urban (big) data by its source or type.....	71
Table 4.3 : Typical features of smart governance for a sample smart city framework.	73



LIST OF FIGURES

	<u>Page</u>
Figure 1.1 : The world’s urban and rural populations, 1950-2050 (United Nations, 2014).....	1
Figure 2.1 : Characteristics and factors of a smart city for assessing a city’s performance as a smart city (Giffinger et al., 2007).	13
Figure 2.2 : Fundamental components of smart city (Nam and Pardo, 2011).	14
Figure 2.3 : Strategic directions of smart city (Nam and Pardo, 2011).	14
Figure 2.4 : Core city systems and their interrelationships within the larger framework of the city’s strategy and governance (IBM, 2009).	16
Figure 2.5 : How cities can and have transformed their core systems (IBM, 2009).	17
Figure 2.6 : Smart city frameworks layers (from bottom to top) (Cisco, 2012).	18
Figure 2.7 : Hierarchy of city components (Cisco, 2012).	18
Figure 2.8 : Stakeholder roles and responsibilities (Cisco, 2012).	19
Figure 2.9 : Evolution of computing (IDC, 2017).	21
Figure 2.10 : Annual size of the global data sphere (IDC, 2017).	22
Figure 2.11 : Global information storage capacity (Hilbert, 2011).	22
Figure 2.12 : World’s technological capacity to store information (1986-2014) (Hilbert, 2015).....	23
Figure 2.13 : Data management solutions (Laney, 2001).	24
Figure 3.1 : Sensing in smart cities (Hancke et al., 2013).	43
Figure 3.2 : Rio de Janerio Operations Centre, Brazil.	47
Figure 3.3 : Architecture of IBM’s “Intelligent Operations Center for Smarter Cities” (IBM Intelligent Operations Center Website).	48
Figure 3.4 : An example for standard operations procedures for IBM’s “Intelligent Operations Center for Smarter Cities” (IBM, 2018).....	48
Figure 3.5 : Map of the proposed locations for the initial 42 Array of Things (AoT) nodes, Chicago (Url-1).....	51
Figure 3.6 : A sensor box sample from Array of Things (AoT), Chicago (Url-1). ..	51
Figure 3.7 : General Architecture of Array of Things (AoT), Chicago (Url-1).....	52
Figure 3.8 : Amsterdam’s City Data portal (data.amsterdam.nl).	54
Figure 3.9 : Perspective image of Masdar City (Url-4).	56
Figure 3.10 : Perspective image of Songdo City (Url-6).	58
Figure 3.11 : A schematic principle of smart waste management for Songdo City in comparison with traditional waste management systems (Url-6).....	59



ASSESSING SMART CITY THEORIES AND MODELS BASED ON THE UTILIZATION OF BIG DATA IN CITIES

SUMMARY

In the wake of the rising city populations and rapid urbanization all over the world, cities are constantly evolving and striving to be smarter and more sustainable to serve their citizens. At the same time, they are experiencing challenges more complex than ever before, and have been looking for more efficient ways to solve these problems. Unfortunately, these challenges due to urbanization may likely be even worse in the future since it is almost impossible to re-build the existing cities. Therefore, there is a need for a modern conceptualization of smart technologies in order to create well-equipped smart cities to increase the urban livability. On the other hand, cities, including their whole infrastructure (e.g., utility systems such as power, water, gas and waste collection, and drainage systems) are continuously being instrumented with smart technologies at the aggregate level. While these smart technologies make human life easier, they also produce huge amounts of data whether through human interaction or not (i.e., buildings are equipped with smart automation and housing systems, and people have smart devices such as smart phones, smart watches and many others), and various techniques have been recently developed for privately and securely collecting, storing, analyzing, processing, integrating and visualizing these big data generated by both city systems and citizens in drastically increasing amounts. As such, smart cities and big data are very significant topics of the 21st century's modern world. Many past, ongoing and future smart city initiatives are introduced by governments and other agencies at the national and local level. These initiatives are shaping the world through huge investments in order to solve the problems associated by the increasing populations all over the world, especially in cities, to provide the efficient use of natural world resources, and finally to improve the quality of life in general.

On the road to smarter cities, big data certainly have a significant role with regards to providing vital information on the city systems and its inhabitants, both physically and virtually. Therefore, one important question is as follows: Where does such data come from, and how can we efficiently utilize this data to achieve smarter cities? With this motivation, the main objective of this research is to aid in understanding the concept of smart cities utilizing a comprehensive assessment of big data technologies and methods. These technologies are evaluated regarding their current or potential use in smart cities, especially to inform the practitioners who are interested in developing smarter cities. As such, this thesis aims to give a general and deep understanding of the big data methods used to characterize and analyze smart cities while assessing the past and current smart city theories and models. This thesis focuses on how the efficient usage of urban data sets radically changed the way people live in cities in the 21st century with the help of information and communication technologies (ICT), and how big data can actually be utilized by city governments to improve urban planning and management processes in the context of smart cities. To achieve this goal, through the evaluation of the related literature and the assessment of current data-driven

applications of selected cities, several smart city principles will be presented in a novel scheme through “smart data management” and “smart people”, which can successfully lead to “smart governance”. To perform smart data management in cities, it is a must to instrument them with better data collection methodologies to ultimately develop better, different and smarter solutions to the problems faced by cities when compared to the past.

Smart data management basically relies on the efficient collection, storage, integration, analysis, sharing, utilization and security of urban sensor-based or non-sensor-based data in a city. Such a data management can certainly help city agencies to improve the service delivery operations (e.g. utility services such as power, water and gas, waste collection), to improve how cities function, and therefore to provide better quality of life for the inhabitants of the city as well as the visitors. Data integration especially plays a critical role in the smart data management. Within almost every industry, companies have been developing visions utilizing these big data that can successfully lead to a variety of new opportunities for them. Similarly, cities have also been deeply influenced with such innovative big data-related visions. Many cities in the world claim to be smart and publish strategical planning guidelines and agendas in order to justify their smartness and resilience for their present and future. Several local and national governments have also started collaborations with industry partners (such as IBM and Cisco and other smaller companies), and they have ongoing multi-disciplinary smart city-focused projects. Partnerships between corporate companies (public and private entities as well as non-profit organizations) and national or local city governments are also main triggering factors that can lead to smarter cities. Academic and civic institutions as well as other public agencies also provide directions towards smarter cities in the domain of citizen and public rights by providing a kind of unbiased participation.

Over the next decades, these public and private initiatives will likely to continue to grow at a rapid pace possibly supported by civic engagements since it is impossible for a city to be smart without public participation and “smart citizens”. It is not enough for city planners to plan for smart cities, and the managers to manage and control cities in smarter ways; but also, inhabitants for whom they work have to be able to access and use the smart technologies in awareness. A city cannot be smart without this engagement of citizens, and smart data management should be supported by people and their utilization of these data. This brings the problems of so-called digital divide and technology adoption, which should be clearly addressed in order for a city to become smart. In this context, this thesis defines a novel terminology, named as “Smartness Adoption”. Similar to the technology adoption, this term introduces the usage and accessibility of smartness by the whole population in the context of social fairness and inequality. This should be achieved to ensure that the whole population including the disadvantaged segments of the society (due to socioeconomic and demographic factors, and declining physical and cognitive abilities) can also be able to enjoy the benefits of smartness. As a result, smart data management and smart people, with civic engagement and citizen participation, can successfully lead to smart governance of a city. With the participation of all city entities including its’ citizens, smart city governance can happen through a secure data-driven decision-making process through the accessibility and analysis of both historical and real-time urban big data.

On the other hand, being a smart city indicates a great scale surveillance on cities and various activities in it, being secret or not. While walking on the streets or moving

from one place to another via driving or public transportation, we are constantly being tracked through devices such as sensors and cameras installed all around the cities. Relatively new technologies such as human face recognition or car plate recognition also have the capability of spying on the citizens anywhere and anytime. Therefore, while these smart city and big data technologies are being developed through solutions that continue to shape urban life in many ways, new principles are also needed for privacy and security arrangements. That is, in parallel to the developments in smart and big data technologies, effective privacy policies should be clearly defined regarding the ownership and usage of the personal or institutional data sources, data archives or real-time data that is routinely being produced in cities as well as to prevent cyber-attacks and decrease the cyber-attack vulnerability in city systems. This is especially critical given the increasing surveillance and tracking levels in cities, whether physically or virtually through online activities. This can help the cities and their citizens protect personal and institutional data sources, data archives, and real-time urban data routinely produced. Besides these privacy and security challenges, there are many other critiques against smart cities. One biggest problem is related to the motivation and purpose of governments and private companies, especially those large ICT companies, in collecting and utilizing the data. Therefore, the question is as follows: Do the governments and private companies want to develop solutions through data, or do they want to drive the data themselves? That is, are they interested in their own agenda given their economic and political views?

After investigating the literature and evaluating the basic concepts about both smart cities and big data, this thesis presents and discusses several successful smart city models especially based on their use of big data-focused technologies towards being smarter and more efficient while serving the citizens. The unique organizational structures and management systems associated with these practices have a significant effect on their success towards becoming smarter. In addition, increasing populations and urbanization have created the most critical challenges for all these cities. This indicates that the main problems these cities are facing are very similar even through these cities are located in geographically, demographically and socioeconomically different regions of the world. As such, they share the same concerns regarding the future, such as the efficient use of natural sources, environmental sustainability, and improvement of quality of life in cities. In order to solve these similar challenges, many smart city practices also leverage similar data-driven methodologies. This discussion can be used as a foundation while focusing on the adaptation of such technologies for other cities in Turkey and also around the world. Therefore, as all these smart and big data technologies all around the world are considered, it becomes clear that it is inevitable for Turkish cities and their governors to stay away from these developments. Although these are very admirable developments compared to a couple of decades ago, there are still improvements needed towards being smarter and making data-driven decisions using historical and real-life data captured. As such, there is a need for a more detailed evaluation of cities in developing countries, such as the City of Istanbul, Turkey, in order to be able to come up with more concrete solutions for the problems faced by these cities.



KENTLERDE BÜYÜK VERİ KULLANIMINA DAYALI AKILLI KENT TEORİ VE MODELLERİNİN İNCELENMESİ

ÖZET

Günümüzde dünya nüfusunun yarısından fazlası kentsel alanlarda yoğunlaşmış durumdadır. Kentsel alanlardaki nüfus artışları ve hızlı kentleşme nedeniyle kentler ve kentsel sistemler zorunlu olarak sürekli bir dönüşüm geçirmektedirler. Bunun yanı sıra her geçen gün, hızlı kentleşmeye paralel olarak geçmişe oranla çok daha karmaşık yeni kentsel problemler ortaya çıkmaya devam etmektedir ve bu problemlerin gelecekte çok daha ileri seviyelere ulaşacağı öngörülmektedir. Dolayısıyla, söz konusu problemleri çözmek üzere yeni ve daha etkin yöntemlerin geliştirilmesi kaçınılmazdır. Bu durum kentsel problemlerin yeni teori ve modeller ile gelişen teknolojiler doğrultusunda yeniden tanımlanarak ilgili problemlere yenilikçi çözümlerin getirilmesini gerektirmektedir. Mevcut kentlerin yeniden inşası mümkün olamayacağına göre, kentsel yaşanılabilirlik düzeyini, diğer bir deyişle, kentlerin ve kent sakinlerinin yaşam kalitelerini arttırabilmek için, akıllı teknolojilerin verimli bir şekilde adapte edildiği yüksek donanımlı akıllı kentlere ihtiyaç bulunmaktadır. Günümüzde akıllı telefonlar, akıllı saatler ve diğer akıllı cihazların kent sakinleri tarafından kullanımı hızla artmaya devam ederken, binalar da artık akıllı otomasyon sistemleri ile donatılmakta, elektrik, su, doğalgaz, atık toplama ve kanalizasyon sistemleri gibi kentsel altyapılar ise çok çeşitli akıllı teknolojiler ile desteklenmektedirler. Söz konusu akıllı teknolojiler bir yandan insan hayatını kolaylaştırmaya devam ederken, aynı zamanda gerek insan etkileşimi ile gerekse kendi başlarına çok büyük miktarlarda veri üretimine sebep olmaktadır.

Dolayısıyla, akıllı kentler (*smart cities*) ve büyük veri (*big data*) konuları, 21. yüzyılın modern dünyasının hem oldukça popüler hem de dikkate değer güncel konularındandır. Bununla beraber, geçmişe oranla kentleri ve kentsel yaşantıyı anlama konusunda kentsel pratiklere olan katkıları hiç de yadsınamayacak boyutlara ulaşmış durumdadır. Öte yandan kent yönetimleri de söz konusu değişim ve dönüşümlere uyum sağlamak için ve kent sakinlerine daha iyi ve kaliteli hizmet sunabilmek adına akıllı ve sürdürülebilir birtakım uygulamalar geliştirmektedirler. Yerel ya da ulusal yönetimler tarafından büyük yatırımlar ile finanse edilip geçmişte uygulanan, günümüzde uygulanmakta olan ya da gelecekte öngörülen birçok akıllı kent yatırımı dünyayı büyük bir hızla şekillendirmeye devam etmektedir. Akıllı kent yatırımlarının en temel ve öncelikli amaçlarından bazıları kentsel alanların hızla artan nüfuslarına çözüm bulmak, dünyadaki doğal kaynakların doğru kullanımını sağlamak ve nihayetinde kentsel yaşam kalitesini arttırmak olarak sıralanabilir.

Öte yandan, akıllı teknolojilerin kullanımına paralel olarak günümüzde hayatın her alanında olduğu gibi veri üretimlerinde oldukça büyük miktarlarda artışlar gözlemlenmektedir. Özellikle kentlerde kent sakinleri ve kent sistemleri arasındaki çeşitli etkileşimler sonucunda ortaya çıkan büyük verinin özel ve güvenli bir şekilde toplanarak uygun koşullarda saklanabilmesi, bir araya getirilerek analiz edilmesi ve

işlenmesi, aynı zamanda belirli bir amaca yönelik olarak görselleştirilerek dijital ortamlarda temsil edilebilmesi ve pek çok süreçte verimli bir şekilde kullanılabilmesi için çok çeşitli teknikler geliştirilmektedir. Bugünün akıllı kentlerine giden yolda bu büyük veri kesinlikle oldukça önemli ve büyük bir rol oynamaktadır. İster fiziksel ister sanal olsun, büyük veri sayesinde kentler ve kent sakinleri hakkında oldukça kritik ve kayda değer ve önem taşıyan bilgiler edinmek mümkündür. Peki bütün bu söz konusu verinin kaynağı nedir ve bu verileri daha verimli bir şekilde kullanarak daha akıllı kentler planlayabilmek nasıl mümkün olabilir? Bu temel sorgulamalar doğrultusunda bu tezin temel amacı, büyük veri teknolojileri ve yöntemlerinin kapsamlı bir değerlendirmesinin ve akıllı kentler kavramının anlaşılabilmesini sağlamaktır. Özellikle akıllı kentler konusuna ilgi duyan şehir planlamacı, mimar, tasarımcı, yönetici veya akademisyenler gibi farklı disiplinlerden uzmanlar için söz konusu büyük veri teknolojilerinin akıllı kentlerdeki mevcut veya potansiyel kullanımları hakkında genel bir bilgilendirme yapılması amaçlanmıştır. Araştırma kapsamında günümüzde uygulanmakta olan akıllı kent teori ve modellerinin literatüre dayalı bir analizi yapılırken bir yandan da genel ve derin bir bakış açısı kazandırmak amacı ile akıllı kentleri karakterize etmek ve analiz etmek için kullanılan büyük veri teknoloji ve yöntemleri incelenmektedir.

Hemen hemen her sektörde, işletmeler tarafından kendileri için çok çeşitli yeni fırsatlar sağlayan büyük veri kullanımına yönelik yeni vizyonlar geliştirilmektedir. Benzer şekilde, kentler de söz konusu büyük veri ve bu verinin faydalı kullanımı ile ilgili vizyonlardan büyük ölçüde etkilenmişlerdir. Kentlerin kendi vizyonlarını geliştirmeleri, kent sakinlerinin ihtiyaçlarını ve sorunlarını daha iyi anlayabilmelerini sağlayacaktır. Kentsel büyük verinin Bilgi ve İletişim Teknolojileri (BİT)'nin de yardımıyla etkin bir şekilde kullanılması 21. yüzyıl kentlerindeki yaşama biçimlerini kökten değiştirmeye devam ederken, bu tez kapsamında büyük verinin akıllı kentler bağlamında kentsel planlama ve yönetim süreçlerindeki kullanım alanları araştırılmaktadır. Bu amaç doğrultusunda, söz konusu literatür incelemesinin yanı sıra, dünyanın farklı coğrafi bölgelerinden farklı özelliklere sahip şehirler seçilmiş ve bu şehirlerdeki büyük veriye dayalı bazı uygulamalar değerlendirilmiştir. Bu değerlendirmenin sonucunda “akıllı yönetişime (*smart governance*)” ulaşabilmek için şu akıllı kent prensipleri belirlenmiştir: “akıllı veri yönetimi (*smart data management*)” ve “akıllı insanlar (*smart people*)”. Günümüzde, akıllı veri yönetimi kapsamında, kentlerin geçmişe oranla karşılaştıkları çok daha karmaşık problemleri çözmek için daha yeni, data etkin ve daha akıllı çözümler geliştirmek adına çok daha iyi veri toplama yöntemleri ile donatılması gerekmektedir.

Akıllı veri yönetimi, temel olarak bir kentteki sensöre dayalı veya sensöre dayalı olmayan verilerin toplanarak uygun koşullarda saklanabilmesi, bir araya getirilerek analiz edilmesi ve işlenmesi, aynı zamanda erişime açılarak paylaşılması, yani verimli bir şekilde kullanılması ve güvenliğinin sağlanması gibi konuları içermektedir. Bu süreçlerin başarılı bir şekilde yürütüldüğü bir veri yönetim sistemi, kentsel sistemler ile elektrik, su ve gaz, atık toplama gibi kentsel kamu hizmetlerinin iyileştirilmesine katkı sağlayacaktır. Aynı zamanda hem kent sakinleri hem de kente gelen ziyaretçilere, yani kentin tüm kullanıcılarına daha iyi ve kaliteli bir kentsel yaşama ortamı sağlayacaktır. Bunun yanı sıra, akıllı veri yönetiminde veri entegrasyonu dediğimiz verilerin bir araya getirilmesi süreci oldukça kritik bir rol oynar. Günümüzde, hemen hemen her sektörde, şirketler sahip oldukları büyük verileri kullanarak yenilikçi vizyonlar geliştirmektedirler ve bu da onlar için çok çeşitli yeni fırsatlara yol açmaktadır. Aynı şekilde, kentlerde üretilen büyük verinin toplanarak bir araya

getirilmesi de kent yönetimlerinde oldukça yenilikçi vizyonların geliştirilmesini olanaklı kılmıştır. Yine günümüzde pek çok kent stratejik planlama kararları adı altında geleceğe dair eylem planlarını yayınlamaktadırlar. Genellikle uzun vadeli bu stratejik planlama hedefleri akıllı sistemleri ve bu sistemlere dayalı uygulamaları temel almaktadır. Yerel ve ulusal yönetimler IBM ve Cisco gibi özel şirketler ile iş birliği içinde ve farklı disiplinlerden birçok uzmanın da katılımıyla pek çok akıllı kent odaklı proje yürütmektedirler. Aynı zamanda söz konusu kent yönetimleri ile kurumsal şirketler (kamu ve özel sektör kuruluşları ile kâr amacı gütmeyen kuruluşlar) arasında kurulan benzer ortaklıklar daha akıllı kentlerin planlanması ve bu kentlerin yönetilmesi süreçlerinin olmazsa olmaz bileşenleridir. Akademik ve sivil toplum kuruluşlarının yanı sıra diğer kamu kurumları da bir çeşit tarafsız bir katılım sağlayarak akıllı kentlerdeki vatandaşlık ve kamu haklarının gözetilmesi konularında destek sağlamaktadır.

Önümüzdeki yıllarda, sivil katılımların da desteklediği kamusal ve özel girişimler ve inisiyatifler büyük bir hızla büyümeye devam edecektir. Akıllı kentlerin halkın katılımı ve “akıllı vatandaşlar” olmaksızın başarılması olanaksızdır. Şehir planlamacılar tarafından akıllı kentlerin planlanması ve kent yöneticilerinin kentleri daha akıllı yönetebilmesi ve kontrol edebilmesi tek başlarına yeterli değildir. Aynı zamanda, kent sakinlerinin akıllı teknolojileri bilinçli olarak kullanabilmeleri de oldukça önemlidir. Kent sakinleri ile ihtiyaç duyulan etkileşimi sağlamayan bir kentin akıllı kent olarak nitelendirilmesi mümkün olmayacaktır. Akıllı veri yönetiminin kentte yaşayan insanlar tarafından desteklenmesi ve insanların bu verilerden maksimum düzeyde yararlanmalarının sağlanması gerekmektedir. Bu durum, akıllı kentler konusu ele alınırken, literatürde dijital ayırım (*dijital divide*) ve teknolojinin benimsenmesi (*technology adoption*) olarak adlandırılan kavramlar üzerinde durulmasını gerektirmektedir. Bu bağlamda, bu tez kapsamında “Akıllılığın Benimsenmesi (*Smartness Adoption*)” olarak adlandırılan yeni bir terminoloji tanımlanmıştır. Teknolojinin insanlar tarafından bilinçli bir şekilde algılanarak kullanılmasına benzer bir şekilde, bu terim, sosyal adalet ve eşitsizlik bağlamında akıllı kent sistemleri ve ilgili teknolojilerin nüfusun tamamı tarafından kullanımını ve erişilebilirliğinin gerekliliğini ortaya koymaktadır. Sosyoekonomik ve demografik faktörler ile fiziksel ve bilişsel yeteneklerin gelişimine paralel olarak toplumun nispeten dezavantajlı kesimleri dahil tüm nüfusun söz konusu teknolojilerden yararlanması sağlanmalıdır. Sonuç olarak, akıllı veri yönetimi ve akıllı insanlar, kent sakinlerinin ve çeşitli sivil toplum oluşumlarının da katılımıyla, bir kentin akıllı bir şekilde yönetilmesine olanak tanır. Kent sakinlerini de içeren tüm kentsel aktörlerin katılımına ek olarak hem eski hem de şimdiki zamanlı kentsel büyük verilere erişim sağlanması ve erişilen verinin analiz edilmesi sonucunda, akıllı kentsel yönetim sistemlerinin veriye dayalı karar verme süreçleri doğrultusunda başarılması mümkün olacaktır.

Öte yandan, kentler ve kentsel aktiviteleri anlamaya yönelik tüm çabalar ve günümüz akıllı teknolojilerinin bu doğrultuda kullanılması nedeniyle esasında çok büyük ölçekli bir gözetim mekanizması altında yaşamlarımızı sürdürmekteyiz. Sokaklarda yürürken, bir yerden bir yere kişisel arabalarımız ya da toplu taşıma araçları ile yolculuk ederken sürekli bir gözetim altındayız. Yüz tanıma sistemleri ya da plaka tespit sistemleri gibi nispeten yeni sayılabilecek bazı teknolojiler bugünlerde her yerde bizi gözetlemeye devam ediyor. Modern hayatın her alanında kullanılmakta olan akıllı teknolojilerin hayatımıza olan etkisi, fiziksel olarak kentlerde gözetlenen aktiviteler ya da sosyal medyada insanlar tarafından gönüllü olarak paylaşılan veriler, yani sürekli bir gözlem altında olma durumu ilk bakışta kulağa biraz ürkütücü gelse de aynı zamanda, söz

konusu akıllı teknolojiler sayesinde dünyayı daha iyi algılayabiliyor ve dünya üzerinde olup biten tüm yaşamsal aktivitelerin kontrol edilmeleri ve yürütülmeleri süreçlerinde bu teknolojilerden yararlanabiliyoruz. Akıllı kent ve büyük veri teknolojileri kentsel yaşamı pek çok yönden şekillendirmeye devam ederken, söz konusu verilerin kaynak ve toplanma yöntemlerine dair gizlilik ve kişisel güvenlik düzenlemelerini içeren yeni ilkelere de mutlaka ihtiyaç duyulmaktadır. Akıllı ve büyük veri teknolojilerindeki gelişmelere paralel olarak, özellikle de kentlerdeki artan gözetim seviyeleri veya sanal ortamlardaki tüm aktivitelerin kaydedilmesi nedeniyle, kişisel veya kurumsal veri kaynaklarına, veri arşivlerine veya şehirlerde rutin olarak üretilen gerçek zamanlı verilere erişim ve bunların kullanım şartlarıyla ilgili gizlilik politikalarının dikkatli bir şekilde düzenlenmesi gerekmektedir. Aynı zamanda kentlerdeki olası siber saldırıları önlemek ve kent sistemlerindeki siber saldırı kırılganlığını azaltmak gittikçe önem kazanmaktadır.

Bu gizlilik ve güvenlik problemlerinin yanı sıra, akıllı kentlere dair birçok başka eleştirel bakış açıları da mevcuttur. Başlıca eleştirilerden bir tanesi yerel ya da ulusal yönetimler ile özel şirketlerin, özellikle kurumsal ve büyük Bilgi ve İletişim Teknoloji (BİT) şirketlerinin, verilerin toplanması ve kullanılması süreçlerindeki motivasyonu ve amacı ile ilgilidir. Bu nedenle, esas sorgulanması gereken konulardan bir tanesi, söz konusu yönetimler ile özel şirketlerin esas amaçlarının, sahip oldukları veriler ile olası problemlere çözüm geliştirmek mi yoksa verileri kendi amaç ve çıkarları doğrultusunda kullanmak mı olduğudur. Yani, kendi ekonomik çıkar ve politik görüşlerine yönelik olarak verinin manipüle edilmesinin önüne geçilmesi oldukça önemli bir konudur.

Bu tez kapsamında, literatür analizine dayalı olarak, akıllı kentler ve akıllı kentlerdeki büyük veri kullanımına yönelik temel kavramlar değerlendirilmektedir. Aynı zamanda, akıllı sistemlerin daha akıllı ve daha verimli olmalarını sağlamak için büyük veri odaklı teknolojilerin kullanıldığı dünyanın farklı coğrafyalarından seçilmiş başarılı akıllı kent modellerindeki birtakım uygulamalar incelenmektedir. Kentlerdeki bu akıllı uygulamaların yürütülmesini sağlayan farklı organizasyon ve yapılar ile yönetim sistemleri incelenmektedir. Aynı zamanda bu kentlerdeki nüfus artışları ve hızlı kentleşmenin sebep olduğu temelde benzer problemlerin, coğrafî, demografik veya sosyoekonomik açılardan dünyanın farklı bölgelerinde yer almalarına rağmen büyük benzerlikler taşıdıklarını göstermektedir. Başka bir deyişle, bu kentler doğal kaynakların verimli kullanımı, çevresel sürdürülebilirlik ve şehirlerdeki yaşam kalitesinin iyileştirilmesi gibi gelecekle ilgili benzer endişeleri paylaşmaktadırlar. Bu benzer problemleri çözebilmek için, incelenen kentlerde kullanılmakta olan pek çok mevcut akıllı kent uygulaması da benzer veriye dayalı yöntemlerden faydalanmaktadır. Öte yandan, dünyadaki tüm bu akıllı ve büyük veri teknolojileri değerlendirildiğinde, Türk şehirleri ve yöneticilerinin bu gelişmelerden uzak durmaları imkânsızdır. Türkiye’de her ne kadar geçmişe oranla söz konusu teknolojilerin kullanımı konusunda oldukça önemli ilerlemeler kaydedilmiş olsa da daha akıllı ve etkin yöntemler geliştirilerek, elde edilen eski ve şimdiki zamanlı kentsel verilerin kullanılması doğrultusunda veriye dayalı yeni karar alma mekanizmalarının geliştirilmesi ya da mevcut mekanizmalarda iyileştirmelerin yapılması gerekmektedir. Böylelikle, bu şehirlerin karşılaştığı sorunlara daha somut çözüm önerileri getirilebilmesi için, Türkiye gibi gelişmekte olan ülkelerdeki İstanbul gibi şehirlerin daha detaylı bir şekilde analiz edilerek değerlendirilmesine ihtiyaç bulunmaktadır. Bu çalışma, bu teknolojilerin Türkiye ve dünyadaki diğer şehirlere adaptasyonu süreci tartışılırken faydalı bir kaynak olarak kullanılabilir.





1. INTRODUCTION

A smart sustainable city (SSC) is an innovative city that uses information and communication technologies (ICT) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects. (International Telecommunication Union (ITU), 2014)

In the wake of the rising city populations and rapid urbanization all over the world, cities are constantly evolving and striving to be smarter and more sustainable to serve their citizens. At the same time, they are experiencing challenges more complex than ever before, and have been looking for more efficient ways to solve these problems. Unfortunately, statistics indicate that these challenges due to urbanization may likely be even worse in the future 30% of the world's population were living in urban areas compared to the rural areas in 1950; however, this ratio became 50% in 2008, and it is expected to rise by 66% in 2050. The urban population is expected to be approximately 6.5 billion in 2050 as seen in Figure 1.1 (United Nations, 2014). As such, there is absolutely a need to find smarter ways to serve the inhabitants of the cities in the presence of this unprecedented rate of urban growth.

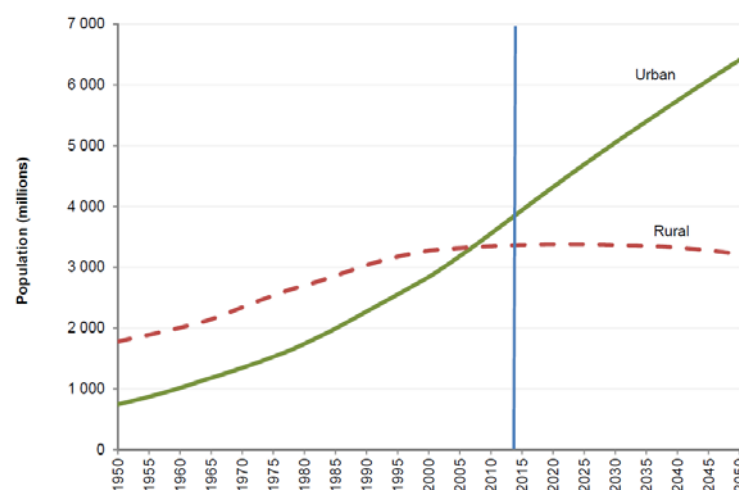


Figure 1.1 : The world's urban and rural populations, 1950-2050 (United Nations, 2014).

Over the last couple of decades, one of the major objectives of city governments is to be able to continuously adopt and instrument smart technologies at the aggregate level for the whole city infrastructure (e.g., utility systems such as power, water, gas and waste collection, and drainage systems). As these various sensors, communication systems and geospatial enabled devices are integrated into the city's infrastructure, and technology providers and companies continue to make extremely fast and innovative contributions to this urban domain, city governments have been able to start developing new plans and strategies towards achieving smartness and connectedness in their cities. While these smart technologies make human life easier, they also produce huge amounts of data whether through human interaction or not (i.e., buildings are equipped with smart automation and housing systems, and people have smart devices such as smart phones, smart watches and many others), and various techniques have been recently developed for privately and securely collecting, storing, analyzing, processing, integrating and visualizing these big data generated by both city systems and citizens in drastically increasing amounts.

Whether big or small, cities need to look beyond the traditional data sources and methodologies in order to achieve this goal, especially by collecting, analyzing, processing, integrating and visualizing huge historical and real-time data from a variety of data streams (which is recently referred to as "big data" in the literature) and getting value out of them. Considering their organizational structures, this is not a trivial task for city governments, and it comes with various challenges including the struggle in adoption of new technologies and sustaining the efficient usage of this data generated by these various sources. However, it is absolutely critical that city managers and planners should be able to understand, evaluate and use these technologies themselves. This will help them make informed choices about the present and future of their cities; however, the challenges of managing smart cities are diverse and complex. Each effort to improve the quality of life in cities must consider the heterogeneity of various technologies as well as the uncertainty within the data sets obtained from individuals, communities, and the infrastructure networks. This is an extremely significant and valuable direction in the wake of the limited and diminishing natural resources all over the world.

Recently, these techniques have been used in almost every field that one can think of. Therefore, any type of organization, big or small, has to understand the importance of

having and using data in innovative ways for their own benefits, and adopt their organizational structures given the new challenges created by big data technologies, which is mostly geared towards getting value from big data. In addition to public and private companies, this is also extremely valid for cities who strive to get smarter. Many past, ongoing and future smart city initiatives are introduced by governments and other agencies at the national and local level. These initiatives are shaping the world through huge investments in order to solve the problems associated by the increasing populations all over the world, especially in cities, to provide the efficient use of natural world resources, and finally to improve the quality of life in general. The integration of previous smart city and big data theories and models will help in understanding the cities and their systems and in planning to build and maintain for the future.

At the same time, since it is almost impossible to re-build the existing cities, there is a need for a modern conceptualization of smart technologies in order to create well-equipped smart cities to increase the urban livability. This will also lead to smart solutions for many urban challenges related to the public transportation and public service deliveries such as power, gas and water. Therefore, the main question is as follows: How can we improve the planning and management of future cities to provide a better quality of life for the citizens? In order to achieve this, there is a need to carefully review the literature focusing on smart cities and big data, and to investigate how they have evolved over the years. While accomplishing this, it is important to note that future cities with smarter services can only be designed through a multi-disciplinary collaboration between a variety of disciplines including architects, planners, engineers, social scientists and city managers.

1.1 Problem Definition

Within almost every industry, companies have been developing visions utilizing these big data that can successfully lead to a variety of new opportunities for them. Similarly, cities have also been deeply influenced with such innovative big data-related visions. Many cities in the world claim to be smart and publish strategical planning guidelines and agendas in order to justify their smartness and resilience for their present and future. Several local and national governments have also started collaborations with industry partners (such as IBM and Cisco and other smaller companies), and they have

ongoing multi-disciplinary smart city-focused projects. Partnerships between corporate companies (public and private entities as well as non-profit organizations) and national or local city governments are also main triggering factors that can lead to smarter cities. Academic and civic institutions as well as other public agencies also provide directions towards smarter cities in the domain of citizen and public rights by providing a kind of unbiased participation.

The most important challenge of city governments is providing safe, accessible and efficient services to the residents, and therefore improving the quality of life for them. A significant component of this challenge is collecting, analyzing, processing, integrating and visualizing big volumes of urban data towards achieving this goal. This requires city managers, planners and engineers to try reducing the uncertainties associated with the city operations through developing and utilizing better techniques to analyze the available data, and digest the lessons and experiences learnt. For this purpose, many cities are increasingly replacing their traditional city planning and management methods with smarter technologies in the wake of rapid urbanization and rising urban populations. However, before introducing such methodologies to find a solution for these challenges, it is important to clearly study the problem at hand. While there are many available big data-focused technologies in the literature that can be utilized in the cities, city governments should also be aware of a variety of problems associated with the adoption of these technologies into various city operations (e.g. design, planning and management). Therefore, there is a need to carefully evaluate and utilize the methodologies tackling the urban big data in detail in order to provide guidance to city governments in their endless journey of being smarter.

1.2 Research Objectives and Questions

The main objective of this research is to aid in understanding the concept of smart cities utilizing a comprehensive assessment of big data technologies and methods. These technologies are evaluated regarding their current or potential use in smart cities, especially to inform the practitioners who are interested in developing smarter cities (e.g., city planners, designers, administrators, researchers). As such, this thesis aims to give a general and deep understanding of the big data methods used to characterize and analyze smart cities while assessing the past and current smart city theories and models.

The main research questions are as follows:

- How can we efficiently assess the big data technologies that can be utilized in cities towards smartness and connectivity?
- How can we identify the best practices in collecting, analyzing, processing, integrating and visualizing the big data in smart cities?
- How can we aid in establishing better organizational structures in smart cities using the big data towards a better quality of life?
- How can we explore the potential and innovative future implementations that can be achieved with the use of big data in smart cities?

1.3 Thesis Contribution

The ultimate goal of this thesis is to provide a better insight and deeper understanding of the urban big data and smart city concepts through an extensive evaluation of the basic theory behind them. As new techniques and technologies are constantly being developed to analyze the big data-related challenges, this thesis will provide guidelines and recommendations for city planners, managers, and engineers in their conquest of utilizing these big data in their daily operations towards smarter cities. In addition, it will guide the readers through many innovative ways of getting value from urban data in smart cities. Through the use of big data, this type of a transformation from traditional governance methods to smart management systems is a big necessity for the cities all around the world, whether developed or developing. After investigating the literature and evaluating the basic concepts about both smart cities and big data, this thesis presents and discusses several successful smart city models especially based on their use of big data-focused technologies towards being smarter and more efficient while serving the citizens, which can help setting up the basic foundations for redesigning the existing cities and creating new smart cities from scratch. In order to solve these similar challenges, many smart city practices also leverage similar data-driven methodologies. This discussion can be used as a foundation while focusing on the adaptation of smart and big data technologies for other cities especially in developing countries all around the world.

On the road to smarter cities, big data certainly have a significant role with regards to providing vital information on the city systems and its inhabitants, both physically and

virtually. Therefore, one important question is as follows: Where does such data come from, and how can we efficiently utilize this data to achieve smarter cities? With this motivation, the main objective of this research is to aid in understanding the concept of smart cities utilizing a comprehensive assessment of big data technologies and methods. These technologies are evaluated regarding their current or potential use in smart cities, especially to inform the practitioners who are interested in developing smarter cities. As such, this thesis aims to give a general and deep understanding of the big data methods used to characterize and analyze smart cities while assessing the past and current smart city theories and models. This thesis focuses on how the efficient usage of urban data sets radically changed the way people live in cities in the 21st century with the help of information and communication technologies (ICT), and how big data can actually be utilized by city governments to improve urban planning and management processes in the context of smart cities. To achieve this goal, through the evaluation of the related literature and the assessment of current data-driven applications of selected cities, several smart city principles will be presented towards the successful management of urban big data in smart cities.

1.4 Thesis Outline

The thesis is divided into the following chapters.

Chapter 1 presents the introduction and problem statement.

Chapter 2 begins with an overview of the literature regarding the major developments in the two main research areas: (a) smart cities, and (b) big data. First, their historical backgrounds are provided in a chronological order, which focus on the events triggering the development of both general smart city and big data theories and models. Second, after reviewing the big data and smart cities literature and technologies separately, this thesis focused on the big data-related studies in the context of smart cities, which is usually referred to as urban big data literature, including the tools and methods for sensing the urban data in cities.

In Chapter 3, with the evolution and transformation of network technologies towards big data technologies, applications of big-data based studies in smart cities are introduced. In addition, new directions are provided and evaluated towards managing city operations smarter in parallel with the development of big data technologies. This

is performed by discussing the theories, methods and tools, identifying the relationships between them, and introducing the selected current data-driven smart city practices. Several key findings are also presented as a result of the comprehensive assessment of these selected cities, which can be utilized by public and private agencies for managing cities more efficiently.

Chapter 4 presents conclusions and discussions while putting forward several main principles towards the management of urban big data in smart cities and leading a future pathway for smart cities driven by big data.





2. SMART CITIES AND BIG DATA

2.1 The Historical Evolution of Smart Cities

This section presents an overview and assessment of the related literature focusing on the definition, characterization and historical evolution of smart cities while reviewing the literature. This type of evaluation is especially critical to comprehend the evolution of cities in their journey towards being smarter. In order to effectively accomplish this goal, the expert knowledge and their vision on the smart cities will be given utmost importance rather than simply sorting and presenting the historical literature. This effort is clearly needed so as to provide a better understanding of the evolution of cities in the context of smartness. It will also focus on both smart city evolution and technological progress especially related to data analysis and information and communication technologies (ICT).

Throughout the history, various definitions have been developed to describe cities in the context of the society they belong to and people that live in them. Over the last decades, a variety of descriptions, some of which are given in Table 2.1, gradually evolved parallel to the concurrent on-going developments with regards to the technological innovations. However, modern cities of the 21st century are mostly characterized by their “smarter” features, and therefore, this thesis will utilize the term “smart” more broadly while focusing on and defining the cities of tomorrow. In addition to being smart, note that many other terms related to data studies can also be considered as contributing prefixes to describe today’s smart cities, which include the following: “data city”, “data responsive city”, “data-fuse city”, and data-induced city”.

Although planning and managing smart cities have received a lot of attention in the 21st century, the concept of smartness in the cities and communities has been critically argued since the early 1990s. The use of term “smart” in the context of cities, on the other hand, goes all the way back to the early 1970s with the theory of “Smart Growth”. This urban planning and transformation theory has emerged in North America first, and gradually spread all over the world in terms of different contexts such as the

“compact city” in the U.K. Compact cities actually aimed to create compact and walkable urban centers, which prevented the inhabitants of the central urban areas from leaving where they live, and therefore preventing the urban sprawl. Although smartness in the cities may or may not be directly related to smart growth and urban sprawl, it is still important to review the history behind the smart city concept.

Table 2.1 : Different descriptions for the cities.

Wired cities (Dutton, 1987)
Fractal cities (Batty and Longley, 1994)
Computable city (Batty, 1997)
Cyber cities (Graham and Marvin, 1999 - Boyer, 1995)
Intelligent cities (Batty, 1990 - Komninos, 2002)
Digital cities (Ishida, 2000)
Ubiquitous cities
Virtual cities
Smart cities (Hall, 2000; Hollands, 2008)
Responsive cities
Hackable city

One of the earliest pioneering implementation of smartness in the cities was seen in the Silicon Valley, California between the years 1993 and 1998, which was called the “Smart Valley”. The main goal of this project was to help create a smart community with the advanced information on the infrastructure through online resources instead of the limited access to traditional data (i.e., printed versions of data). While creating smart communities and governments, the main challenges were to provide public access to all these online systems and the information they contain, and to connect people to each other and to the government. The project aimed to find efficient ways to achieve this by sharing information publicly and serving citizens to improve their lives (Lindskog, 2004).

Another pioneering event was “The Global World Forum on Smart Communities” in 1997, which is usually given as the starting point of the smart city timeline in the literature. This eventually led to years of debates regarding how to define and achieve smartness in the cities. Similarly, the first institutional definitions of smartness have been introduced in the “Smart Communities Implementation Guide” through a

collaborative effort by California Department of Transportation, San Diego State University and International Center for Communications in 1997 (International Center for Communications, 1997). In this study, a smart community was described as “*a geographical area ranging in size from neighborhood to a multi-county region whose residents, organizations, and governing institutions are using information technology to transform their region in significant ways*”. This definition implies the collective actions amongst governments, industries, academia, and the citizens instead of individual entities working in isolation. Resulting developments as part of this effort aimed to be disruptive (i.e., scalable and cost-effective) rather than incremental. As such, a smart community was defined as the one where both the governments, critical agencies (e.g., healthcare facilities, schools and companies) and citizens understand and make informed decisions together while efficiently utilizing the technology, which transforms the city life towards a positive direction. This can also help communities utilize the available resources and projects in a faster manner to benefit from the existing city infrastructure such as the transportation, telecommunications and other services. Therefore, instead of an incremental change, a significant transformation can occur, which helps the citizens manage and control their own lives as they live, work, travel, shop and entertain within a city. Such smart communities also provide economic competitiveness in the global economy, and they can attract more industries and companies to their region as a result of this advanced telecommunications and connected infrastructure.

Since 1990s, there had been many definitions of a smart city in the literature. For example, Hall (2000) defined a smart city, focusing on the vision of the city of the future, as follows: “*A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens*”. Hall’s definition was very significant since it describes the utilization of real-time data in city systems as follows: “*With advanced monitoring systems and built-in smart sensors, data can be collected and evaluated in real time, enhancing city management’s decision-making*” (Hall, 2000). Note that this definition also lists several critical components that are absolutely critical in order to achieve smarter cities: critical infrastructure and citizens, and data and decision

making. Hollands (2008), on the other hand, defined a smart city as an “urban labelling” phenomenon and stated that there was not a perfect definition for a smart city since each definition may lack the precision. The huge literature on the smart cities since the beginning of 2000s also points out that it is almost impossible to perfectly define a smart city including all aspects of a city with the technological advances. However, regardless of whether this lack of precision exists or not, the definition of Hall (2000) is still very valid, and this thesis will mainly utilize the aforementioned components of the definition as vital pillars for smart cities.

In addition to these definitions, there are countless theories that have tried to characterize smart cities in the literature. One of the early attempts to conceptualize a more tangible smart city model was that of Giffinger et al. (2007). This study described a smart city with its six different characteristics as follows: smart economy, smart people, smart governance, smart mobility, smart environment and smart living. These characteristics are still valid even today and each characteristic is associated by a certain number of factors (Figure 2.1). **Smart economy** represents the competitiveness of a city which includes the following: city’s innovative spirit, entrepreneurship, productivity, flexibility, and its international embeddedness and ability to transform. **Smart governance** leads to the participation in decision-making for city processes regarding the public and social services, which indicates the transparency of political strategies and perspectives. **Smart environment** focuses on the city’s natural resources, which is directly related to the city’s natural conditions, levels of pollution, environmental protection and sustainable resource management. **Smart people** includes both social and human aspects of a city, which represents the city’s level of qualification including the affinity to life-long learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism, open-mindedness and participation in public activities. **Smart mobility** represents the accessibility within the city and availability of information and communication technologies (ICT)-infrastructure, which aims to achieve sustainable, innovative and safe transportation systems. **Smart living** represents the quality of life in a city, which may include cultural facilities, health conditions, individual safety, housing quality, education facilities, touristic attractivity and social cohesion. These characteristics and factors were identified with an extensive analysis on the performance assessment of a city towards becoming smarter.

Based on the model of Giffinger et al. (2007), another definition of a smart city is as follows: A smart city is attained “*when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance*” (Caragliu et al., 2009). In addition to previous definitions, this one has also introduced the discussion of sustainability and optimal management of the resources through better governance in a city.

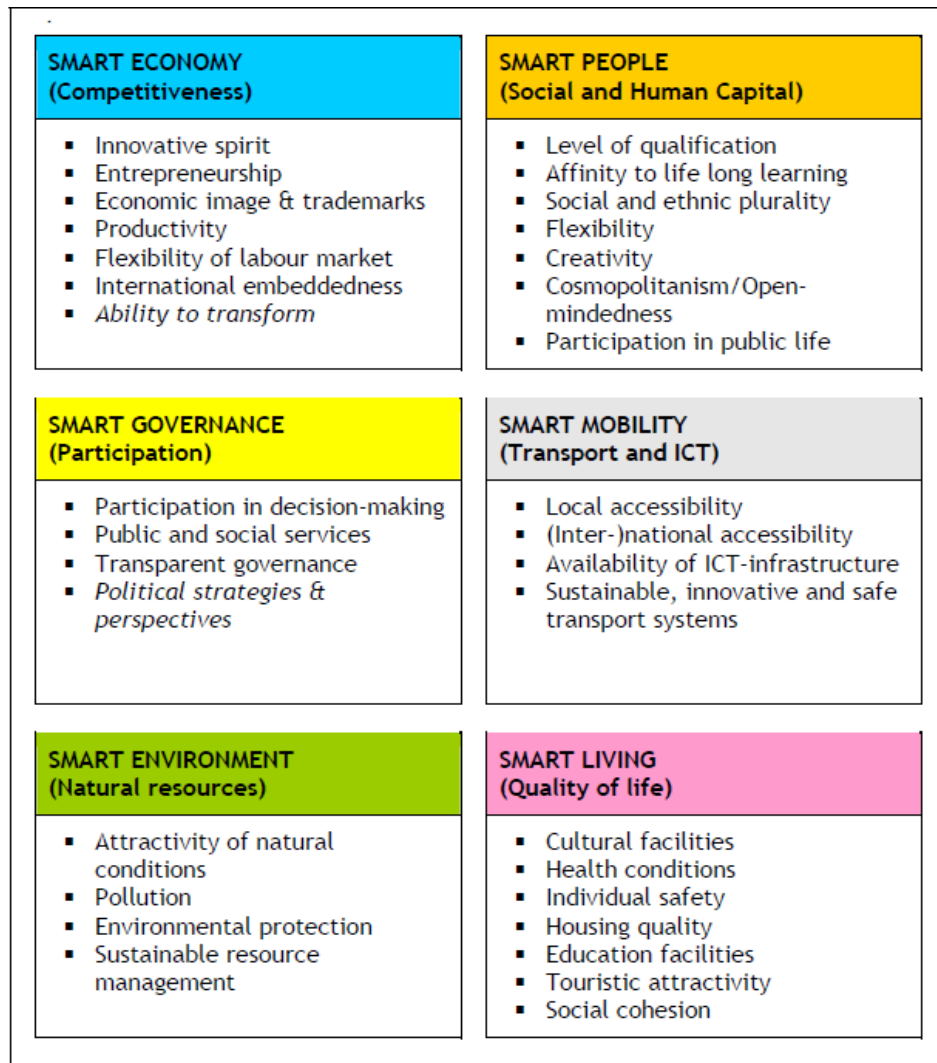


Figure 2.1 : Characteristics and factors of a smart city for assessing a city’s performance as a smart city (Giffinger et al., 2007).

Another notable and comprehensive smart city model has been presented by Nam and Pardo (2011), where they conceptualized and characterized smart cities in three dimensions: technology, people and institutions (Figure 2.2). In addition to

technological factors, they stated that institutional and human factors must be taken into account to create fully smarter cities. This is especially critical since a city cannot be smart if it does not consider the needs of its institutions and communities while using advanced technologies in the city governance and management. Nam and Pardo (2011) also offered their key dimensions as strategic principles for making a city smart through the integration of technology factors, learning for human factors and governance for institutional factors (Figure 2.3).

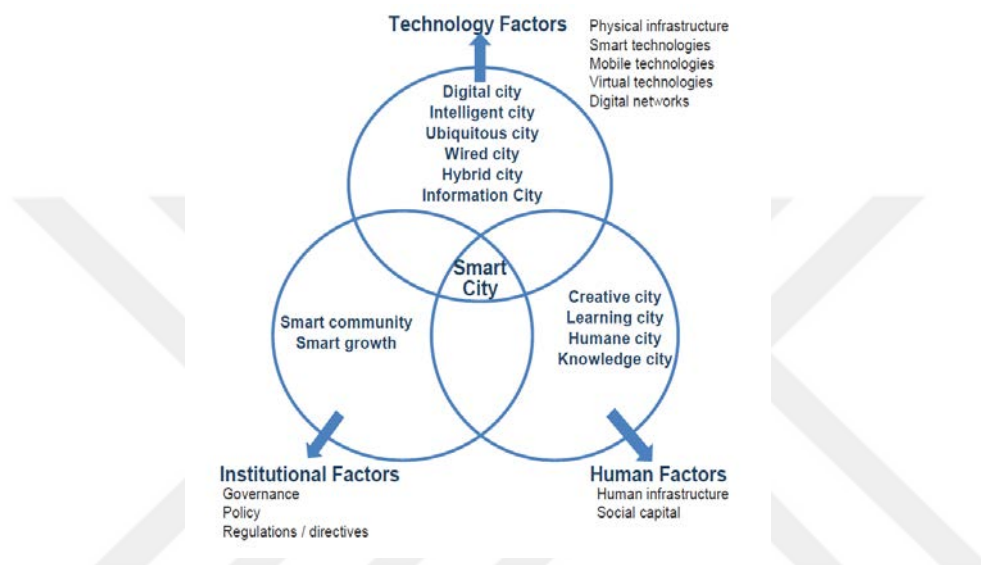


Figure 2.2 : Fundamental components of smart city (Nam and Pardo, 2011).

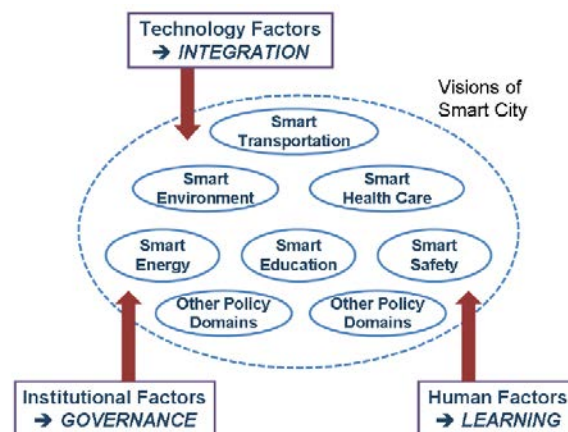


Figure 2.3 : Strategic directions of smart city (Nam and Pardo, 2011).

In addition, a comprehensive analysis of the literature review has been performed with a focus on 116 existing definitions of smart and sustainable cities in order to come up with a standardized version and commonly accepted description (ITU, 2014). This study proposed the following definition based on this comprehensive analysis: “A

smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects". Similarly, Caragliu et al. (2009) also stated that the smartness of a city was related to its sustainability because of its future existence and resilience capability.

On the other hand, corporations have also recognized the need to focus on ways to make cities smarter since the early 2000s, and these initiatives led to several smart city foundations with real-life applications. For instance, IBM played a leading role among these corporations. They first launched the "IBM's Smarter Planet" initiative in 2008, which helped industries, cities and societies to be more productive and smarter (IBM, 2008). Second, IBM released their vision of smarter cities in 2009 (IBM, 2009) towards more sustainable and resilient cities in the future. Similar to Hall (2000), their model on the smart city vision categorized the systems of a city in three main groups: infrastructure, networks and environments. These groups were central to providing better operations and strategies for the following seven core systems: city services, citizens, businesses, and city networks such as transportation, communication, water and energy networks (Figure 2.4; Figure 2.5). According to IBM, the efficiency of these systems would be critical in identifying the optimal path towards the success of a city in delivering its goals as well as determining the level of this success (IBM, 2009). Batty et al. (2012) evaluated IBM's smart city model and concluded that their model is based on urban typology, which could help in identifying the present and future problems related to smart cities. Traditional methods have extensively been utilized to solve these problems; however, with the technological advances in the last couple of decades, information and communication technologies (ICT) should be used to find state-of-the-art solutions instead of these conventional methods, according to Batty et al. (2012). Batty et al. (2012) also stated that ICT should be merged with traditional infrastructures, coordinated and integrated using new digital technologies in a smart city.

The model proposed by Giffinger et al. (2007) has presented the six characteristics and their associated factors for a smart city; however, IBM's model (IBM, 2009) brought this debate one step further by questioning the aforementioned seven core city systems with the following two questions: What are the current practices in cities? What can a

city really could do to get smarter in the future? IBM (Harrison et al, 2010) continued to improve this model by establishing the foundations and principles for the “Smarter Cities” concept in the following three “Information Technology (IT)” categories: instrumented, interconnected and intelligent, by describing smart cities as “*urban areas that exploit operational data, such as that arising from traffic congestion, power consumption statistics, and public safety events, to optimize the operation of city services*”. **Instrumented** here refers to those physical and virtual sensors as the sources that provide almost real time real-world data whereas **Interconnected** indicates the data integration via a computing platform in order to provide this information to various city agencies. **Intelligent**, on the other hand, refers to the advanced modeling, optimization, analytics and visualization tools needed to make data-driven and informed operational decisions. This type of a three-step approach can help a city adapt the behavior of its’ inhabitants towards the optimal utilization of the available city infrastructure and resources (i.e., sensing and controlling energy and water consumption, waste management, transportation systems, and using optimization-based models to increase the efficiency of the city resources). Therefore, for a city to be smart, there should be an intelligent interaction between the city and citizens, which will contribute to operational efficiency while maintaining or enhancing the quality of life (Harrison et al., 2010).

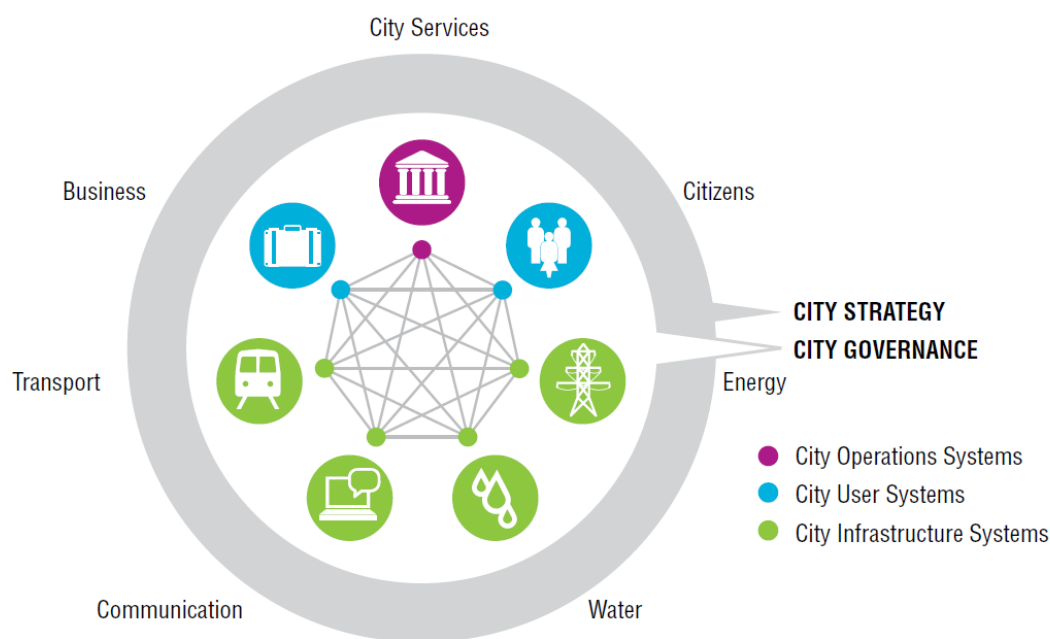


Figure 2.4 : Core city systems and their interrelationships within the larger framework of the city’s strategy and governance (IBM, 2009).

Today...	What if a city could...	Already, cities are...
City services Service delivery in silos with one size fits all	Tailor services to the needs of individual citizens	Using technology to integrate the information systems of different service delivery agencies to enable better services for citizens
Citizens - Cities have difficulty using all the information at their disposal - Citizens face limited access to information about their healthcare, education and housing needs.	- Reduce crime and react faster to public safety threats, by analyzing information in realtime? - Use better connections and advanced analytics to interpret vast amounts of data collected to improve health outcomes?	- Putting in place a new public safety system in Chicago, allowing realtime video surveillance and faster more effective response to emergencies - Giving doctors in Copenhagen instant access to patients' health records, achieving the highest satisfaction and lowest error rates in the world.³⁸
Transport Transporting people and goods is dogged by congestion, wasted hours and wasted fuel.	Eliminate congestion and generate sustainable new revenues, while integrating all transport modes with each other and the wider economy?	Bringing in a dynamically priced congestion charge for cars to enter Stockholm, reducing inner-city traffic by 25 percent and emissions by 14 percent, while boosting inner-city retail by 6 percent and generating new revenue streams.³⁹
Communication - Many cities have yet to provide connectivity for citizens "Going online" typically means at slow speeds and at a fixed location.	Connect up all businesses, citizens and systems with universal affordable high-speed connectivity?	Merging medical, business, residential and government data systems into a so-called ubiquitous city in Songdo, Korea, giving citizens and business a range of new services, from automated recycling to universal smartcards for paying bills and accessing medical records.
Water Half of all water generated is wasted, while water quality is uncertain.	- Analyze entire water ecosystems, from rivers and reservoirs to the pumps and pipes in our homes? - Give individuals and businesses timely insight into their own water use, raising awareness, locating inefficiencies and decreasing unnecessary demand?	Monitoring, managing and forecasting water-based challenges, in Galway, Ireland, through an advanced sensor network and realtime data analysis, giving all stakeholders – from scientists to commercial fishing – up-to-date information.
Business Businesses must deal with unnecessary administrative burdens in some areas, while regulation lags behind in others.	Impose the highest standards on business activities, while improving business efficiency?	Boosting public sector productivity, while simplifying processes for business in Dubai through a Single Window System that simplifies and integrates delivery and procedures across a range of almost 100 public services.⁴⁰
Energy Insecure and unsustainable energy sources.	Allow consumers to send price signals – and energy – back to the market, smoothing consumption and lowering usage?	Giving households access to live energy prices and adjust their use accordingly, as in a Seattle-based trial, reducing stress on the grid by up to 15 percent and energy bills by 10 percent on average.⁴¹

Figure 2.5 : How cities can and have transformed their core systems (IBM, 2009).

The interest on smart cities was not limited to IBM. In 2011, Cisco also published a report discussing how to achieve smart and connected city services and communities with the creative use of technologies across key community functions, real estate, utilities, mobility, and community services. They promised to transform physical communities into connected communities that can realize sustainability, resilience, livability, and economic enhancement goals by providing a cloud-based smart city services infrastructure (Cisco, 2011). In 2012, Cisco published some recommendations about how to create smarter cities through a smart city framework by defining layers from bottom to top level (Figure 2.6) as follows: city objectives to improve social, environmental and economic pillars, city indicators to match with city objectives, city components (Figure 2.7) to detail city assets which are physical components of a city such as utilities, transportation, real estate and city services, and city contents to map objectives to best practices and policies (Cisco, 2012). In this work, Cisco also outlined the roles of five key stakeholders and relationships among them (Figure 2.8). In the

following years, Cisco continued to offer new technologies to cities. For example, the concept of “The Internet of Everything (IoE) for Cities” based on “Internet of Things (IoT)” aimed to connect people, process, data, and things to improve the ‘Livability’ of cities and communities (Cisco, 2013). Several smart city practices that use IoT will be illustrated in Chapter 3.



Figure 2.6 : Smart city frameworks layers (from bottom to top) (Cisco, 2012).

Utilities	Transportation	Real Estate	City Services
Power	Rail	Residential	Healthcare
Water	Road	Commercial	Education
Waste	Air	Retail / Hotels	Fire / Police / Defense
N/A	Logistics	Public Buildings	Municipal Services

Figure 2.7 : Hierarchy of city components (Cisco, 2012).

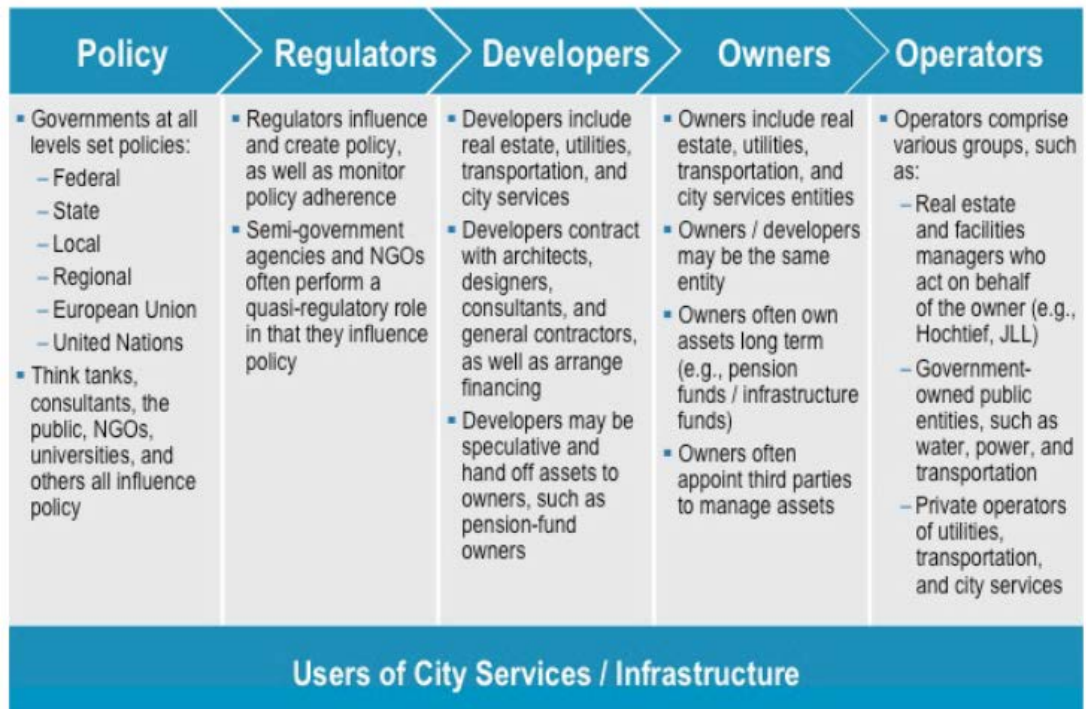


Figure 2.8 : Stakeholder roles and responsibilities (Cisco, 2012).

Currently, many cities in the world claim to be smart, and publish strategical planning guidelines and agendas in order to justify their smartness and resilience for their present and future. Several local and national governments have also started collaborations with industry partners (such as IBM and Cisco and other smaller companies), and they have ongoing multi-disciplinary smart city-focused projects. Over the next decades, these public and private initiatives will likely to continue to grow at a rapid pace possibly supported by civic engagements since it is impossible for a city to be smart without public participation. That is, smartness is not only for cities and their planning or management operations. It is also a need for inhabitants of a city to be smart, where they are called as “smart citizens”. Therefore, it is not enough for city planners to plan for smart cities, and the managers to manage and control cities in smarter ways; but also, inhabitants for whom they work have to be able to access and use the smart technologies in awareness. Partnerships between corporate companies (public and private entities as well as non-profit organizations) and national or local city governments are also main triggering factors that can lead to smarter cities. Academic and civic institutions as well as other public agencies also provide directions towards smarter cities in the domain of citizen and public rights by providing a kind of unbiased participation.

2.2 The Historical Evolution of Big Data

It is evident from the review of the smart city literature that historical and real-time data are critical for a city to be smarter. As such, this section will review the data-focused studies with a specific interest in the following very widely used concept of “big data”, while introducing the historical background behind its evolution. This term has first been used approximately 20 years ago; however, the technology was not sufficient enough to focus on large and complex data sets at the time. Recent technological advances, on the other hand, led to methods that can successfully be used to solve these issues. As the technology has advanced more and more, big data started to somehow transform every aspect of human life and eventually became a relatively critical concept for smart cities.

“Data” can anonymously be defined as the smallest piece of any information. The term of “big data”, on the other hand, is literally defined by Oxford Learners Online Dictionary (2018) as sets of information, which are too large or too complex to handle, analyze or use with standard methods. The “big data” term has first been used in a NASA research paper in 1997 that focused on visualization, for which the data sets were generally very large (Cox and Ellsworth, 1997). At that time, computer storage capacities were known to be insufficient while dealing with these big data sets as stated in the paper, especially due to the limitations with respect to the memory capacities, and capacities of local and remote disks. This problem was called as the problem of “big data” (Cox and Ellsworth, 1997). Thus, the size of the data was the actual reason behind the nomenclature of “big data” in the first place; however, “big data” cannot be defined only by the size in terms of its size in a disk. As such, the critical point is that “big data” cannot be easily processed by conventional methods and tools, and this is actually the main problem associated with such data sets especially because of their structural differences from the traditional data sets. Many researchers have recognized the need to focus on new methodologies to solve this problem related to the “big data” itself. In order to provide solutions for this problem, it is necessary to comprehend the previously developed big data concepts thoroughly. This comprehensive understanding can lead the way towards more intelligent and smarter cities through new and better technologies.

A good starting point, therefore, can be the focus on the “bigness” of big data in size. International Data Corporation (IDC), in their latest issue of 2017, categorized the creation and usage of the computing data in three main periods: 1) 1st Platform (Before 1980), 2) 2nd Platform (1980 to 2000), and 3) 3rd Platform (2000 to today) (Figure 2.9). According to IDC, the amount of the created data from and in the world started to increase substantially after the year of 2000, and they predict that the data that will be produced all around the world will reach 160 zettabytes by 2025 (Figure 2.10). Note that a zettabyte is equal to 10^{21} times a byte, which is used to indicate the unit of digital information.

Hilbert (2011 and 2015) also provided an idea on the technological capacity of the world based on storage of available data by comparing the analog or printed information with the digital information in 2011 (Figure 2.11) and later in 2015 (Figure 2.12). Very similar to IDC’s report, these studies pointed out that early 2000s should be symbolically considered as the breaking point in the history towards the realization of the “beginning of the digital age”. Reviewing Hilbert’s works, Mayer and Cukier (2013) stated that “information revolution” and “digital age” became a reality in the world in 2000s although there have been many ideas on these concepts since the 1960s.

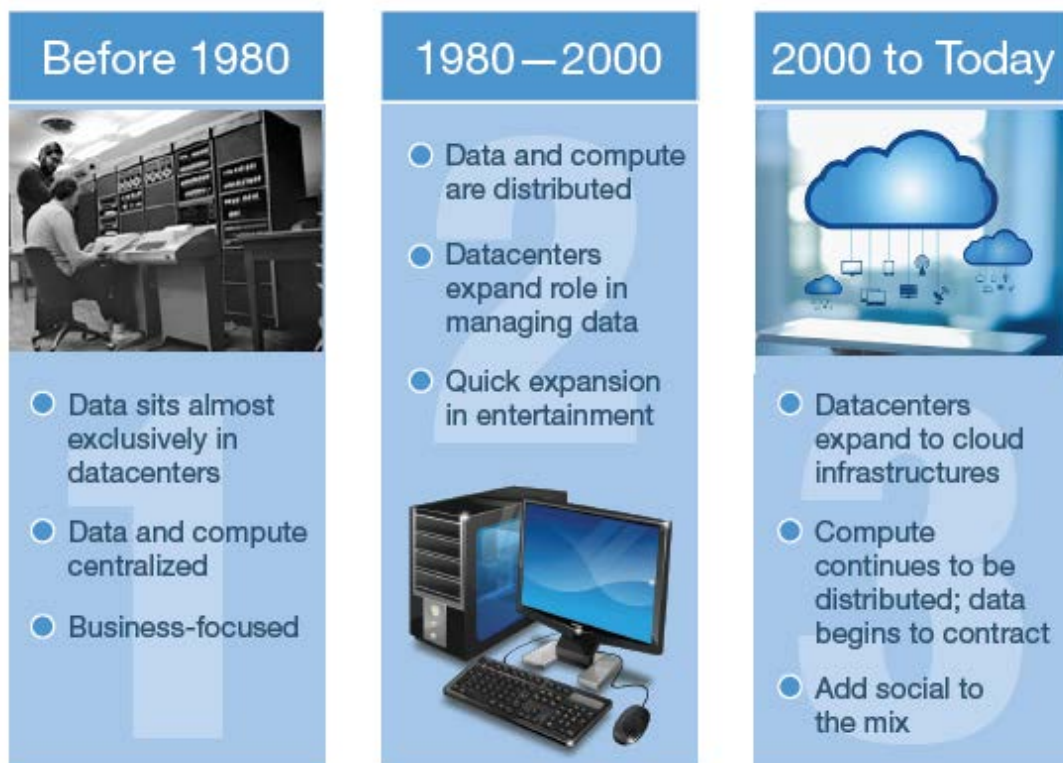


Figure 2.9 : Evolution of computing (IDC, 2017).

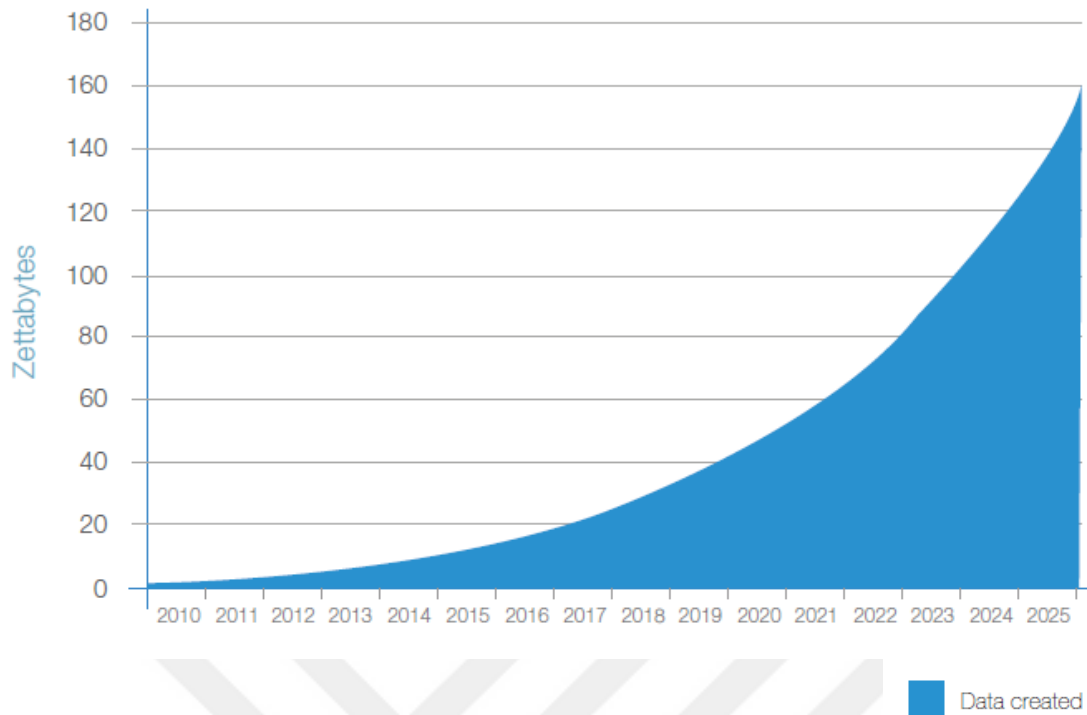


Figure 2.10 : Annual size of the global data sphere (IDC, 2017).

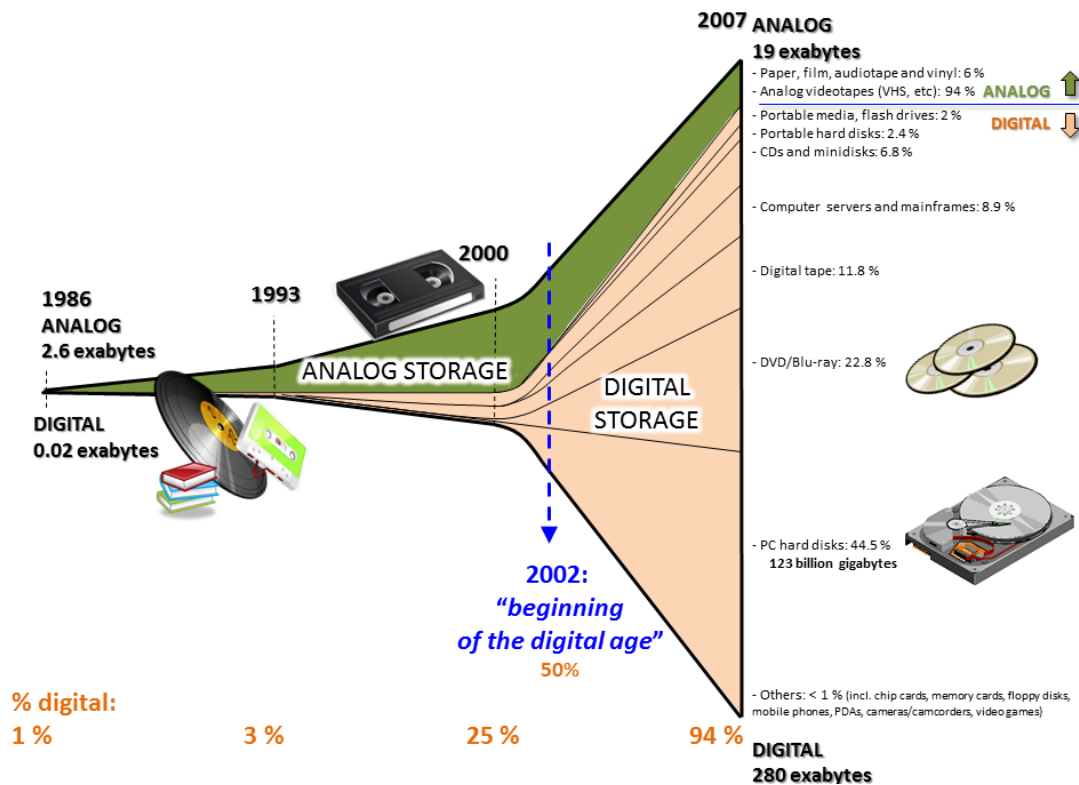


Figure 2.11 : Global information storage capacity (Hilbert, 2011).

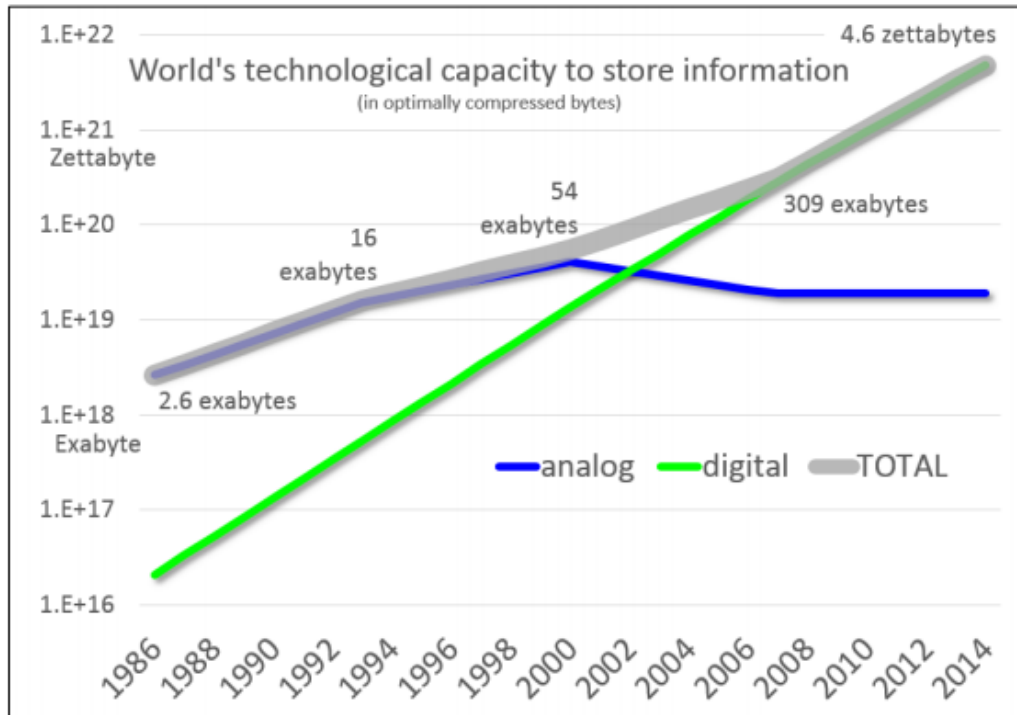


Figure 2.12 : World’s technological capacity to store information (1986-2014) (Hilbert, 2015).

In addition to examining the size of data, how to identify, control and evaluate this data have also gained importance over the years. In order to be able to control and manage the “big data”, innovative and novel approaches are needed over the current traditional data management principles utilized by many current businesses. Actually, many such businesses and disciplines are driving traditional data management methodologies to their limits, which helps in creating novel and better approaches. For example, several new definitions have been developed in the literature, which provide the basic characteristics of “big data” as volume, velocity and variety. These are usually called the 3Vs of big data (Laney, 2001; Figure 2.13). **Volume** is usually associated with the amount of data that cannot be processed by traditional analytical methods and computing technologies (Miller, 2015), and the size (bigness) of this volume is absolutely critical (Batty, 2018). **Velocity** is the speed of data flowing from the real world (Miller, 2015), which are also created in real-time (Kitchen, 2016), and it is a representation of the temporal frequency of the collections and observations (Batty, 2018). **Variety**, on the other hand, is related to if and how structured the data is (structured or not, semi- or un-structured) (Kitchin and McArdle, 2016), and is an expansion of data sources beyond traditional formats and sources (Miller, 2015). This

is also related to the type or kind (Batty, 2016a) and diversity and extent of the data (Batty, 2018).

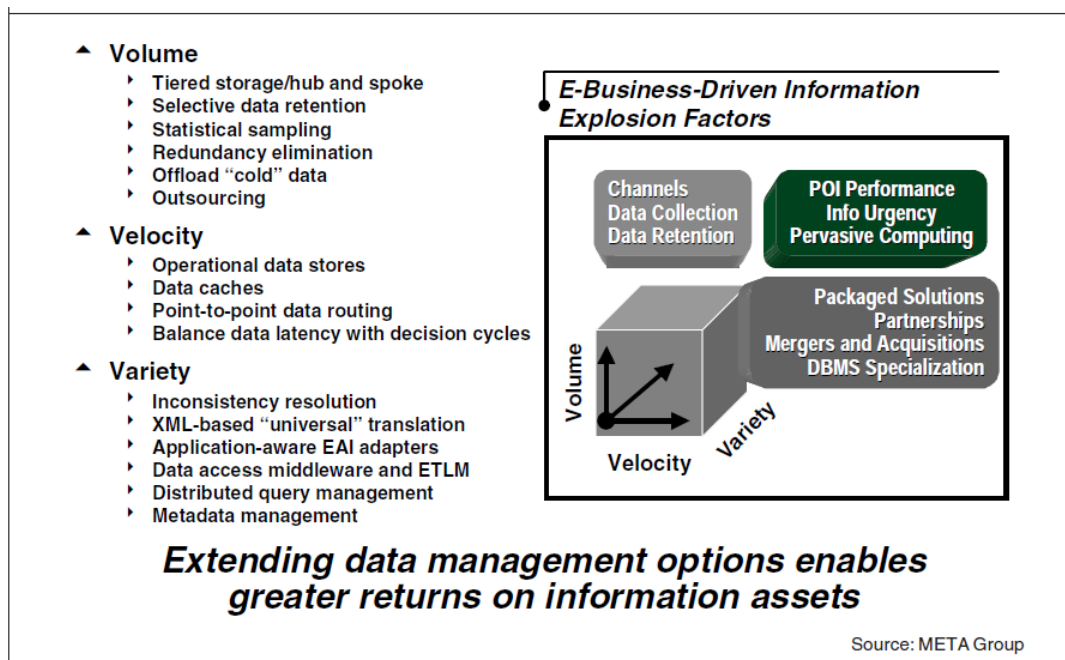


Figure 2.13 : Data management solutions (Laney, 2001).

Regardless of the size, type and methodologies associated with big data sets, Wired Magazine editorial by Anderson (2008) claimed that the end of theory era started with the age of big data, which led to the discussion and dispute of atheoreticalness of big data. Note that atheoreticalness indicates that a theory can arise somehow naturally from the data itself, which is still an on-going debate. As such, Anderson (2008) clearly stated that any scientific theory would be obsolete given the tremendous size and volume of big data as we live in a "Petabyte Age" in which more data at the scale of petabytes can be stored in the cloud instead of the traditional storage units such as previous floppy disks, hard disks, and even disk arrays. For that reason, an entirely new approach was required. Anderson (2008) expressed this new approach as follows: "With enough data, the numbers speak for themselves". Anderson (2008) also indicated the need to view the data mathematically at first, and then establish a context around the data, as part of this new approach. According to him, the newly available huge amounts of data would be a great new opportunity to understand the world with correlations instead of causations. Taking it even further, the editorial of this study actually ends with the following questions: "What can science learn from Google?" (Anderson, 2008). For example, one field that science can learn atheoretically from

Google is the field of health. It is known that early detection of disease activity and a fast response after the detection can actually lessen the effect of both seasonal and pandemic influenza. Online web search queries submitted by millions of people all around the world can successfully be used to improve such an early detection by monitoring the health-seeking behavior of individuals (Google, 2009). This was simply a way to analyze large amounts of Google search queries and had the capability to lead to successfully tracking the influenza in areas with a large population of web search users. Google (2009) was striving for making better predictions and estimations by identifying better and meaningful correlations between the web search queries and demographics of the affected region.

However, this debate on being theory-free will probably never come true since many researchers still continue to make scientific theory-based contributions related to big data utilizing, stimulating, and enlightening endless new definitions and characteristics of big data. For example, more V's have been added to the original 3V-based characterization of big data (Laney, 2001) since the introduction of the 3V concept (e.g., the veracity, variability, value). Batty (2018) recently speculated that big data was a concept that cannot be defined simply by 4 or 5 V's. Citing the work of Dutcher (2014), in which answers for the definition of big data from more than 40 thought leaders from different industries were combined, Batty (2018) stated that big data was more about the tools needed to process these data sets rather than their size or volume. Similar to Batty (2018), another work opposing the V's view point was presented by Kitchen and McArdle (2016), who stated that 3V's were not correct and mostly misleading in defining the "big data" since volume and variety were not the conditions needed for a data set to be big, without velocity and exhaustivity. This wrong characterization led to a confusion while defining the digital boundaries of the big data, according to their work in which they explored what constitutes the big data. **Exhaustivity** was a concept introduced by Mayer-Schonberger and Cukier (2013) in their national bestseller book named "Big Data". They formulated **Exhaustivity** as "n=all" concept, in which all available data should be utilized rather than samples of parts of it, as done by the traditional statistics.

Another characterization of big data was proposed by Mayer-Schonberger and Cukier (2013) in their famous "Big Data" book in the context of the daily use of big data with a variety of real-life examples. They emphasized three main shifts, namely the terms

of “More, Messy, and Correlations”, and they came up with a new concept called “**Datafication** of Everything” which means representing everything with data such as words, locations and interactions. They stated that these terms could be utilized to create **value** out of data, which was also the concern of Batty (2018). While questioning big data’s basic difference from traditional and sampling data which are mostly being collected for a specific purpose and usage, they were pointing out that big data could be used to answer questions of “what” instead of questions of “why”. That indicates that big data can be used in predictive analysis, which may not explain the cause of a problem, but it can only indicate the existence of a problem by creating many correlations instead of causations showing what, not why. Creating value with big data is about using these correlations in innovative and also creative ways with new insights. Mayer-Schonberger and Cukier (2013) also discussed the implications, risks and ways to control the big data, and provided some future directions in the presence of big data sources all around the world.

In addition to the problem of how to define and characterize big data, another significant problem is related to the question of who actually owns the data. For this purpose, Zwitter (2014), examined big data stakeholders in three main groups: big data collectors, big data utilizers and big data generators. **Big data collectors** are those that determine what type of data is collected, which data sets are stored, and how long they are stored. They basically govern the big data collection and utilization processes. **Big data utilizers**, on the other hand, are on the utility production side. They might collect the data without a certain purpose, and they can define the purpose for which data is being collected. For example, Zwitter (2014) stated that the purpose could be simply related to identifying behaviors by imposing new rules on the users and audiences or manipulating the social processes. It could also be dependent on achieving a competitive advantage over others by combining and fusing these new data sets towards advancing the knowledge and developing novel methodologies. Finally, **big data generators** can be divided into three main groups in itself; 1) Natural actors that generate massive amounts of data voluntarily or not voluntarily and knowingly or not knowingly, 2) Artificial actors that produce data as a direct or indirect consequence of a certain task or function, and 3) Any other physical phenomena, which generate a lot of data by their nature. These phenomena can also be measured in detail leading to

such massive data flows although they do not necessarily generate data directly (Zwitter,2014).

2.3 Big Data in Smart Cities

2.3.1 Urban big data

One of the main focus of this thesis is the identification of the useful methods that can successfully utilize the urban data (data related to cities) towards designing and controlling cities so that they can become smarter. Therefore, this section will deal with the types, sources, representations and perceptions of the urban big data towards understanding its main characteristics and applications. In addition, city-focused approaches will be evaluated to adopt the aforementioned big data methodologies that were summarized in the previous sections with real-life applications in the context of urban big data. Similar to every industry having its own unique type of data, which may have special characteristics different from other industries, urban data are also significantly different from each other. Cities, with their own unique data, actually serve as test beds to assess and verify which conceptual general big data theories are valid and useful for urban data sets or not.

Since the end of 20th century, similar to any industrial entity, the focus on big data in cities has gradually increased in their relatively long journey to become smarter while effectively serving the public. In this context, the term “urban big data” is used to represent the big data generated by cities. This urban big data includes every possible measurable feature of the cities, including but not limited to the population characteristics, demographics, socioeconomics, social networks, transportation data, utilities, buildings, weather information and air pollution. Batty (2013) defined these urban data as “*data for cities that are invariably tagged to space and time*”. This is a fairly accurate definition since urban big data is mostly being produced automatically and continuously by a variety of sensor forms including mobile phones and computers, which can clearly provide a better understanding on what happens where and when in cities. According to Batty (2013), urban data could be managed and analyzed in two ways temporally in order to understand how urban systems and cities function and be managed: long term (for strategic planning) and short term. Supported by the advancement in ICT, Batty (2016a) pointed out that the focus has been changing towards shorter time spans, creating a finer data analysis in order to better comprehend

what was really important in cities in order to be smarter and more automated. In addition, Batty (2016a) stated that the organization, tame, storage and processing of the urban big data would tell a lot about the city itself, and how the citizens of that city could move and interact with each other in space and time.

Especially the development and use of advances in ICT radically changed the use of these big data sets in cities. As such, big data in cities (urban big data), are primarily characterized by their volume and size, which is quite different from the traditional data sets that have been used to understand the cities and plan their future (Kitchin, 2014; Batty, 2016a). However, these urban big data sets may also be unstructured since they are so large, and they exist without a specific order, according to Batty (2016a). Therefore, Batty (2012a) indicated the need to comprehend this nature of urban big data in order to understand the cities, through the exploration of critical issues related to how the city is connected, how it generates its data, how these data sets can force developing new models and theories, and how these strategic models can be utilized to better plan the city. For this purpose, various methods and tools have been developed in the last sixty years on par with the advancement in the computational science. These tools allowed the data to be continuously and automatically collected, digitally stored, analyzed and processed in multiple ways. For example, the developments in sensor technology and their embedding in the environment led to continuous capturing and generation of big data in real-time. These sensors cannot only manage and control citizen activities in a city, but they can also enable these people to collect and share their own data through devices such as smartphones. (Batty, 2016a).

In addition to real-time streamed data obtained via sensors temporally, (Batty, 2016) discussed at least two other types of data that could be classified as big. An example is the spatial data obtained by sensing the surfaces of objects using aerial images, image processing and remote sensing. These images can be obtained through satellites, drones and other devices; however, they are limited when compared to the temporal data sets. That is, such temporal data sets are unbounded and continuously collected, and becomes bounded only when the sensor creating this data is turned off. Spatial data, on the other hand, is collected for only one cross-section in time, and it may take place over a short time interval. Geographic information systems (GIS) especially make use of different features of this spatial data. Although they are big, these data sets do not usually require a continuous data collection process.

Besides the temporal and spatial data types mentioned so far, another classification of urban data includes the following two groups: physical data and social (including economic) data. **Physical data** usually corresponds to the data that can be collected by geographic information systems (GIS), and can be represented in two different formats: **raster data** which is described as location-based spatial features (surfaces) on maps represented by grid cells, pixels or polygons, and **vector data** which is described as object-based models where objects are represented by points, lines and polygons.

Whether real-time or not, it is absolutely critical that these spatial and temporal urban big data sets should be gathered, combined and analyzed all together in order to better plan for the future of the cities and make them smarter. Bettencourt (2014) called such a planning process a computationally intractable problem in the presence of bigness and complexity of these data in cities, which becomes even more challenging with the addition of more variables that leads to the creation of multiple versions of cities.

In addition to the given urban big data classifications presented above, Thakuriah et al. (2015) presented another classification technique based on the data sources, and obtained the following classified groups: sensor systems, user-generated content, administrative data (open and confidential micro-data), private sector transactions data, data from arts and humanities collections, and hybrid data sources including linked data and synthetic data (Table 2.2).

The first group includes those urban big data collected from the infrastructure through moving object sensors and IoT. The urban infrastructure is a source to huge amounts of data created by a variety of sensor in the urban infrastructure. Examples include but not limited to transportation, health, energy, water, waste, weather systems, structural health monitoring systems, environmental management and buildings. Types of sensors included for this group can detect activity and changes in various urban phenomena including infrastructure and buildings; land cover, water, tree cover and environmental conditions in urban areas; movement of people, car and animals; and any activity such as patterns of service usage and locations. These sensors can also be wirelessly connected, mobile, and gradually more embedded and distributed. Generally, governments or companies employ these sensors, and they may be accessible to public or other entities under privacy and governance conditions. For example, they can be used by researchers in academia to develop better methodologies

for smarter cities. Other examples include those sensors related to connected vehicle systems, vehicle-to-grid systems, smart grid systems (i.e., power network), and those that can help seniors and people with disabilities through assistive technologies. Remote sensing has also received increasing attention lately after the collection of massive amounts of high resolution spatiotemporal data rapidly through satellites, planes and drones. In addition, if data is collected and analyzed over a long period of time through sensors, urban social scientists can utilize this information to study social, economic and environmental changes, and their impact on communities. Therefore, the focus on smart communities has become increasingly involved with urban sensor systems, especially through their integration with ICT solutions. In the future, these sensors will be even more significant due to such rapidly growing technologies, such as the tiny and intelligent sensors that can be embedded into almost everything including houses, cars, furniture, clothes and even humans. The concept of IoT is also extremely helpful since it can provide the capability to connect and manage all these sensors through the communication networks and cloud-based services (Thakuriah et al., 2015).

Second group is based on the urban big data generated by **social and human sensors**, which is generally referred as crowdsourcing (i.e., Volunteered Geographic Information, and User-Generated Content (UGC)). That is, data is generated directly by the citizens when they utilize the sensors located in smart technologies (e.g., smartphones, smart watches and GPS), social media, or any other social activity through their participation in social, economic and civic activities. These data are referred as active data unlike the traditional passive survey and research data. They include voluntarily generated data by the users on any idea, problems, solutions, information on events, disruptions and other social and civic activities, and also data related to the internet search, customer ratings, and web usage and trends. Users submit and publish these data continuously through the web, social media and other available tools. Especially these online social network platforms such as Twitter, Facebook, LinkedIn, Foursquare and others), other online platforms such YouTube and Flickr, and user-created online content sites such Wikipedia, TripAdvisor and Yelp have been receiving more interest among researchers since they provide valuable information on people's habits, whereabouts, opinions and intentions. Such data can successfully be utilized in order to detect and monitor events and patterns of interest in cities, identify

concerns, emotions and preferences among citizens, particularly in response to news, city operation changes and disruptions. This can help better understand the real-time urban dynamics (Thakuriah et al., 2015).

Third group includes the micro level administrative data collected by governments through the daily registration processes, transactions and records. For example, tax and revenue agencies collect data on citizens regarding the tax-involved revenues generated, licenses issued, and any other real estate and vehicle related transactions made. Similarly, employment and other benefits agencies gather information on income, earnings and other benefits. These data can definitely help in improving urban policies, and they have been shown to have larger sample sizes and less errors compared to conventional survey data. Through the integration of different data sets, correlations and relationships can be formed spatially and temporally. However, the successful utilization of these data cannot be possible without making them accessible to public and other entities without copyright or any other restrictions. Recently, there have been many initiatives towards openly sharing the data in many cities nationally and internationally, as part of the governments' citizen-centric transparency, collaboration and innovation policies. The result is the creation of open data portals where government agencies upload these administrative data in an aggregated and anonymized manner to remove any personal identification. This anonymization is necessary to protect the individuals and their private data through data protection laws or other governance mechanisms. These data are extremely useful for urban social scientists that are involved in economic and social policy research, and those researchers in engineering, health and medicine (Thakuriah et al., 2015).

Similar to the previous group, daily transactions of the public are also recorded by private companies, where they can develop detailed customer profiles from a variety of sources (e.g., Google, Facebook and Amazon). These companies continuously track customer activities and patterns through privately owned sensor systems. Very well-known examples include the financial transactions through credit or debit cards, loyalty cards or apps, customer accounts for utility and financial companies, and other customer service records for purchases and service agreements. Many companies like Google and Amazon utilize these data in order to improve the business management, future forecasts and create better customer relations. Utility companies also use the power consumption data to understand the energy demand and high risk locations.

Though very critical, companies usually do not share much of these data in an open data portal like environment with public. Recent developments such as data breaches have led the European Union and other governments to come up with stricter rules to avoid such leaks on personal data (Thakuriah et al., 2015).

The fifth group includes the massive amounts of data through the collections of arts and humanities. These data basically represent the whole life in a city, through texts, images, sounds, linguistic collections, and media repositories such as films, arts, material culture and digital objects. They are usually highly unstructured, represent the vision and sound-related patterns and transformation in cities, and they can be mapped and visualized in order to observe the social, cultural and built environment patterns in cities. For example, any particular object (e.g., souvenirs, pins, menus, buttons, advertisements, and other written document) presented in museums and other galleries can shed a light on the social, creative, civic, political and physical dynamics of a city. Such knowledge can be digitized and presented via 3-D mapping, cultural landscape mapping, and other media analysis and advanced visualization techniques. The utilization of such information can lead to new findings whereas facilitating civic engagement, community involvement and information sharing (Thakuriah et al., 2015).

Last but not the least, the combination, integration, linkage and fusion of these different data sets, whether structured or unstructured, are also critical in order to make informed decisions based on data. This constitutes the last group, which includes the hybrid data. For example, while conducting a survey, the participants can be asked to provide data on their locations regarding with a particular activity, and therefore combined data sets can be obtained by design. On the other hand, power consumption and traffic patterns of the citizens can be monitored and integrated together, which is an example of data fusion. Generally, data collection with regards to multiple domains can be successfully attained through supporting surveys via location-based sensors and web sources such as social media and other platform. This can lead to the retrieval of information from transportation, energy, weather, safety, and other urban sectors. The U.S. Census is usually very useful for such data collection; however, it turns out that the increasing costs has led to a process that does not seem to be sustainable. Therefore, the U.S. Census Bureau has also started to look for smarter and more innovative solutions through Internet that can reduce the costs but also can maintain a certain level

of data quality. These data should be integrated and analyzed by multi-disciplinary research teams including architects, engineers, urban planners, social scientists as well as governments and public and private companies (Thakuriah et al., 2015).

Table 2.2 : Types of urban big data and illustrative user communities (Thakuriah et al., 2015).

Urban Big Data	Examples	Illustrative User Communities
Sensor systems (infrastructure-based or moving object sensors)	Environmental, water, transportation, building management sensor systems; connected systems; Internet of Things	Public and private urban operations and management organizations, independent ICT developers, researchers in the engineering sciences
User-Generated Content (“social” or “human” sensors)	Participatory sensing systems, citizen science projects, social media, web use, GPS, online social networks and other socially generated data	Private businesses, customer/client-focused public organizations, independent developers, researchers in data sciences and urban social sciences
Administrative (governmental) data (open and confidential micro-data)	Open administrative data on transactions, taxes and revenue, payments and registrations; confidential person-level micro-data on employment, health, welfare payments, education records	Open data: innovators, civic hackers, researchers Confidential data: government data agencies, urban social scientists involved in economic and social policy research, public health and medical researchers
Private Sector Data (customer and transactions records)	Customer transactions data from store cards and business records; fleet management systems; customer profile data from application forms; usage data from utilities and financial institutions; product purchases and terms of service agreements	Private businesses, public agencies, independent developers, researchers in data sciences and urban social sciences
Arts and Humanities Data	Repositories of text, images, sound recordings, linguistic data, film, art and material culture, and digital objects, and other media	Urban design community, historical, art, architecture and digital humanities organizations, community organizations, data scientists and developers, private organizations
Hybrid data (linked and synthetic data)	Linked data including survey-sensor, census-administrative records	Urban planning and social policy community, government data organizations, private businesses and consultants

Batty (2016a) discussed the current and possible future contributions through big data-based applications. For example, today, thanks to the big data, it is possible to understand human behaviors on a shorter time scale than before using databases obtained using sensors such as smart card transportation cards. However, it is absolutely critical to focus on the planning and evolution of cities for long term purposes rather than short term based on the knowledge gained from the urban big

data. As such, efficient methodologies such as data mining and machine learning models are needed to access, extract, store, understand, fuse and analyze the big data sets. For these methodologies to work successfully within the optimal computational time, the characteristics of the velocity (speed) of the data transmission should also be explored according to Batty (2016a). Finally, in order to make use of the big data towards managing the city and planning for a better future, a needs assessment study should be conducted to understand the requirements on how a city government can act fast to address the needs of the public while concurrently utilizing the big data sources. These data sources and discussions on how to sense the urban big data will be presented in the next section.

2.3.2 Sensing the urban big data

Batty (2016a) divides the big data collection process into two main groups according to the type of the source producing the data: a) **fixed sensors** which are passive and located on objects that do not have the ability to move by themselves, and b) **mobile sensors** which can actively move around the environment possibly when people are using them. Fixed sensors routinely transmit data to a kind of control center, which usually stores or archives data for controlling purposes after being analyzed. These sensors can sometimes provide real-time management of the city activities as well. On the other hand, mobile sensors have the capability of being moved by people or any other object in space and time, and produces data generated by these actual movements. The past data obtained from these sensors are generally referred to as historical data and can provide valuable information on the activities in the cities. These sensors can also work online to provide real-time information. Historical and real-time information, together, can help city governments make informed decisions regarding their planning and management operations.

Batty (2016a) characterized the big data in cities generated by real-time streaming from fixed or mobile sensors where the temporality was its main dimension. He also discussed the big data in terms of focusing on time rather than space. To support this idea, he stated that the main objective of the previous urban theories had been to find immediate solutions to existing urban problems without future prospects. The reason for this was the limited accessibility to temporal data where spatial data sets were observed at a cross-section in time for many years. Learning more regarding the overall temporal processes can actually provide a lot of information regarding the evolution

of cities over decades and even centuries. This historical knowledge can also support the information gained from real-time data sets, and can help cities become smarter (Batty, 2016a).

Conventionally, other urban data collection methods include questionnaires or general surveys conducted on populations with a specific purpose and on a special topic. These data sources are different from the aforementioned big data generating sensors; however, they are still significant since they usually provide valuable information with a specific goal and can even provide more accuracy than other big data sources. In the end, multiple questionnaires and surveys can also be a part of the whole big data sets. Nevertheless, one has to be careful since such conventionally collected data have correlations rather than causations, which distinguish them from more innovative data collection techniques.

Conventional or not, the quality of data actually depends on the quality of the source which generates it. This is also similar for urban big data. If sensors fail, they are turned off or they are inactive at a specific location and time, and therefore data cannot be captured. This will lead to missing or lost data sets. It is easier to recognize these problems and develop interpolation- or missing data-focused techniques to solve them when the data is structured (e.g. if they are represented by rows and columns in an Excel spreadsheet).

In summary, 3V's of big data – **volume, veracity and velocity** – are definitely valid for the urban big data generated by cities; however, they may not be enough to provide a full understanding. Therefore, recently, new characteristics have been added to 3V's, such as **variability** which implies a degree of inconsistency in the representation, and **veracity** with respect to the quality of the data, which has an impact on the robustness of the analysis (Batty, 2015). Batty (2018) also defined **veracity** as the level of accuracy and uncertainty in the data since the data could be messy and stochastic, and it could be less controllable with low quality and accuracy. Another characteristic recently added to this group, namely, **Value** is based on what the purpose of the data is and what insights it brings to the city and public (Batty, 2018).

Note that the escalation in the use of big data is not only related to the sensing technologies, but it is also associated with human feedback; however, many big data sources are sensors which create the data automatically and routinely, and people themselves who create their own data (i.e., crowdsourcing) (Batty, 2013).



3. APPLICATIONS OF BIG DATA TECHNOLOGIES IN SMART CITIES

Within almost every industry, companies have been developing visions utilizing the big data that can successfully lead to a variety of new opportunities for them. Similarly, cities have also been deeply influenced with such innovative big data-related visions. Indeed, cities have to develop their own visions so that they can have a better understanding of the needs and problems of their citizens. The literature review has showed how the efficient usage of urban data sets with the help of information and communication technologies (ICT) radically changed the way people live in cities in the 21st century. As such, this chapter will explore how big data can actually be utilized to improve urban planning and management processes.

For this purpose, this chapter will start with a brief overview and short history of the network-focused technologies in parallel to the evolution of big data and smart cities. In addition, two new fields of research will be shortly discussed, namely, “urban analytics” and “urban informatics”, which are directly dealing with the adaptation of main big data theories into the smart city concept. Therefore, this thesis will help in understanding the basics of big data utilization in cities through the ICT advancements. These advancements have significantly increased the awareness of such a utilization to manage, control and improve the urban data processes in cities. In order to achieve this, ICT-based current implementations, best practices and successful operations will be studied in order to comprehend the impact of these technological developments on cities in the context of urban big data.

3.1 From Networks to Big Data in Cities

Before discussing the applications of big data technologies in smart cities, it is critical to understand the overall evolution from networks to big data applications in cities. Although the history of computing goes much older until 1950s due to the governmental, institutional and military applications, the computing technology was offered to the public for individual use in 1980s. This was due to the first development of LAN (Local Area Network) technologies and Fiber Optic Networks in 1970s, which

were first used extensively in 1980s. Second, 1980s were the years where PCs (Personal Computers) or microcomputers were introduced to the public. In 1990s, WWW (World Wide Web) and the Internet were accessible to the public, originating from the Ethernet, one of the networking technologies developed at Xerox Parc in 1970s, which led to the development of MAN (Metropolitan Area Network) and WAN (Wide Area Network).

“LAN allowed the computers used by employees in a building to connect each other whereas MAN led to the interconnections of computers in a geographic area or region and WAN constituted a wider computer networks of different countries connected through telecommunication systems” (Cambridge Online Dictionary, 2018). World Wide Web, developed in 1990s, on the other hand, is a global collection of documents and other resources, and the Internet is a global system of interconnected computer networks. Another important technological advancement significant for cities was the Fiber Optic Networks developed in 1970s, which plays a significant role for the information flow between one place to another through the pulses of light being sent through a fiber optic cable. All these technologies formed the concept of information and communication technologies (ICT), which are absolutely critical for efficient urban big data usage and implementation in cities towards being smarter. However, the main trigger behind the adaptation of ICT is the development of personal computers and their usage by the public, which led to the generation of even more data by the individuals and utilization of the generated data in various ways.

In his pioneering review work on smart cities and big data, Batty (2012a) presented several early attempts on using these technologies such as the use of routine service delivery to the whole population in cities through the WANs in Singapore in 1980s. Even broader, he indicated that the delivery of WANs to everywhere in the world through the WWW was established in 1990s. Batty (2012a) also underlined two important terms focusing on the integration of communities and cities, “The Wired Society” by Martin (1977) and “Wired Cities” by Dutton et al. (1987), as the earliest attempts of using the network technologies in cities to support city services such as police operations, ambulance and fire services, waste disposal and others before even the ICT was utilized.

The next step that revolutionized the area of urban big data in smart cities was the digital miniaturization as mentioned by Batty (2013). That is, the major shift of

computers being embedded into every object possible, including even human beings, led to the generation of unprecedented quantities of data, especially in large cities. This data generation was due to measurements of every human action with the use of devices such as computers, smart phones, smart watches and smart bands as people use them more and more. Some of them being capable of sensing the motions, these devices are actually personalized sensors and can be used almost anywhere, which enables the monitoring and collection of big data even from the inhabitants of a city (Batty, 2013). As such, all the hardware and software technologies are more centralized today compared to before since their early inceptions in 1950s. According to Batty (2013), these innovative sensors could generate new data streams in real-time with providing precise geo-locations, and the databases created based on this real-time data collection could be processed and integrated later in order to add value to the data. How cities handle these sensor and database operations actually show how cities can get smarter basically. Of course, while talking about the sensors, there is a need to focus on the inhabitants of the city as well. Smart cities cannot be achieved without smart people, as stated by Batty (2013).

People getting access to the WWW and the Internet (Web 2.0) simply allowed more user generated content, and their usability and interoperability all around the world through sources such as Wikipedia, Facebook, Flickr and blogging. Crowdsourcing, a way to obtain information or provide input on a specific issue from a large number of people via the Internet, improved this access drastically over the last years. In addition, cloud computing allowed all these data to be stored and analyzed online, which also revolutionized the whole ICT domain. Cloud computing is an information technology that enables the access and use of shared pools of resources and higher-level services with minimal management effort over the Internet. These technologies will advance to an even higher level with machine readable content as part of semantic web (Web 3.0) in the near future, which will help cities even more while analyzing their urban big data.

In order to get a better and deeper understanding on how urban systems function, there is a need to develop better theories and analyses to understand the networks in cities, such as social, communication utility and transportation networks. These new theories also need novel big data-focused methodologies in order to solve the associated problems based on complexity theory in order to build a science of cities (Batty, 2013).

Batty (2013) clearly stated that smartness in cities would be pertaining primarily to the ways in which sensors could generate new data streams in real time with precise geo-positioning, and how the data bases that were subsequently generated could be integrated in order to add value. In addition, he pointed out the common sine qua non of the argument: Smart cities can be achieved only with smart people. Beyond a deeper understanding of how urban systems function for short term purposes, there is a need for a new theory and analysis as part of the complexity theory to understand the networks (Batty, 2012b; Batty, 2013). Such a new approach was provided by Batty (2012b) by the shift of thinking from ‘cities as machines’ to ‘cities as organisms’ so as to understand the complex cities of today. While thinking cities as organisms, their networks and interactions should be given utmost importance in order to clearly understand the actual dynamics of new cities. Urban big data can actually include those that are obtained from fixed sensors, responding physical actions and human activities, such as smart transportation cards or social media data (e.g. *Facebook, Instagram or Twitter*). The data obtained from them represent different types of interactions in a city (Batty, 2016a).

New methods and tools are needed while working with big data due to the structural differences between traditional and non-traditional big data sets. The terms of “Urban Analytics” and “Urban Informatics” are generally being used to differentiate the use of data in cities from the conventional urban studying methods. The emerging discipline of Urban Informatics deals with the exploration and understanding of urban systems by utilizing novel data sources. The major potential of Urban Informatics-based research and applications is in the following four areas: (1) enhanced strategies for dynamic urban resource management, (2) theoretical insights and knowledge discovery of urban patterns and processes, (3) new strategies for urban engagement and civic participation, and (4) new developments in urban management, and planning and policy analysis (Thakuriah et al., 2015). Urban Informatics innovatively utilizes urban big data sources by improving or repurposing traditional urban models that are founded on a variety of principles. Urban Informatics are also based on data-driven approaches, which are generally derived from theory only. It is important to note that all these divergent research approaches have started to converge in many ways with the development of new technologies. However, Thakuriah et al. (2015) clearly stated that varying degrees of challenges were associated with using big data and urban

informatics including the technological, methodological, theoretical, epistemological and political economy challenges.

According to Batty (2016a), new insights from big data technologies could help us to manage the urban systems more efficiently and possibly more equitably via the rapid automation of the routine functions to serve the needs of the city, such as the utilities like power and oil, and other basic necessities like food and water.

3.2 Managing Smart Cities with Big Data

The previous section clearly indicates that there are a variety of methods that can be used to analyze urban big data. Therefore, it is absolutely critical to be able to utilize these methods successfully to manage and run smart cities. For this purpose, the first step is through and efficient planning for better and smarter cities. In this context, Batty (2013, 2016, 2016b) provided valuable information on various methodologies in order to sense the city and its data, and he also pointed out the need to come up with different data-driven approaches to change the way of planning the cities while trying to make them smarter in the presence of countless data sensors in every section of the city. This type of novel approaches of the 20th century, according to Batty (2016b) would trigger cities to lead “a different kind of planning for a different kind of a city”. That is, cities will be instrumented with better data collection methodologies to ultimately develop better, more different and smarter planning solutions when compared to the past. As such, urban big data obtained from the city sensors can certainly help city agencies to improve the service delivery operations (e.g. utilities such as power, water and gas, and waste collection), to improve how cities function, and therefore to provide better quality of life for the inhabitants of the city as well as the visitors. This can happen through a data-driven decision-making process for the cities to serve the needs of their citizens especially through the accessibility of both historical and real-time urban big data. These data can be utilized in endless possible ways in order to improve the services in the cities (Batty, 2016a). However, Bettencourt (2014) discussed two problems related to this data utilization towards better planning, which he calls the “*planner’s problem*”: the knowledge and calculation problems. The knowledge problem is related to the accessibility to information on every aspect of the city infrastructure, services, and social lives of the citizens. This information can be utilized to understand the current state of the cities at the control center level. The calculation

problem, on the other hand, refers to the associated computational complexity to perform the actual task of planning. This includes the number of necessary steps to evaluate all possible scenarios in order to find the best possible course of action (Bettencourt, 2014).

When city governments overcome these obstacles, it will be possible to obtain better and smarter solutions to many problems in cities. Several promising planning solutions in the context of transportation include the presence of highly automated transit networks as well as connected and automated vehicles (CAVs) in some cities all around the world, which can help in curing the traffic operations and safety related problems. In addition, urban big data, when utilized efficiently, offers many opportunities for a better social interaction in the cities, and can provide efficient ways to detect the system disruptions such as power outages and roadway closures. In order to achieve this, there is a need to (a) develop better cognitive analyses of how the citizens behave and find their way as part of the city systems such as transportation networks (Batty, 2013), and (b) instrument cities with new infrastructure networks to collect better and more data both in the physical and virtual environments. For example, this type of planning-focused cognitive analyses based on real-life data can especially help transportation agencies in counting the number of travelers on each transportation line and making informed decisions such as assigning the traffic to a different route when there is a disruption on a certain route (i.e., traffic congestion). Therefore, this type of urban big data utilization can lead to a new and better understanding of the planning and management processes in cities in the context of smartness with big data. For example, currently, there are many new opportunities for architects to design their buildings, for urban planners to plan urban spaces, and certainly for the governments or municipalities to make strategic planning decisions in their domain.

Designing smart living spaces and providing smart services for their citizens have also been a priority for the city governments for a long time. Therefore, there have been many ongoing investments to provide such a smarter quality of life for the inhabitants of cities recently. Another example is the use of digital tools in architectural and urban design towards drawing projects better and faster as well as organizing the documents more efficiently. Today, the inevitable use of Building Information Modelling (BIM) systems has initiated the collaborative and integrative use of data in all phases of the

building and construction processes from concept to design, and design to construction, and by all construction disciplines such as architecture, mechanical and civil engineering.

In addition to better planning for smarter cities, how to manage them smartly is also another significant issue to focus on. As such, cities, including their whole infrastructure (e.g., utility systems such as power, water, gas and waste collection, and drainage systems), are being instrumented constantly with smart technologies at the aggregate level. At a smaller scale, buildings are also equipped with smart automation and housing systems, and people have smart devices such as smart phones, smart watches and many others. While all these smart technologies make human life easier, they also produce huge amounts of data whether through human interaction or not. This section, therefore, will present the organizational structures of several existing applications and best practices in the context of managing cities smarter, and will elaborate on how the produced big data can be utilized to achieve this.

The utilization of big data for better understanding and management in smart cities led to so-called “urban big data analytics” or “real-time data analytics” which has previously been introduced. In addition, those cities that utilize various sensors embedded in their systems to produce real-time data are called “real-time cities”. Hancke et al. (2013) proposed seven different types for sensing the major urban dynamics of smart cities (Figure 3.1): smart surveillance, smart infrastructures, smart transportation, smart services, smart healthcare, smart buildings and smart electricity and water distribution.

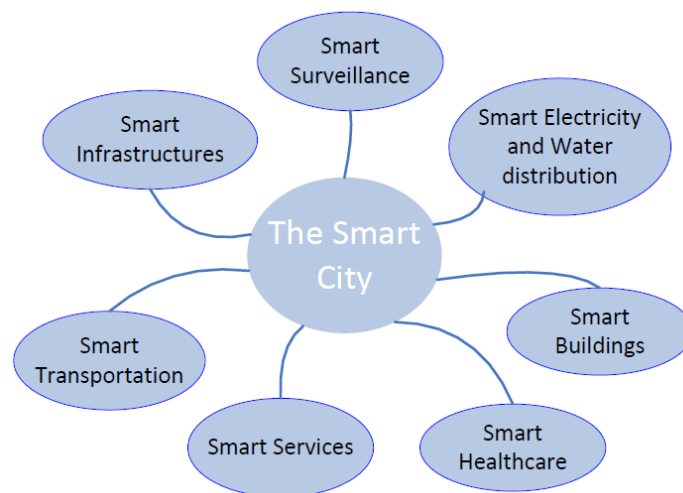


Figure 3.1 : Sensing in smart cities (Hancke et al., 2013).

According to Kitchin (2014), data produced from these different types of sensing operations in cities could enable the real-time analysis of the whole city with all its' systems including the urban governance, and bring out more efficient, sustainable, competitive, productive, open and transparent cities. He called this whole process as "smart urbanism" pointing out two distinct but related visions that make a city smart. First, he discussed the pervasive and ubiquitous computing and digitally installed devices in every part of the urban environment. These are used to monitor, manage and regulate the city networks and processes, historically and in real-time. In addition, the smart technologies used by citizens and mobile computing enable them to interact with and navigate the city while producing huge amounts of data themselves, which is referred as "everyware" by Greenfield (2006). Second, he indicated the need for city governments to drive their economy and governance by innovation, creativity and entrepreneurship, and develop a knowledge-based economy in addition to be managed by smart people through ICT.

Many city agencies actually use ICT and other smart technologies to serve their citizens more efficiently and provide response in faster ways. One example is directly related with the internet itself. Instead of waiting long queues physically in buildings, citizens can now handle their tasks online easily. Second, the data can be accessed and utilized through electronic mediums and innovative data processing capabilities. This became possible with the increasing data storage capabilities in the first place although the amount of data was also increasing towards the huge data sets. City governments also had to transform their urban processes for their city services with the new technology developments. The traditional database archives were gradually transferred to electronic and even online only environments. In addition, new data sets were produced for processing and analyzing through online operations, sensors that provide real-time information, social networks, and other types of surveillance techniques. These data were also made openly accessible by many cities to the public to promote public access and engagement, or they were shared with the citizens with a certain limitation regarding the privacy. This new wave of public and open data platforms has taken the process of data utilization in cities even one step further.

It is clear that smart technologies led to better data generation and collection in cities as well as more efficient data storage, fusion, analysis, processing and visualization, which effectively helps in improving the lives of citizens. Note that the difference of

today's urban data from the past is essentially its "bigness" and its' continuous production in cities, as discussed in the previous sections. According to Kitchin (2014), big data transformed the knowledge and governance in cities into a more sophisticated, wider-scale, finer-grained understanding and management, providing a real-time understanding and control of urbanity. Kitchin (2014) also divided the sources of big data in three categories: directed, automated and volunteered. Directed data are those that are generated by traditional forms of surveillance. These surveillance techniques include but not limited to immigration passport controlling systems while entering a country. Automated data, on the other hand, are generated inherently and automatically by a device or system such as web clicks, smart travel cards, mobile phones, consumer behaviors at shopping websites or credit card transactions of consumers. Finally, the volunteered data are those user generated data from social media (e.g., Facebook and Twitter) and crowdsourcing through various platforms such as Wikipedia. According to Kitchin (2014), directed and volunteered data could definitely provide useful insights into city systems and lives of citizens. However, he stated that automated data was the most significant one in the context of real-life city operations for understanding and managing cities by surveillance, sensor networks and the "Internet of Things (IoT)", and for tracking people and objects. As such, Batty et al. (2012) defines smart cities as *"constellations of instruments across many scales that are connected through multiple networks which provide continuous data regarding the movements of people and materials in terms of the flow of decisions about the physical and social form of the city"*.

Whether individual services are provided by the relevant city agencies at a local scale or by relevant state government units at a national scale, there is a recent interest in integrating all these services and controlling them in one central place with the collaboration of different service areas. These places are usually called as "city operations centers", "control centers", "control rooms", "command centers", or "situation rooms" in different locations and cities. One of the earliest example of such a centralized management in a city was the one established in the City of Rio de Janeiro, Brazil, in 2011, with the partnership of the Brazilian government and IBM (Figure 3.2). Functioning 24 hours and 7 days, the single operations center was called the Rio Operations Center, which gathered data and processes from thirty different city agencies in order to provide a holistic view of the city. In addition, using the analytical

models developed by IBM such as machine learning, this center aimed to predict and manage response to emergency situations, such as traffic incidents or weather events. The center also allowed for officials from multiple domains to collaborate in managing the daily city operations including the traffic flow and public transit systems as well as the power and water supply services. The weather forecasting was also possible in the center through the IBM's forecasting models in order to plan for and manage incidents such as flooding. For this purpose, the forecasting system was fusing a huge amount of data collected in the city from the river basin, topographic surveys, the municipality's historical rainfall logs, and radar feeds in order to develop a unified mathematical methodology. It was able to predict rain and flooding and has recently been used to investigate the impact of such weather incidents on other city networks, such as roadway flooding or power outages.

This type of center does not only transform the city to be smarter through the application of novel technologies but can also provide better and more reliable information for city management. This information can be shared with the public through mobile devices and social networks (e.g., Facebook, Twitter) in order to inform them about the city operations such as frequent updates on weather and traffic (i.e., alternative routes during special events such as sports games, concerts, and festivals). IBM's new alert system used in the city can also get the feedback from the inhabitants through tracking the receipt of messages in order to ensure an appropriate and effective response. This also provides a huge amount of data since the whole response is being tracked from the start to finish. City planners and responders can utilize this data to better understand which locations, networks and population groups are more vulnerable to certain disruptions, and therefore improve their plans and policies for a better response time and coordination (IBM, 2011).

IBM is also marketing this center-focused technology for cities as "Intelligent Operations Center for Smarter Cities". This technology aims to integrate the city systems in order to provide visibility to the overall city and the underlying agencies, and help optimizing operational efficiency in the city (Figure 3.3; Figure 3.4). IBM basically explains that integrated data visualization, real-time collaboration, and deep analytics can help city agencies better prepare for city disruptions, plan for smarter growth, and coordinate and manage more efficient response efforts. As a result, this will improve the efficiency of the overall city operations so that city officials can

effectively deliver services in a more resilient and sustainable fashion, while protecting citizens and driving economic growth (IBM, 2018).



(a)



(b)

Figure 3.2 : Rio de Janeiro Operations Centre, Brazil.
(Photo by David Levene for the Guardian, source: <https://www.theguardian.com/cities/2014/may/23/world-cup-inside-rio-bond-villain-mission-control>)

IBM continues to improve new smart and data-related technologies to help governments around the world in order to provide for and protect inhabitants with analytical solutions spanning a wide range of government responsibilities, including public safety, defense, national intelligence, social programs, cyber security as well as finance and operations. In addition to IBM, who has taken a pioneering role and dominated the smart city-related challenges, many other technology companies like Cisco, Microsoft and Siemens also continue to work towards the adaptation of their technologies to cities in the context of ICT.

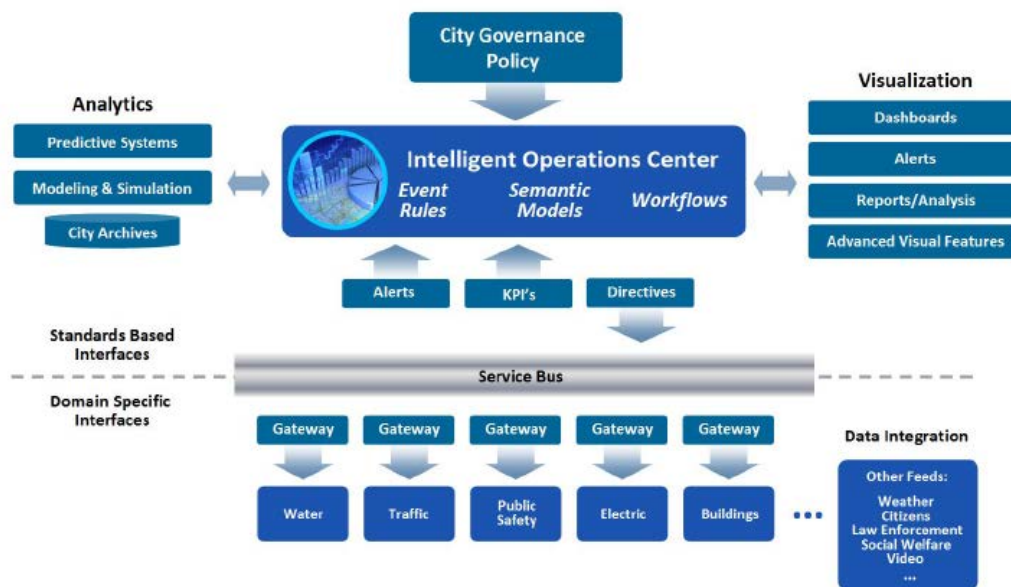


Figure 3.3 : Architecture of IBM’s “Intelligent Operations Center for Smarter Cities” (IBM Intelligent Operations Center Website).

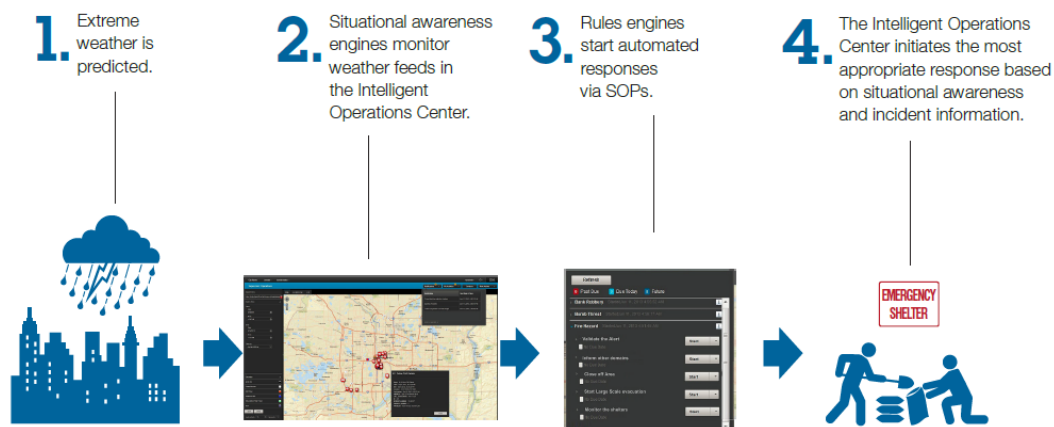


Figure 3.4 : An example for standard operations procedures for IBM’s “Intelligent Operations Center for Smarter Cities” (IBM, 2018).

3.3 Selected Current Data-driven Smart City Practices

This section presents and discusses several successful smart city models especially based on their use of big data-focused technologies towards being smarter and more efficient while serving the citizens. This discussion will be used as a foundation while discussing the adaptation of such technologies for other cities in the world. These big data can be gathered and analyzed through the city networks and by any urban activity performed by the citizens and visitors of a city. By analyzing, processing and integrating these intentionally or unintentionally produced data in cities, it is possible for architects, planners, engineers, social scientists and city managers to create better urban arrangements for a better and high qualified city life. For example, this big data analysis can help in providing smartness, connectedness and sustainability for cities by having a control on the environmental management of the natural resources. Towards achieving this “smart and sustainable city infrastructure”, smart theories and models can be applied on every city system such as its buildings, governance, transportation network, utility systems such as water, power, gas and waste collection, and emergency services (i.e., healthcare, fire, traffic accidents, and disasters).

In addition, this section will focus on a data-driven assessment based on several successful smart city and big data implementations from all over the world, including the following cities that have a long history of urbanization and historical background: The City of Chicago, United States; the City of Singapore, Southeast Asia; and the City of Amsterdam, Europe. In addition to these cities, there are two smart city initiatives that will be discussed in this chapter, which focus on creating smart cities from scratch. These cities are Masdar City in Abu Dhabi, The United Arab Emirates, and Songdo City in South Korea. All these cities have been selected strategically to cover multiple continents of the world and focusing on both developed and developing countries.

3.3.1 The City of Chicago, IL, United States

One leading example of the current successful smart city models worth assessing is the so-called Array of Things (AoT), which is based on the Internet of Things (IoT) technology. This project has been developed through a collaboration among scientists

from variety of agencies, universities, local governments and the communities of Chicago. This technology is defined as follows: *“AoT is an urban sensing project, a network of interactive, modular sensor boxes that will be installed around Chicago to collect real-time data on the city’s environment, infrastructure, and activity for research and public use”*. AoT system is expected to serve as a fitness tracker for the city, while gathering data for the city performance on the factors such as climate, air quality and noise. Therefore, city environment, infrastructure and activities in the city are being monitored and examined, which have direct impact on the livability levels of Chicago. These data are constantly being provided to field experts, who can add even more value to the data by extensive methodological analyses in order to make the city healthier, more livable and better manageable. For example, such data can be utilized to proactively predict and efficiently address challenges such as accidents and crimes (Url-1).

A distinctive feature of the AoT is the open access data portal website, which allows the inhabitants of the city to access all innovative applications provided at the website. An example is that locations of all the sensor boxes mounted on traffic poles and street lights are shared at this portal (Figure 3.5). These urban sensor boxes (Figure 3.6; Figure 3.7; Figure 3.8) gather data on the air and surface temperature, atmospheric pressure, lighting, vibration, air pollutants such as CO, NO_x, SO₂ and ozone, noise, and pedestrian and vehicle volumes. This can help better managing the city infrastructure, preventing property damages and even anticipating diseases in advance towards finding a better relationship between the diseases and urban environment. In addition, based on the data on the most heavily used areas in the city, AoT can help pedestrians to find safer and more efficient routes, especially while walking late at night. Similarly, drivers can also be informed on the traffic light timings during peak hours so that they can also have information on the delays on the roadways so that they can select alternative routes. This can also improve pedestrian safety and reduce air pollution that happens due to traffic congestion. The developers of AoT still continue to develop new sensors to monitor other urban factors affecting the city such as the environmental events (e.g., floods, standing water, precipitation and wind) (Url-1).

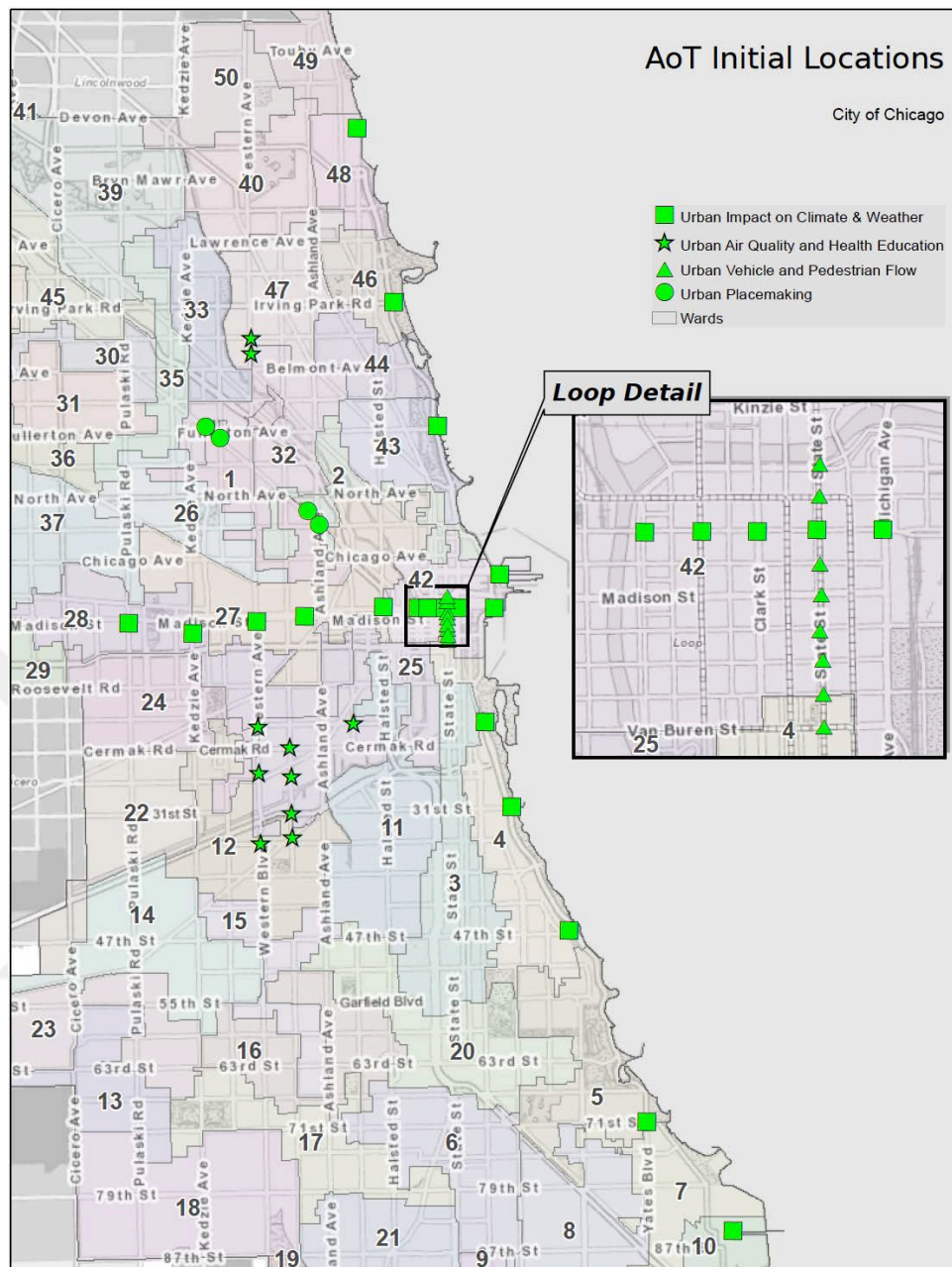


Figure 3.5 : Map of the proposed locations for the initial 42 Array of Things (AoT) nodes, Chicago (Url-1).



Figure 3.6 : A sensor box sample from Array of Things (AoT), Chicago (Url-1).

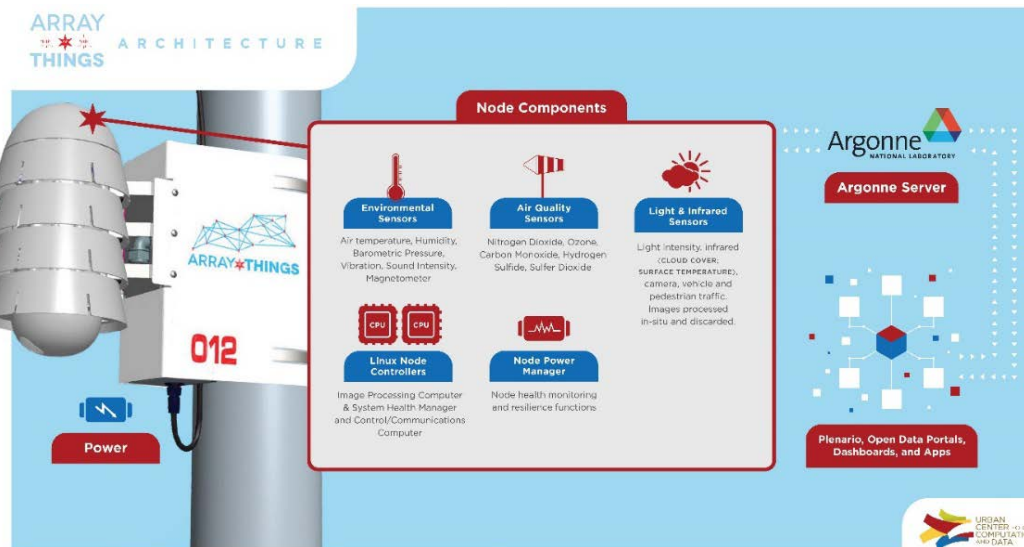


Figure 3.7 : General Architecture of Array of Things (AoT), Chicago (Url-1).

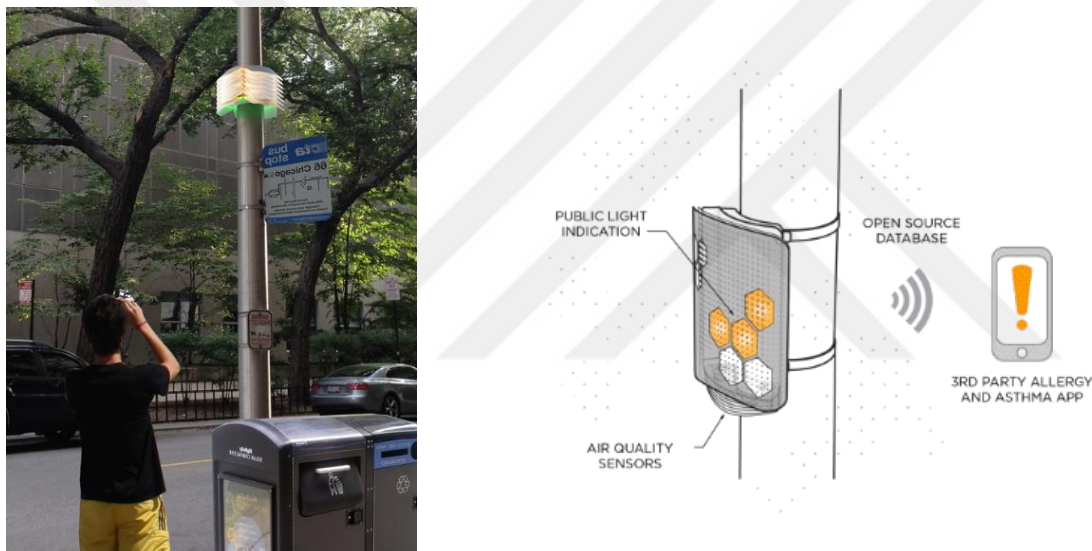


Figure 3.8 : Sensor Box Mounted at the Street Light of Array of Things (AoT), Chicago (Url-1).

3.3.2 The City of Singapore, Southeast Asia

The City of Singapore’s initiative is called as the “Smart Nation”, which established a vision towards being an economically competitive and livable city. This project is led by the government through collaborations with public and private sectors. It aims to utilize the digital smart technologies in the whole nation towards building a better Singapore, improving the life, building more connected communities, supporting businesses to successfully grow through innovation, and enabling citizens to achieve their goals related to jobs and other opportunities. Among these technologies, “Smart Nation Sensor Platform” aims to deploy sensors and other IoT devices in the entire city. Another technology named “Smart Urban Mobility” leverages urban data and

other digital technologies such as artificial intelligence and automated vehicles in order to enhance the urban transportation operations. Similar to Chicago, the City of Singapore also has an open-data access for public. All the data sets collected by agencies are available and accessible to the citizens through online portals. This type of open access, established under privacy policies, is critical in order to increase the human participation in city governance and develop citizen-centric solutions in cities (Url-2).

There are also several research initiatives through a collaboration between universities and the government such as the “LIVE Singapore!”, which is conducted by the MIT SENSEable City Lab. This project is also a part of the Future Urban Mobility research initiative at the Singapore-MIT Alliance for Research and Technology (SMART) and funded by the National Research Foundation (NRF) of Singapore. The ultimate objective of this project is to provide public access to a variety of relevant real-time data sources, through the development of an open access platform. This platform collects, analyzes and distributes this real-time data, which simply reflects the urban mobility in a city (Kloeckl et al., 2012). Providing such real-time information to the inhabitants of a city visually and tangibly will enable them to make synchronized decisions on par with their environment and the city. That is, the citizens will be aware of the events and activities happening around them just by exploring this platform that provides real-time information, and therefore can make more informed decisions.

3.3.3 The City of Amsterdam, Europe

The City of Amsterdam has established their smart city model with a focus on the following thrusts: (a) infrastructure and technology, (b) energy, water and waste, (c) circular city, (d) governance and education, and last but not the least, (e) citizens and life. Under the first thrust, one successful project is called the “City Data”, which has been managed by Gemeente Amsterdam (OIS) since 2015. Similar to Chicago and Singapore, this project also focuses on the big data sharing through an open access data portal, which gathers and shares as much data as possible throughout the city freely with any person that wants to utilize the data (public data). Note that some certain data sets are only available to the city government only (non-public data). This city data portal aims to strengthen the economy of the City of Amsterdam and its surrounding region by sharing the public available data to citizens and companies (Figure 3.8). Utilizing this data source, citizens, companies, universities and other

entities can develop their own customized solutions for their needs, which would not be possible or would be too expensive without this data portal (Url-3).

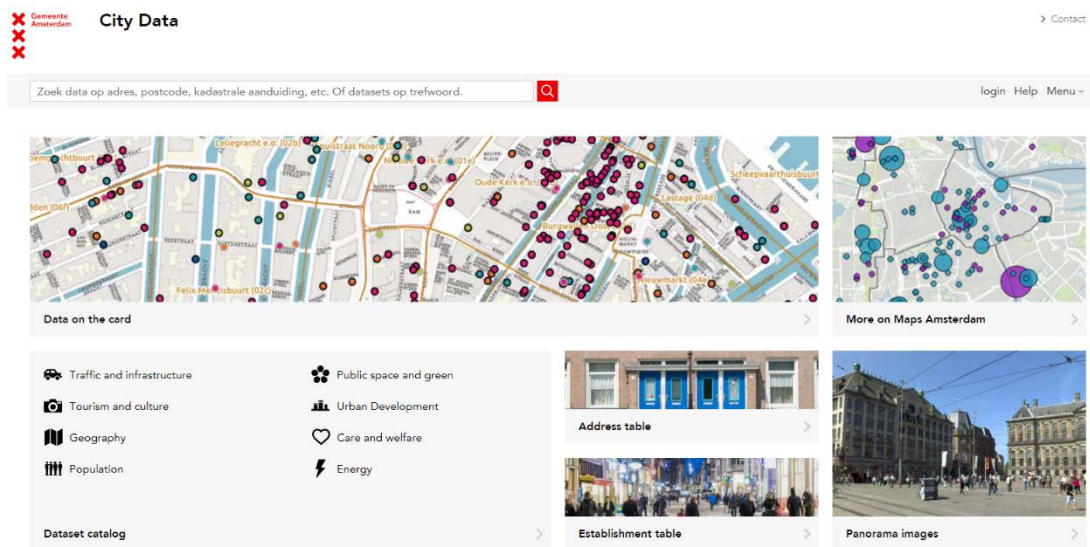


Figure 3.8 : Amsterdam’s City Data portal (data.amsterdam.nl).

This open data project has had four main benefits over the years. First, it created a **transparent** relationship between the government and citizens through the open access of governmental data and information. Second, providing open access to the available city data led to many innovative initiatives through the **release of social and commercial value**. Third, the project allowed the citizens to actively engage and **participate in city governance**, not only limited with the elections only but through the successful information dissemination and citizen involvement in decision-making. Lastly, the decentralization and information dissemination enhanced the city **efficiency**. All this data can be visually illustrated through GIS-based maps, easily searched and downloaded, and linked automatically to other systems such as web services through Application Programming Interfaces (API) (Url-3).

Related to the open access data portal, another successful project is called “Smart Mobility”. This project aims to improve the urban safety, accessibility, quality of life (i.e., providing clear air) and attractiveness of the City of Amsterdam (i.e., creating attractive public spaces). Through such data-driven strategies and innovative technological developments, Amsterdam is striving to become a smart city (Url-3).

Another smart city-focused project in Amsterdam is the “Smart Citizen Kit”, which has been started in 2014. This project focuses on the air quality aspects in the city, tries to increase the public awareness on the environment, and helps the public make

informed decisions through real-life data collection. This project helps citizens to easily measure the air quality (e.g., humidity, noise, temperature, CO, NO₂ and light intensity) in their own community. It is significantly different from other projects since it actively involves the ordinary citizens in the process of measuring the air quality. The kit is nothing but a type of sensor connected to a network, which can be installed anywhere outside a household. It evidently collects several measurements and transfers the resulting data through the citizen's internet connection. All this data is simultaneously shared on the web so that all participants, not only in Chicago but also in other parts of the world, can make comparisons regarding their kit data. These results can also be visually mapped. For example, the noise data (average noise level per session specifically) can be visually illustrated weekly to provide more information to the city and public. This project clearly shows an initiative where participants can collect and compare data themselves and share them with others. It is definitely a big step from smart cities towards smart citizens. A significant component of such a project is the feedback from the public. On June 16, 2014, Smart Citizen Kit was evaluated by the participants regarding the findings of the overall experiment of data measuring and sharing. It was found out that the participants were generally happy with the overall process; however, the technology could still be improved (Url-3).

The City of Amsterdam also tested a "Smart Lighting" system in order to help improve safety and save energy through a variety of remote operations and sensors, which can be adjusted for a variety of conditions. For example, lighting can be changed or dimmed according to the weather conditions, and colored lighting can actually help managing the vehicular and pedestrian traffic flow. Movement sensors can also be utilized if the lighting has to be brighter. At the end, saved energy can be successfully utilized for other city functions such as powering the Wi-Fi network or collecting other data such as air quality. It is a remarkable implementation since saving energy is a critical component of a smart city (Url-3).

3.3.4 Masdar City in Abu Dhabi, United Arab Emirates

The Government of Abu Dhabi, as part of a developing country, also strives to utilize state-of-the-art technologies towards the creating of a carbon neutral and zero waste desert community. With the contribution from traditional Arabic settlements, the government has created the Masdar City Initiative (Figure 3.9), which is a city developed from scratch. This Masdar City project aims to develop renewable energy

and provide cleaner technology solutions to the public in order to provide a life beyond the oil itself. This city, when fully developed, is expected to be center for the development of new and innovative solutions towards smarter energy production, with the involvement of highest levels of expertise. The knowledge gained from this project has already helped the government to develop the Abu Dhabi's 'Estidama' rating system for sustainable building and infrastructure (Url-4).



Figure 3.9 : Perspective image of Masdar City (Url-4).

Masdar City is developed as a mixed-use, low-rise and high-density environment, which also includes the headquarters for the International Renewable Energy Agency and the recently completed Masdar Institute. The city is also strategically connected to the neighboring communities and the international airport through efficient roadway and railway networks. The government aims to have this city as the first modern community that can operate without fossil-fueled vehicles. The nearest transportation

hub and other amenities are at most 200 meters to the communities. Therefore, the city is designed to encourage walking rather than driving whereas the shaded streets and public spaces offer an eye-catching environment for the public, protected from the harsh climate. Another aim is to have the suburbs of the city contain wind and photovoltaic farms, research fields and plantations, which will allow the community to be completely self-sufficient regarding the energy.

Benefiting from emerging technologies and utilizing the lessons learnt from the initial phases of the implementation, the whole masterplan for the city is to be highly flexible, dividing the city into two sectors. Beginning with the larger sector, urban growth is expected to allow for the expansion of the city towards the outskirts, without causing a sprawl as seen in many other cities. These design principles are scalable and applicable to any location around the world regardless of the Masdar City's design principles based on the location and harsh climate. This can be used as a blueprint for the smart and sustainable city of the future. In addition, Masdar City is planned to be a carbon neutral and environmentally friendly city in such a harsh climate, on the desert fringes of Abu Dhabi (Url-4).

Although the intentions of the government were towards constructing the city as of 2018 (starting in 2006), and it was supposed to have 50,000 residents, who was going to travel to work from the city through futuristic pod cars, things have not worked out the way they were supposed to. Unfortunately, 5% of the city has been built only, with only 300 permanent inhabitants. Very few companies have moved to the city, and the carbon neutrality is not going to pass 50% according to the design manager. The city was also meant to be vehicle-free; however, the transportation network has been abandoned with only 2 of 100 stations completed. This is clearly a very significant example of a very prospective initiative that turned out to be not as successful as expected. This indicates the need for better planning and coordination between the public and private partners in order to achieve the promised results (Url-5).

3.3.5 Songdo City, Songdo International Business District, South Korea

Similar to the City of Masdar, another smart city initiative has been developed in South Korea. Located at the gateway to Northeast Asia, the 1,500-acre Songdo City is a model for future, sustainable and smart city developments, not only in Asia but across the world. The City of Songdo has already been built 50%, with 30,000 residents,

33,000 jobs and 70% fewer emissions. The city is pedestrian-friendly, with walkable roadways, 40% green areas, and a population density which promotes the active urban mobility. The residential communities have been developed to have larger green areas and all below-grade parking lots. A Central Park-like 100-acre recreational park is established within the city, and sea canals are powered by wind turbines, which are refreshed every day. All the design principles in the city include sustainable solutions towards smarter building performance, green infrastructure and efficient community planning. More specifically, the city includes 45 million square feet of office space, 30 million square feet of residential space, 10 million square feet of retail, 5 million square feet of hotel facilities and 10 million square feet of public realm, in addition to an international high school, world-class hospital, museum and university campuses (Figure 3.10, Figure 3.11) (Url-6).



Figure 3.10 : Perspective image of Songdo City (Url-6).

In contrast with the City of Masdar, Songdo has been one of the most successful cities in the recent years. The city has a variety of smart features such as self-emptying waste bins, which are transferred to a central location via vacuum chutes. However, like many other new cities, the growth in the city has been slow. Over the years though, it reached approximately more than half of the target population. Transportation connections between the City of Songdo and the capital, which is 65 km, away, have

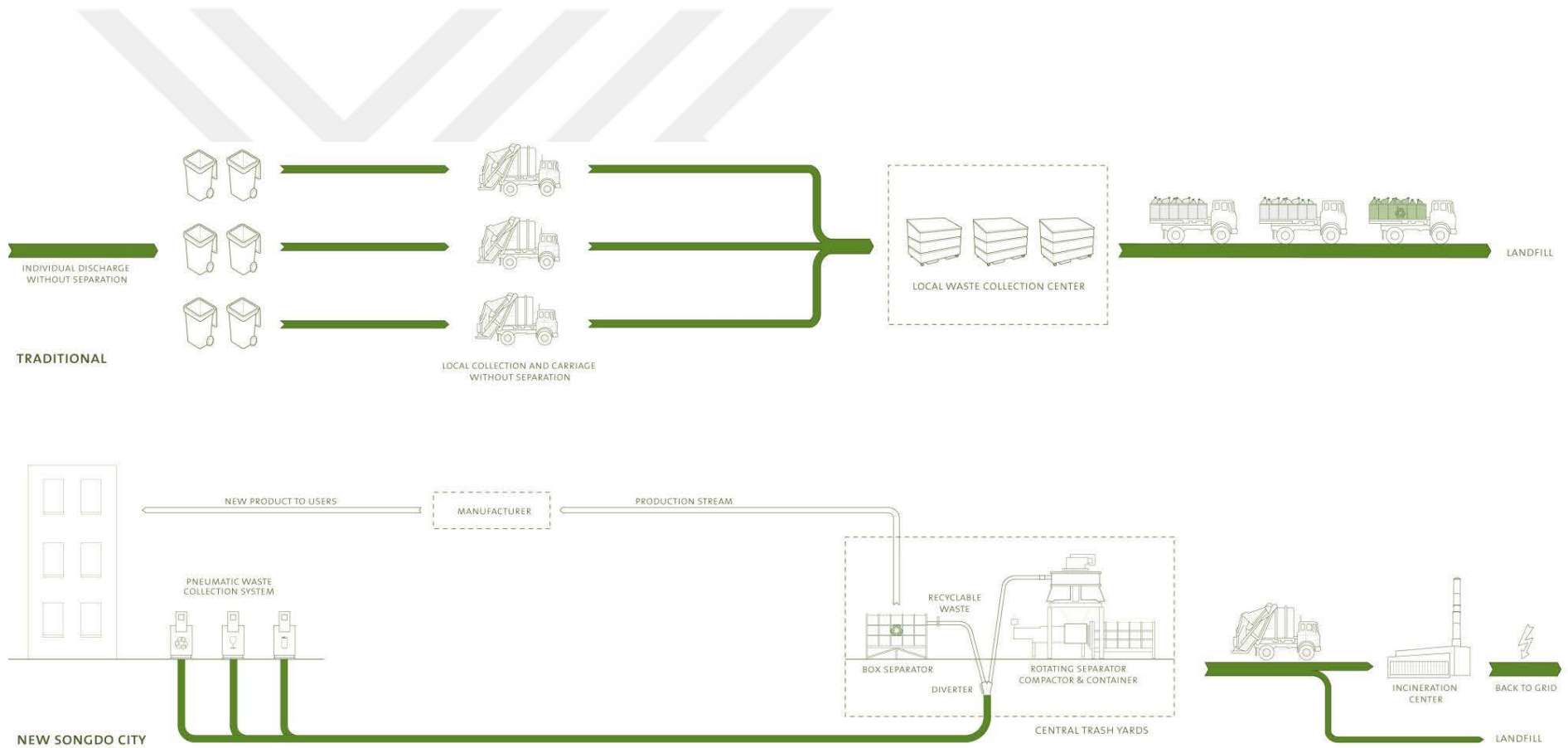


Figure 3.11 : A schematic principle of smart waste management for Songdo City in comparison with traditional waste management systems (Url-6).

not been completed yet. This has been the main problem in attracting more companies to relocate to Songdo. Inhabitants, on the other hand, have been enjoying the life in the city. They have been cycling in the city green space, which constitutes 40% of the entire city, including the 4.2 million square foot Central Park. Regardless of these success stories, this city is still a test bed in the context of surveillance and privacy, and can achieve more smartness, connectedness and sustainability in the future, according to Cisco (Url-5).

3.4 Key Findings

The previous sections presented a study on geographically diverse suite of locations in order to evaluate several successful and unsuccessful smart city initiatives all around the world. As a result of this evaluation, this section presents several key findings for the selected initiatives that can be utilized by public and private agencies for managing cities more efficiently. These key findings are summarized in Table 3.1 and Table 3.2 for both re-designed existing cities and cities designed from scratch in the context of this thesis. Findings specifically indicate that all the studied smart city practices have specific needs and challenges. The unique organizational structures and management systems associated with these practices have a significant effect on their success towards becoming smarter. In addition, increasing populations and urbanization have created the most critical challenges for all these cities. This indicates that the main problems these cities are facing are very similar even through these cities are located in geographically, demographically and socioeconomically different regions of the world. As such, they share the same concerns regarding the future, such as the efficient use of natural sources, environmental sustainability, and improvement of quality of life in cities. In order to solve these similar challenges, many smart city practices also leverage similar data-driven methodologies. The following paragraphs focus on the key findings in more detail.

First of all, it is obvious that every smart city should have an efficient system to gather, analyze and openly share both historical and real-time data. These data should be usually stored in one central location, and they should be made accessible to the public through online sources. These are generally called as open access portals, which share the data according to established privacy policies at a city. This type of open data sharing concept leads to transparency and democracy within the cities through

Table 3.1 : Summarized key findings for selected current smart city initiatives (re-designed existing cities).

REGION	United States	Southeast Asia	Europe
CITY	CHICAGO	SINGAPORE	AMSTERDAM
Website	https://arrayofthings.github.io/ http://www.smartchicagocollaborative.org/	https://www.smartnation.sg/about/Smart-Nation	https://amsterdamsmartcity.com/
Example Project Names	"AoT (Array of Things)" "Smart Chicago"	"Smart Nation" "Smart Nation Sensor Platform" "Smart Urban Mobility" "LIVE Singapore!" "Future Urban Mobility"	"City Data" "Smart Mobility" "Smart Citizen Kit", "Smart Lighting"
Vision	- Better manageable and more liveable city by adding value to the collected data by extensive methodological analysis	- Being an economically competitive and livable city	- Ensuring that Amsterdam will be livable, now and in the years to come
Project Scopes	- Real-time data collection through sensor boxes installed around the city - Based on the Internet of Things (IoT) technology - For research and public use - Open access data portal - Civic engagement - Informed decision-making	- Deploying sensors and other IoT devices in the entire city - Open access data portal - Civic engagement - Informed decision-making	- Open access data portal - Civic engagement - Informed decision-making
Various Collaborators	- Collaboration among scientists from variety of agencies, universities, local governments and the communities of Chicago	- Led by the government in collaborations with public and private sectors	- Creates the overview of the system, and connects communities to share expertise and startups

Table 3.2 : Summarized key findings for selected smart city initiatives (cities designed from scratch).

REGION	United Arab Emirates	South Korea
CITY	MASDAR CITY	SONGDO CITY
Website	https://www.fosterandpartners.com/projects/masdar-city/	https://www.kpf.com/projects/new-songdo-city
Vision	To achieve Smart City Design Principles through a testbed	
Project Scopes	- Sustainable buildings and infrastructure - Carbon-neutral and zero waste desert community - Smart and renewable energy production - Transportation without fossil-fueled vehicles - Infrastructure supporting vehicle-free and walking rather than driving - Self-sufficient energy infrastructure - Wind and photovoltaic farms at suburbs - Research fields and plantations - Urban growth strategy without sprawl	- Pedestrian-friendly, with walkable roadways - 40% green areas and all below-grade parking lots - Population density which promotes the active urban mobility - A Central Park-like 100-acre recreational park - Sea canals powered by wind turbines - Self-emptying waste bins which are transferred to a central location via vacuum chutes
Collaborators	Led by the government in collaborations with public and private sectors	
Pros and Cons	- 5% of the city has been built only - Collaboration between public and private sector is very limited - Attracting people and businesses has become the main problem - Plans and strategies for development have not been successfully implemented	- 50% of the city has been built - Collaboration between public and private sector is successful - Attracting people and businesses has become the main problem - Development strategies have become successful

establishing a direct link between the city governments and citizens. Citizens, as a result, can have an opportunity to be a part of the whole decision-making process and governance through active participation. Open data sharing also encourages innovative approaches to solve the problems of the city (e.g., startups for improving mobility and safety). Regardless of data being shared openly or not, city agencies can also utilize these big data efficiently to help support their daily city operations such as transportation and utility services. These analyses results are also shared with the inhabitants of the city so that they can make informed decisions.

As various sensors, communication systems, and geospatially enabled devices are integrated into the city's infrastructure, heterogeneous data sets are produced which are fed into the cities' information management systems at high volume, velocity, and variety. Meaningfully integrating and analyzing these large, complex, and insightful databases on a large scale is a challenge facing many city governments. As such, cities should look beyond the traditional approaches, and aim to create a secure, unified, integrated and accessible geospatial database that includes all these heterogeneous data sets related to the city systems such as building efficiency, utilities, transportation and mobility, emissions, economic development and energy balance. This can help city departments and agencies to better collaborate among themselves, and therefore to make more efficient data-driven and informed decisions to improve the quality of life for the inhabitants of the city. Best smart city practices also employ a cloud-based collaborative environment to capture, share, analyze, and visualize related data across different agencies and departments within the city seamlessly and flexibly.

On the other hand, while many cities around the world have developed and implemented several promising initiatives, they have not been able to summarize effectively, evaluate, or share their data to measure and quantify their benefits, nor have they been able to incorporate them into their related decision-making processes. The complexity of data acquisition and data processing in the city government stems from the diversity of the service areas, and types of services and layers of jurisdiction. The lack of staff and software tools to handle such "big data" is another critical barrier for data-driven decision making. The associated problem is not only within the city government. Public and private agency coordination and communication is also absolutely critical to achieve smartness. Therefore, a unified cloud-based data acquisition and analysis platform is developed in every smart city to facilitate seamless

data sharing. For such data sharing, data security and privacy are always primary concerns. Those cities that have been known to be smart have also been developing strategies for data protection security and data access control.

Last but not the least, having long-term visions for strategical and efficient planning and management is absolutely critical for cities to become smarter. Cities that only think about the present cannot reach the smartness and connectedness in the future. Based on the extensive data sharing, evaluation and civic participation, cities can track their performance on dimensions that are meaningful given their inhabitants' needs and future development goals. Those cities that can successfully accomplish these can become more livable, smart and connected, and offer better opportunities for their citizens in the future.

Among the cities that have been studied, the smart city practices of Masdar City and Songdo City, developed from scratch, are promising works for the smart and sustainable cities of the future. When compared with Masdar City, Songdo City has relatively become more successful due to its successful development. That is, approximately 50% of Songdo City has been completed whereas only 5% of Masdar city has been built. In addition, the prospected transportation network of Songdo City is relatively more complete than Masdar City. Songdo City is also more connected to its central cities of the country compared to Masdar City, which increases the attractiveness of newly designed smart city to move in. These two smart city practices show again the need for a long-term planning strategy towards being successful in developing a well-designed and a well-operated smart city. For this purpose, these cities can be utilized as test beds in order to define a general framework for the resilient and smart cities of the future. When they are fully constructed, valuable data can be obtained through the urban data processes within the cities, which can be very useful for city planners and other practitioners all around the world. On the other hand, as seen in Table 3.1, there are many lessons that can be learnt from various initiatives and applications in already existing cities such as Chicago, Singapore and Amsterdam. These metropolitan cities can hardly be compared by Masdar City and Songdo City developed from scratch; however, all these cities can still learn from each other. The combined knowledge obtained from the experiences of the existing cities with a long history and with more recent challenges experienced by cities developed from scratch can be extremely valuable for other cities in the world, especially for the cities in

developing countries. Although different cities will experience distinct problems due to a variety of reasons such as their culture and government styles, several features should always be present regardless of the location such as open data sharing, connectivity and interoperability of different departments and agencies in sharing and analyzing data towards making decisions, and civic engagement.





4. CONCLUSIONS

In the wake of the rising city populations and rapid urbanization all over the world, cities are constantly evolving and striving to be smarter and more sustainable to serve their citizens. At the same time, they are experiencing challenges more complex than ever before, and city governments have been looking for more efficient ways to solve these problems. In this context, this thesis mainly aimed to provide a better insight and deeper understanding of the urban big data and smart city concepts through (a) an overview and exploratory assessment of the related literature is presented focusing on the smart city vision and experiences in the world, and (b) a thorough evaluation of the basic theory behind them. This is conducted in order to help filling the knowledge void related to the big data-focused needs of the cities to make them smarter. Through this assessment, this thesis also provides some guidelines and recommendations for city planners, managers and engineers in their conquest of utilizing these big data in their daily operations towards smarter cities. This type of evaluation is especially critical to comprehend the evolution of cities in their journey towards being smarter. In addition, it guides the readers through many innovative ways of getting value from urban big data in smart cities.

First of all, the review of the smart city literature clearly indicates that both historical and real-time data are critical for a city to be smarter. The literature review presented in this study has showed how the efficient usage of urban big data sets with the help of information and communication technologies (ICT) radically changed the way people live in cities in the 21st century. Note that the concept, “big data”, has been first used approximately 20 years ago; however, the technology was not sufficient enough to focus on large and complex data sets at the time. Recent technological advances, on the other hand, led to methods that can be successfully used to solve these issues. As the technology has advanced more and more, big data has been somehow transforming every aspect of human life and has eventually become a relatively critical concept for smart cities. Especially through the developments in the digital miniaturization, communication networks and the Internet, the use of big data

technologies has gradually evolved in cities. It eventually became possible to measure every human activity with the use of digital devices (e.g., computers, smart phones, smart watches, smart bands), to track physical actions in cities by sensors, and also to investigate city systems in the form of networks and interactions.

As such, within almost every industry, companies have been developing visions utilizing this big data that can successfully lead to a variety of new opportunities for them. For example, currently, there are many new opportunities for architects to design their buildings, for urban planners to plan urban spaces, and certainly for the governments or municipalities to make strategic planning decisions in their domain. Another example is the use of digital tools in architectural and urban design towards drawing projects better and faster as well as organizing the documents more efficiently. Today, the inevitable use of Building Information Modelling (BIM) systems initiated the collaborative and integrative use of data in all phases of the building and construction processes from concept to design, and design to construction), and by all construction disciplines such as architecture, mechanical and civil engineering.

Similarly, cities have also been deeply influenced with such innovative big data-related visions. For example, designing smart living spaces and providing smart services for their citizens have been a priority for the city governments for a long time. Therefore, there have been many ongoing investments to provide such a smarter quality of life for the inhabitants of cities recently. Indeed, cities have to develop their own visions so that they can have a better understanding of the needs and problems of their citizens, and new methods and tools are needed while working with big data due to the structural differences between traditional and non-traditional big data sets. This led to two new fields of research, namely, “urban analytics” and “urban informatics”, which are directly dealing with the adaptation of main big data theories into the smart city concept. These research fields have been trying to understand urban systems by utilizing the urban big data generated in cities while improving or repurposing traditional urban models through the advancements in information and communication technologies (ICT).

In order to manage, control and improve the urban data processes in cities, this type of urban big data utilization can lead to a new and better understanding of the planning and management processes in cities in the context of smartness with big data.

However, to achieve these goals, it is critical to evaluate the existing cities and their data management processes, and to develop smart city-focused principles based on this evaluation. This thesis has successfully accomplished this through the evaluation of the related literature and the assessment of data-driven applications of selected cities in Chapter 3, as seen in Table 4.1. In this thesis, these principles are basically classified into two groups in a novel scheme: smart data management and smart people, which can successfully lead to smart governance. To perform smart data management in cities, it is a must to instrument them with better data collection methodologies to ultimately develop better, different and smarter solutions to the problems faced by cities when compared to the past.

Currently, many cities in the world claim to be smart, and publish strategical planning guidelines and agendas in order to justify their smartness and resilience for their present and future. Smart data management of Table 4.1 basically relies on the efficient collection, storage, integration, analysis, sharing, utilization and security of urban sensor-based or non-sensor-based data in a city. Such a data management can certainly help city agencies to improve the service delivery operations (e.g. utility services such as power, water and gas, waste collection), to improve how cities function, and therefore to provide better quality of life for the inhabitants of the city as well as the visitors. Data integration especially plays a critical role in the smart data management. Several local and national governments have started collaborations with industry partners (e.g., IBM and Cisco and other companies), and have ongoing multi-disciplinary smart city-focused projects. In the future, these public and private initiatives will likely to continue to grow at a rapid pace possibly supported by civic engagements since it is impossible for a city to be smart without public participation.

As such, cities, including their whole infrastructure (e.g., utility systems such as power, water, gas and waste collection, and drainage systems) are being instrumented constantly with smart technologies at the aggregate level, which are extensively discussed in Chapter 2 (Table 4.2). While all these smart technologies make human life easier, they also produce huge amounts of data whether through human interaction or not. For example, buildings are also equipped with smart automation and housing systems, and people have smart devices such as smart phones, smart watches and many others.

Table 4.1 : Smart city principles through the usage of urban (big) data.

Smart Data Management	Ability to manage urban data processes	Data Collection	- Different types of urban data can be collected from different sources including every measurable feature of cities (Table 4.2)
		Data Storage	- Traditional, online and cloud-based environments
		Data Integration	a) Coordination between different data sources - Among agencies and departments of national or local governments - Between public, private, non-profit agencies and academia
			b) Connected and integrated city systems, networks and interactions in the data context (Internet of Things - IoT)
		Data Analysis	- Mathematical and statistical models for real-time and historical data
		Data Sharing	a) Governmental or Private Sector Data b) Open Access or Confidential Data
		Data Utilization	- Creating short-term and long-term value from data
		Data Security	- Providing security to prevent data breaches, leaks and hacks
+			
Smart People	Ability to access and use the smart technologies in awareness	Digital Divide or Technology Adoption	- Ensuring the usage of smart technologies by all segments of the population
		Data Privacy	- Developing new policies for personal data protection
=			
SMART GOVERNANCE	Ability to manage cities using Smart Data Management and Civic Engagement	Citizen Involvement	- Informing public with open access data and ensuring their participation in decision-making
		Civic Participation	
		Transparency and Democracy in Governance	

Table 4.2 : Various classifications for urban (big) data by its source or type.

Sensor-based or Non-sensor-based Data
- Fixed or Mobile Sensors
- Passive or Active Sensors
- Real-time or Non-real-time Sensors
- Online Websites
- Social Media
- Smart Devices and Applications
Governmental or Private Data
Directed, Automated or Volunteered Data
Physical Data (e.g., location, building footprints, weather conditions)
Social Data (e.g. population characteristics, consumer preferences, political views)
Economic Data (e.g., income, banking transactions, stock exchange)
Socio-economic Data (e.g., education level, income, vehicle ownership)
Spatial, Temporal or Spatiotemporal Data
Limited or Unlimited Data (collected for a specific purpose in a specific time or not)
Short-time or Long-time Data (collected in specific time periods or not)
Structured, Semi-structured or Unstructured Data

Therefore, a city cannot be smart without the engagement of citizens, and smart data management should be supported by people and their utilization of these data. This brings the problems of so-called digital divide and technology adoption, which should be clearly addressed in order for a city to become smart. As a result, smart data management and smart people, with civic engagement and citizen participation, can successfully lead to smart governance of a city. Therefore, smartness is not only for cities and their planning or management operations. It is also a need for people in a city to be smart, where they can be called as “smart citizens”. To re-iterate, a city cannot be smart without including all segments of the society. Therefore, this thesis defines a novel terminology, named as “Smartness Adoption”. Similar to the technology adoption, this term introduces the usage and accessibility of smartness by the whole population in the context of social fairness and inequality. This should be achieved to ensure that the whole population including the disadvantaged segments of the society (due to socioeconomic and demographic factors, and declining physical and cognitive abilities) can also be able to enjoy the benefits of smartness. One simple example is the ridesharing services such as Uber and Lyft. These services can be used if and only if a person has a smartphone and credit card, and can successfully use the application on his/her phone any time needed. However, these services can segregate the low income populations since they may not have a smart phone or credit card, and

older populations who may not be able to use the application at all. This type of segregation should not happen in a smart city. As such, it is not enough for city planners to plan for smart cities, and the managers to manage and control cities in smarter ways; but also inhabitants for whom they work have to be able to access and use the smart technologies in awareness. Partnerships between corporate companies and national or local city governments are also main triggering factors that can lead to smarter cities. Academic and civic institutions as well as other public agencies also provide directions towards smarter cities in the domain of citizen and public rights by providing a kind of unbiased participation.

To sum up, with the participation of all city entities including its' citizens, smart city governance can only happen through a secure data-driven decision-making process through the accessibility and analysis of both historical and real-time urban big data. In Table 4.3, some of the features of smart governance are presented, which are extracted from the evaluation of the related literature and smart city applications. First, a smart city needs a smart infrastructure through real-time sensors, smart decision making for city systems and utilities, and data-driven resilience and sustainability. This should be supported by smart mobility to provide accessibility to the whole segments of the population, and smarter emergency response operations due to disasters or other incidents. In addition, smarter solutions for the use of natural resources are absolutely critical in order to achieve a smart environment. Finally, smart living encompasses the social fairness and quality of life in a city with all the inhabitants, buildings, agencies and facilities. These features can be utilized to assess the performance of a city in how smart a city is.

Specifically, these features should be supported by smart city and big data technologies. These technologies can help shaping urban life in many ways, and they should be developed through solutions that have sufficient privacy and security arrangements. That is, in parallel to the advances in smart and big data technologies, effective privacy policies should also be developed in order to prevent cyber-attacks and decrease the cyber-attack vulnerability in city systems. This can help the cities and their citizens to protect personal and institutional data sources, data archives, and real-time urban data routinely produced. The day-by-day increasing surveillance levels dictate the need for such security measures to protect all the data generated by cities. Mayer-Schonberger and Cukier (2013) calls this phenomenon as the “the dark side of

big data”. According to them, the cities should control the big data securely, not be controlled by them, which can be very disruptive. As such, city governments in collaboration with technology companies and other civic institutions should always be looking for better cyber-security technologies to protect their citizen’s privacy against entities that try to steal them.

Table 4.3 : Typical features of smart governance for a sample smart city framework.

SMART INFRASTRUCTURE	- Instrumenting city infrastructures with data collection sensors (e.g., buildings, roads, bridges, basic utility systems) - Data-driven decision-making in basic city systems and utilities (e.g., power, gas and water distribution, waste management, street lighting) - Real-time surveillance systems (e.g. traffic cameras) - Data-driven resilience (Ability to cope with unexpected disruptions) - Data-driven sustainability (smart usage of city resources)
SMART MOBILITY	- Transportation accessibility within the city or between cities - Tracking human and vehicle activities with smart surveillance and smart public transportation cards - Ridesharing (e.g. Uber, Lyft)
SMART EMERGENCY SERVICES	- Healthcare, Fire and Police Services - Disaster Management
SMART ENVIRONMENT	- Environmental Sustainability (e.g. air and water pollution, agriculture)
SMART LIVING	- Quality of Life (e.g. social fairness, communities, education, employment, poverty)

On the other hand, being a smart city indicates a great scale surveillance on cities and various activities in it, being secret or not. While walking on the streets or moving from one place to another via driving or public transportation, we are constantly being tracked through devices such as cameras installed all around the cities. Relatively new technologies such as human face recognition or car plate recognition also have the capability of spying on the citizens anywhere and anytime. A famous television series of CBS channel in the United States called “Person of Interest” begins with the following quote: “*You are being watched. The government has a secret system, a machine that spies on you every hour of every day*”. Although this is a science fiction show, it still has some merit, and this quote summarizes the current situation well since

there are so many smart technologies in our lives that keep track of our activities (e.g., city sensors and cameras).

Besides these privacy and security challenges, there are many other critiques against smart cities. One biggest problem is related to the motivation and purpose of governments and private companies, especially those large ICT companies, in collecting and utilizing the data. Therefore, the question is as follows: Do the governments and private companies want to develop solutions through data, or do they want to drive the data themselves? That is, are they interested in their own agenda given their economic and political views? Especially the latest Facebook example (Facebook sharing data on people with foreign entities) indicates how deep and critical the tracking and data utilization is, where all people voluntarily share their personal data on such social media platforms (e.g. Twitter, Facebook, Instagram) in the forms of thoughts, locations, and photos. However, these surveillance-focused technologies also help the city and its' citizens better understand the city systems and operations, and therefore more efficiently manage the city. Note that the smartphones are actually nothing but sensors that continuously collect data about our activities; however, they are also used for a variety of purposes that help us in our daily lives.

Another critical view is presented by Koolhaas (2014) at a meeting where he was mainly asking the following question: "Are Smart Cities Condemned to Be Stupid?". This is directly related to the previous discussion on the motives of public and private sector. He is basically questioning if a smart city can be achieved with the values of the public rather than private companies. He states that stupidity comes from the fact that cities have been becoming more predictable, and less adventurous for the citizens. In addition, he questions the increasing comprehensive surveillance systems in cities. He futuristically suggests safe rooms in every house, to escape from digital surveillance and tracking, similar to the Faraday Cage in physics. Similarly, Sennett (2012) discusses and questions the level of control in cities through the digital revolution. He states that treating a city as a machine is not the solution. That is, although the technology is an excellent tool for cities, it can really stupefy the people living it, which is not the goal of smart cities at all. In addition, the city systems should be open to shifts, uncertainties, and messiness experienced in real-life, according to him.

As all these smart and big data technologies in different cities in the world are considered, it becomes clear that it is inevitable for Turkish cities and their governors

to stay away from these developments. In Turkey, various steps have also been taken into account by the national and local city governments and their agencies. Every city and every government agency have been trying to serve the citizens in smarter ways. For this purpose, they usually organize and set up their own smart systems separately for their routine operations in collaboration with different technology providers. In addition, they have been recently archiving their data (e.g., printed log files and other data) and sharing them online with the citizens through services such as “e-government”. Every Turkish citizen can log in to this e-government system with their own and unique identity number, login name and password. The system gives the availability to get government-related personal information regarding health, census, and others to the users. In some cases, it allows the users to conduct some operations without waiting long lines at the agencies’ physical offices. Although these are very admirable developments compared to a couple of decades ago, there are still improvements needed towards being smarter and making data-driven decisions using historical and real-life data captured. The online data sharing, for example, should not be limited to government operations of a personal nature. It can also allow citizens to make informed decisions through open access data, based on lessons learned by the world’s successful smart city practices such as those discussed in this thesis.

As such, there is a need for a more detailed evaluation of cities in developing countries, such as the City of Istanbul, Turkey, in order to be able to come up with more concrete solutions for the problems faced by these cities. While accomplishing these goals, it is of utmost importance to utilize more advanced data analysis and visualization techniques. One example can be the use of data-driven Geographic Information Systems (GIS)-based techniques. For example, GIS can be utilized in order to investigate the roadway crash occurrences spatially and temporally based on crash, traffic, weather, demographics, socioeconomics and roadway design data. This can contribute to more reliable data-driven traffic safety plans and models. Another example can be the use of disaster data for better and smarter emergency planning and management. Disasters like earthquakes can cause substantial harm to the built environment and people; however, data obtained from these earthquakes can help assess the impact of the earthquakes on communities and develop smarter emergency plans. Specifically, for example, data on power outages, roadway closures and demolished buildings can provide a better understanding on the actual earthquake

impact. The information gained from the findings of this such studies can assist the city in identifying critical and/or less resilient regions and determining different demographic and socioeconomic groups which were relatively more affected by the consequences of disasters than others. Therefore, a very promising future research direction is to delve deeper into the characteristics of a city like Istanbul based on the smart city-focused framework created in this thesis. In addition, future work can also include a deeper analysis on the artificial intelligence-based techniques as well as the mathematical and statistical models such as machine learning and neural networks, which can be used to analyze the urban big data.







REFERENCES

- Anderson, C.** (2008). The End of Theory: The Data Deluge Makes the Scientific Method Obsolete. *Wired Magazine*. Retrieved February 20, 2018, from <https://www.wired.com/2008/06/pb-theory/>.
- Batty, M.** (1990). Intelligent cities: using information networks to gain competitive advantage, *Environment and Planning B*, 17, 247-256.
- Batty, M.** (1997). The computable city, *International Planning Studies*, 2, 155-173.
- Batty, M.** (2012a). Smart Cities, Big Data, *Environment and Planning B*, 39, 413-415.
- Batty, M.** (2012b). Building a science of cities, *Cities*, 29, S9-S16.
- Batty, M.** (2013). Big Data, Smart Cities, and City Planning, *Dialogues in Human Geography*, 3, 274-279.
- Batty, M.** (2015). Does big data lead to smarter cities? Problems, pitfalls and opportunities, *I/S A Journal of Law and Policy for the Information Society*, 11, (1), 127-151.
- Batty, M.** (2016a). Big Data and the City. *Built Environment*, 42, 3, 321-337.
- Batty, M.** (2016b). How can Big Data Used in Urban Planning? *Alexandrinepress*. Retrieved April 27, 2018 from <http://www.alexandrinepress.co.uk/planning-with-big-data>.
- Batty, M.** (2018). Data about Cities: Redefining Big, Recasting Small. Rob Kitchin, Tracey P.Lauriault, Gacin McArdle (Eds.), *Data and The City* (Part 1, Chapter 3, pp.31-44). London: Routledge. Retrieved from <http://books.google.com/books>.
- Batty, M., Axhausen K., Fosca G., Pozdnoukhov A, Bazzani A., Wachowicz M., Ouzounis G., and Portugali Y.** (2012). Smart cities of the future, *The European Physical Journal Special Topics*, 214, 481-518.
- Batty, M., Longley, P.** (1994). *Fractal Cities: A Geometry of Form and Function*. London and San Diego, CA.: Academic Press.
- Bettencourt, Luís M A** (2014). The Uses of Big Data in Cities. *Big Data*, 2(1),12-22. Retrieved April 27, 2018 from https://www.researchgate.net/publication/274046137_The_Uses_of_Big_Data_in_Cities.
- Cambridge Online Dictionary** (2018). Retrieved February 20, 2018, from <https://dictionary.cambridge.org/>.
- Caragliu, A., Del Bo, C., & Nijkamp, P.** (2009). Smart cities in Europe, *Proceedings of the 3rd Central European Conference in Regional Science, Košice, Slovak Republic, Oct 7-9*.

- Cisco** (2011). *Smart + Connected City Services Cloud-Based Services Infrastructure Enables Transformation of Busan Metropolitan City*. Cisco Internet Business Solutions Group (IBSG). Authors: Tony Kim, Shane Mitchell, Nicola Villa.
- Cisco** (2012). *Smart City Framework: A Systematic Process for Enabling Smart + Connected Communities*. Cisco Internet Business Solutions Group (IBSG). Authors: Gordon Falconer, Shane Mitchell.
- Cox M., Ellsworth D.** (1997). *Application-Controlled Demand Paging for Out-of-Core Visualization* (Report NAS-97-010). Moffett Field, CA: NASA Ames Research Center, MS T27A-2.
- Dutcher, J.** (2014). 'What is big data?', Data Science Berkeley Blog, Retrieved April 27, 2018, from <http://datascience.berkeley.edu/what-is-big-data/>.
- Dutton, W. H., Blumler, J. G., & Kraemer, K. L.** (1987). *Wired cities: Shaping future communication*. New York: G.K.Hall.
- Harrison, C., Eckman B., R. Hamilton, Hartswick P., Kalagnanam J., Paraszczak J., & Williams P.** (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*, Volume 54 Issue 4, pages 350-365.
- International Center for Communications** (1997). *How California's Communities Can Thrive in the Digital Age*. California Department of Transportation, San Diego State University, International Center for Communications. California.
- Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler- Milanovic, N., & Meijers, E.** (2007). *Smart Cities: Ranking of European Medium-Sized Cities*. Vienna. Austria: Centre of Regional Science (SRF), Vienna University of Technology.
- Google** (2009). Detecting influenza epidemics using search engine query data. *Nature* Vol 457, doi: 10.1038/nature07634.
- Greenfield, A.** (2006). *Everyware: The dawning age of ubiquitous computing*. Boston: New Riders.
- Graham, S., and Marvin, S.** (1999). Planning Cyber-Cities: Integrating Telecommunications into Urban Planning. *The Town Planning Review*, 70(1), 89–114.
- Hall, R. E.** (2000). The Vision of a Smart City, 2nd International Life Extension Technology Workshop, Paris, France, September 28.
- Hilbert, M., and Lopez P.** (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. *Science* 01 Apr 2011: Vol. 332, Issue 6025, pp. 60-65. doi:10.1126/science.1200970.
- Hilbert, M.** (2015). Quantifying the Data Deluge and the Data Drought. *Background note for the World Development Report 2016*. World Bank, Washington, DC April 2015.
- Hollands, R. G.** (2008). Will the real smart city please stand up? *City*, 12(3), 303–320. doi: 10.1080/13604810802479126.
- IBM** (2008). Smarter Planet Website. Retrieved February 20, 2018, from <https://www.ibm.com/smarterplanet/us/en/>.

- IBM** (2009). A Vision of Smarter Cities: How Cities Can Lead the Way into a Prosperous and Sustainable Future. *IBM Institute for Business Value*, Somers, NY.
- IBM** (2011). Retrieved February 20, 2018, from <http://www-03.ibm.com/press/us/en/pressrelease/35945.wss>.
- IBM** (2018). Intelligent Operations Center Website. Retrieved February 20, 2018, from <https://www.ibm.com/us-en/marketplace/city-insights>.
- IDC (International Data Corporation)** (2017). Data Age 2025: The Evolution of Data to Life-Critical Don't Focus on Big Data; Focus on the Data That's Big. *IDC White Paper sponsored by Seagate, April 2017*.
- Kitchin, R. and McArdle, G.** (2016). What makes Big Data, Big Data? Exploring the ontological characteristics of 26 data sets, *Big Data & Society*, January–June 2016, doi: 10.1177/2053951716631130.
- Kitchin, R.** (2014). The real-time city? Big data and smart urbanism, *GeoJournal* (2014) 79:1–14. doi: 10.1007/s10708-013-9516-8.
- Kloeckl, K., Senn O. and Ratti, C.** (2012). Enabling the Real-Time City: LIVE Singapore! *Journal of Urban Technology*, 89-112, doi: 10.1080/10630732.2012.698068.
- Komninos, N.** (2002). *Intelligent Cities: Innovation, Knowledge Systems and Digital Spaces*. London and New York: Routledge.
- Koolhaas, R.** (2014). "Rem Koolhaas Asks: Are Smart Cities Condemned to Be Stupid?" 10 Dec 2014. ArchDaily. Retrieved February 20, 2018, from <<https://www.archdaily.com/576480/rem-koolhaas-asks-are-smart-cities-condemned-to-be-stupid/>> ISSN 0719-8884.
- Laney D.** (2001). 3D Data Management- Controlling Data Volume, Velocity and Variety. In Meta Group. Retrieved February 20, 2018, from <https://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf>.
- Lindskog, H.** (2004). Smart communities initiatives. In *Proceedings of the 3rd ISOneWorld Conference*. Las Vegas, NV, Apr 14-16.
- Martin J.** (1977). *The Wired Society: A Challenge for Tomorrow*. NJ: Prentice-Hall,
- Mayer-Schonberger, V., Cukier, K.** (2013). *Big data: A revolution that will change how we live, work and think*. London: John Murray.
- Miller, H. J.** (2015). Space-time Data Science for a Speedy World, *I/S: a journal of law and policy for the information society*.
- Mitchell, William** (2007). Intelligent Cities. *UOC Papers, Iss. 5*. Retrieved February 20, 2018, from <http://www.uoc.edu/uocpapers/5/dt/eng/mitchell.pdf>.
- Nam T., and Pardo T. A.** (2011). Conceptualizing Smart City with Dimensions of Technology, People and Institutions, *The Proceedings of the 12th Annual International Conference on Digital Government Research*.
- Oxford Learners Online Dictionary** (2018). Retrieved February 20, 2018, from <https://www.oxfordlearnersdictionaries.com/>.

- Sennett, R.** (2012). “No one likes a city that’s too smart”. The Guardian. Retrieved February 20, 2018, from <https://www.theguardian.com/commentisfree/2012/dec/04/smart-city-río-songdo-masdar>.
- Thakuriah, P., N. Tilahun and M. Zellner** (2015). Big Data and Urban Informatics: Innovations and Challenges to Urban Planning and Knowledge Discovery. In *Proceedings of National Science Foundation Workshop on Big Data and Urban Informatics*, pp. 4-32.
- Townsend, A.** (2013). *Smart cities: Big data, civic hackers, and the quest for a new utopia*. New York: W.W. Norton & Co.
- Url-1** <<https://arrayofthings.github.io/>>, date retrieved 22.04.2018.
- Url-2** <<https://www.smartnation.sg/about/Smart-Nation>>, date retrieved 22.04.2018.
- Url-3** <<https://amsterdamsmartcity.com/>>, date retrieved 22.04.2018.
- Url-4**<<https://www.fosterandpartners.com/projects/masdar-city/>>, date retrieved 22.04.2018.
- Url-5**<<https://www.architectural-review.com/rethink/typology/typology-new-towns/10007024.article>>, date retrieved 22.04.2018.
- Url-6** <<https://www.kpf.com/projects/new-songdo-city>>, date retrieved 22.04.2018.
- Zwitter, A.** (2014). Big Data ethics, *Big Data & Society* 2014 1, doi: 10.1177/2053951714559253.





CURRICULUM VITAE

Name Surname : Makbule YILDIRIM
Place and Date of Birth : Muğla, Turkey, 1980
E-Mail : yildirimmkbl@gmail.com
B.Sc. : 2004, Yıldız Technical University, Istanbul, Turkey
Faculty of Architecture
Department of Architecture

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2004 – 2006
Junior Architect at ARAL ARCHITECTURE with Doç. Dr. Turhan Nejat Aral.
- 2006 – 2009
Architect at different architectural offices.
- 2009
Member of the 2nd Place Winner Team for the “Architectural and Urban Design Competition of Denizli Government House and its Environment”.
- 2010 – 2016
Senior Architect and Project Coordinator at EMRE AROLAT ARCHITECTURE for the following projects:
 - Zorlu Center Mixed Use Complex, Istanbul
 - Yalıkavak Palmarina, Bodrum
 - Mecidiyeköy Towers Mixed Use Complex, Istanbul (Quasar Istanbul and Torun Center)
 - Manisa Metropolitan Municipality Complex, Manisa

