Toronto Augmented Reality Map: Enhancing citizen engagement with open government data using contemporary media platforms

by

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A thesis exhibition presented to OCAD University

in partial fulfillment of the requirements for the degree of

Master in Design (MDes) in Digital Futures

49 McCaul, April 15-19, 2017

Toronto, Ontario, Canada, April 2017

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Abstract

This thesis investigates how visualization strategies and media platforms affect citizen engagement with urban public data. There is currently an international movement towards government transparency and accessible information as developed nations become more urbanized and information technology more ubiquitous. Concurrently, new media platforms (e.g., virtual and augmented reality) are evolving rapidly and show promise of mass adoption. These factors together offer design researchers a unique opportunity to develop new forms of citizen-facing media. I therefore developed an interactive augmented reality application that works with a printed map of the city of Toronto to overlay open government data as visualized digital content. An iterative practice-based research approach was used. Usability tests demonstrated that a strength of augmented reality is its facilitation of multi-user engagement. This thesis concludes by discussing how the Toronto augmented reality map can be made into an interactive citizen-facing installation in the public sphere.

Keywords: augmented reality, virtual reality, data visualization, open government data, smart cities, public sphere, geographical information systems (GIS)

Acknowledgements

I would like to acknowledge my parents for being so supportive during my educational years and offering me some peace of mind in knowing that I always have a home to go back to.

I would like to thank my supervisors, Nick Puckett and Dr. Sara Diamond, for being so wonderful to work with and for giving me the opportunity to learn from their expertise. You both helped me develop my practice and achieve personal goals throughout this degree program and you should know that I am deeply appreciative for it.

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Chapter 1: General Introduction

1.1 Thesis Summary and Rationale

This thesis investigates how visualization strategies and contemporary media platforms affect citizen engagement with urban open government data. There is currently an international movement incorporating the themes of government transparency and accessible public information as developed nations become more urbanized and information technology more ubiquitous. Concurrently, new consumer-level media platforms like virtual and augmented reality are evolving rapidly and show promise of mass adoption. These factors together offer design researchers a unique opportunity to develop new forms of citizen-facing media relevant on the international scene. This thesis therefore describes the development of an interactive augmented reality map of the city of Toronto designed to present open government data to citizens in a way that is engaging, educational, and could aid public participation in democratic affairs.

To situate this thesis and the rationale summarized above within a broad contemporary context the literature review section of this paper outlines in detail the following interrelated concepts: Global urbanization (section 2.2), the Smart City movement (section 2.3), the Open Data Movement (section 2.4), and virtual and augmented reality modern media platforms (section 2.5). As the world continues to develop in the Information Age, people all around the world are migrating away from rural regions to cities for socioeconomic reasons. To deal with this huge influx, the Smart City concept was born and is now an ongoing international mission combining the efforts of academic institutions, businesses, and governments to incorporate information and communication technologies (ICTs) for the purpose of city management and increased quality of life. Smart city technological infrastructure cannot however predict and solve all urban issues as they emerge, and so citizens must engage with governments with the information and concerns they have regarding public life in order to implement solutions. To maintain trust with the public, as well as create opportunities for innovation and economic growth, governments around the world have opened up public databases to the citizenry. These government open data portals are primarily web based, with mobile apps often developed by governments or citizens to transform these data into information visualizations or functional services. As new media technologies like virtual reality and augmented reality become more available to consumers, and show promise for mass adoption, I argue that design research oriented around citizen-facing new media based on public data is warranted. These new technologies may inspire increased citizen engagement with public data and affairs, and may even encourage citizens to empower themselves by developing their own media based on publically available data.

The main hypothesis of this thesis is that the mediums of virtual and augmented reality, with their unique affordances, can be to communicate open government data to citizens in order to aid them in engaging with public affairs. Such a design artifact could be used to draw the attention of citizens, and inspire them to learn more about the city of Toronto and its evolution as a Smart City. Virtual reality offers users a real sense of being in the virtual environment, and so a designer can curate an educational experience to present public data to users and give them the opportunity to explore the data in a unique and engaging way. Augmented reality on the other hand offers a similarly unique experience, where there is a blend of the virtual and real, and users can explore virtual representations of city information seemingly placed in their immediate real-world environment. The research questions of this thesis are formalized below.

1.2 Research Question(s)

This thesis investigates how visualization strategies and new media platforms, specifically virtual and augmented reality (VR & AR), affect citizen engagement with urban open government data. This broad scope can be broken down into the following more specific questions: (1) How can urban open government data be presented through VR and AR in a way that is both engaging and informative? (2) How can the city of Toronto benefit from incorporating AR and VR in their communications between citizens and city government? (3) Can VR and AR be used to aid citizens engaged in democratic processes, and increase the awareness that their city is becoming “smart”?

1.3 Personal Motivations and Relationship to Research Assistantship

This Masters thesis project is loosely related to my work as a research assistant in the Visual Analytics Laboratory here at OCAD University. My research assistantship is directed by President of OCAD University Dr. Sara Diamond and we are working on a joint project, referred to as the iCity project, in collaboration with other Toronto-based universities (e.g., University of Toronto), as well as external industry partners (e.g., IBM, ESRI, etc.) to develop a web-based city data analytics platform for the city. This online analytics platform integrates 3D city modeling, a dashboard-style platform for interactive charts and graphs, and advanced data visualizations for predicting and simulating city behaviour (e.g., predicting city traffic based on quantified traffic-camera data, predicting population movement based on mobile-sensor data, etc.). This platform is intended for city planners, urban space designers, and a condensed and curated version for the general public.

The purpose of this section is to clarify that the aims and outcomes of this thesis and my research assistant work are distinct. The primary audience of the lab work is for professionals and uses traditional screen-based web applications to deliver services. This thesis project on the other hand is intended to be exploratory and future-oriented, focusing on virtual and augmented reality platforms that are not included in the iCity project. My audience is intended primarily as the general citizenry, and the aim is that using these new media platforms can inspire citizen engagement and enthusiasm that is distinct from traditional web and mobile media.

My personal reasons for undertaking this project are threefold. For one, the iCity project gave me a sense for new economic opportunities growing around Toronto related to information communications technologies. Second, the iCity project inspired an appreciation in me for the aesthetics of maps and geospatial representations. Finally, I entered OCAD university with the expressed intention of working with virtual and augmented reality, as these are exciting new media platforms with a potential new world of possibilities.

Chapter 2: Literature review and theoretical background

2.1 Introduction and summary of theoretical framework

The purpose of this chapter is to situate the research question and resulting design artifacts into a theoretical framework and real-world context. The aim is to demonstrate that while there is an established body of research focused on the benefits of transparent government and the use of information technologies to communicate with citizens, there is little work focused on the potential uses of experimental new media platforms like virtual and augmented reality in this context. Through this literature review, I will argue that these platforms show potential for mass adoption in the near future, and thus may afford new possibilities for citizens to engage with democratic state information and participate in public life.

This literature review will advance through the following interconnected themes until culminating in the main argument for this thesis. This literature review begins by explaining the growing need for advanced communication technologies in cities, due to the recent rapid increase in growing urban populations. As urban populations become denser via attracting people for socioeconomic reasons, utilizing communication technologies becomes necessary for optimizing city management and maintaining good quality of life for citizens. This has led to the concept of the smart city, an action-oriented area of research dedicated to understanding how communication technologies can be implemented to solve urban problems and increase the operational efficiency of cities. To monitor and make decisions based on the enormous amount of city data, dashboards and even advanced modeling techniques are developed. The smart city concept further broadens itself to include citizen-oriented mandates such as fostering and supporting a creative and educated workforce, as well as ensuring that communication technologies are used to maintain the integrity of public institutions. Of course, smart city infrastructure cannot predict and solve all urban problems that emerge, and so an informed citizenry must be able to engage in democratic processes to have an influence on public life and policy.

In the interest of maintaining democratic health and public trust, the open government data movement claims that governments have an obligation to share its public data with citizens. This has led to open government data portals and public services through the web. Open government data is an engine for economic growth, as entrepreneurs develop and distribute novel services to the public. Here, open government data portals and cross-platform services are reviewed to demonstrate how emerging communication technologies are utilized to manifest this democratic mandate and engage with citizens in new ways.

I argue that as new emerging communication technologies like augmented and virtual reality become more popular, there are new opportunities for citizens to engage with open government data and public life. I further argue that the city of Toronto can benefit from being a pioneer in developing and implementing services using these new platforms, both for the intrinsic benefits of their unique affordances, but also for the purpose of projecting a public image of technological and social progressivism. I conclude this section by introducing virtual and augmented reality technologies and defining their unique properties and affordances. This leads to the next chapter, which outlines the development of the design prototype of this thesis, which is an exploration of these new technologies for the purpose of engaging citizens with open government data and aiding in the democratic process.

2.2 Rapid urbanization and implications for government

The continuing trend of rapid global urbanization has important implications when considering the economic and social challenges that must be met in order to maintain sustainable levels of development and quality of life for city dwellers. If left unchecked, rapid urbanization can overwhelm a region’s infrastructure and lead to problems including rapid sprawl, pollution, environmental degradation, lack of access to public resources (e.g., health or transportation services), and unsustainable production and consumption patterns leading to economic stress. To mitigate these disastrous effects, governments can implement policies in an attempt to prevent these issues from arising, and help monitor the rapid changes taking place worldwide by gathering relevant and timely data to inform future decisions. This section details past, present, and predicted future trends of global urbanization that policy makers and citizens must contend with.

In 2014, the Department of Economic and Social Affairs of the United Nations Secretariat published a report compiling national statistics and revealed a consistent pattern towards rapid urbanization worldwide. Consider that in 1950, 30% of the world population lived in urban areas, increasing to 54% in 2014, and now projected to be 66% by 2050. In 1950, the approximate world urban population was 746 million compared to 3.9 billion in 2014. Continuing population growth and urbanization suggest that by 2050, 2.5 billion more people will be living in cities. Ever since 2007, the number of worldwide urban dwellers has exceeded that of the population living in rural areas, which is thought to have currently reached its maximum population. This significant social and economic change appears to be consistent for the foreseeable future.

Patterns of urbanization vary across regions worldwide. Just a few countries are currently home to half the world's urban population. China has the largest urban population with 758 million, and India is second with 410 million. Half of the world's urban population is accounted for if we also include the USA (263 million), Brazil (173 million), Indonesia (134), Japan (118 million), and the Russian Federation (105 million). These absolute numbers are interesting when one considers that Asia and Africa are considered to be the regions with some of the lowest percentage of their overall populations in urban regions, with 48% and 40% respectively. In contrast, despite the lower absolute population size, the regions with the highest proportions of the population in urban regions include North America (82%), Latin America (80%), and Europe (73%). Refer to Figure 1 to see urban population percentages by country from 1950 to the present.

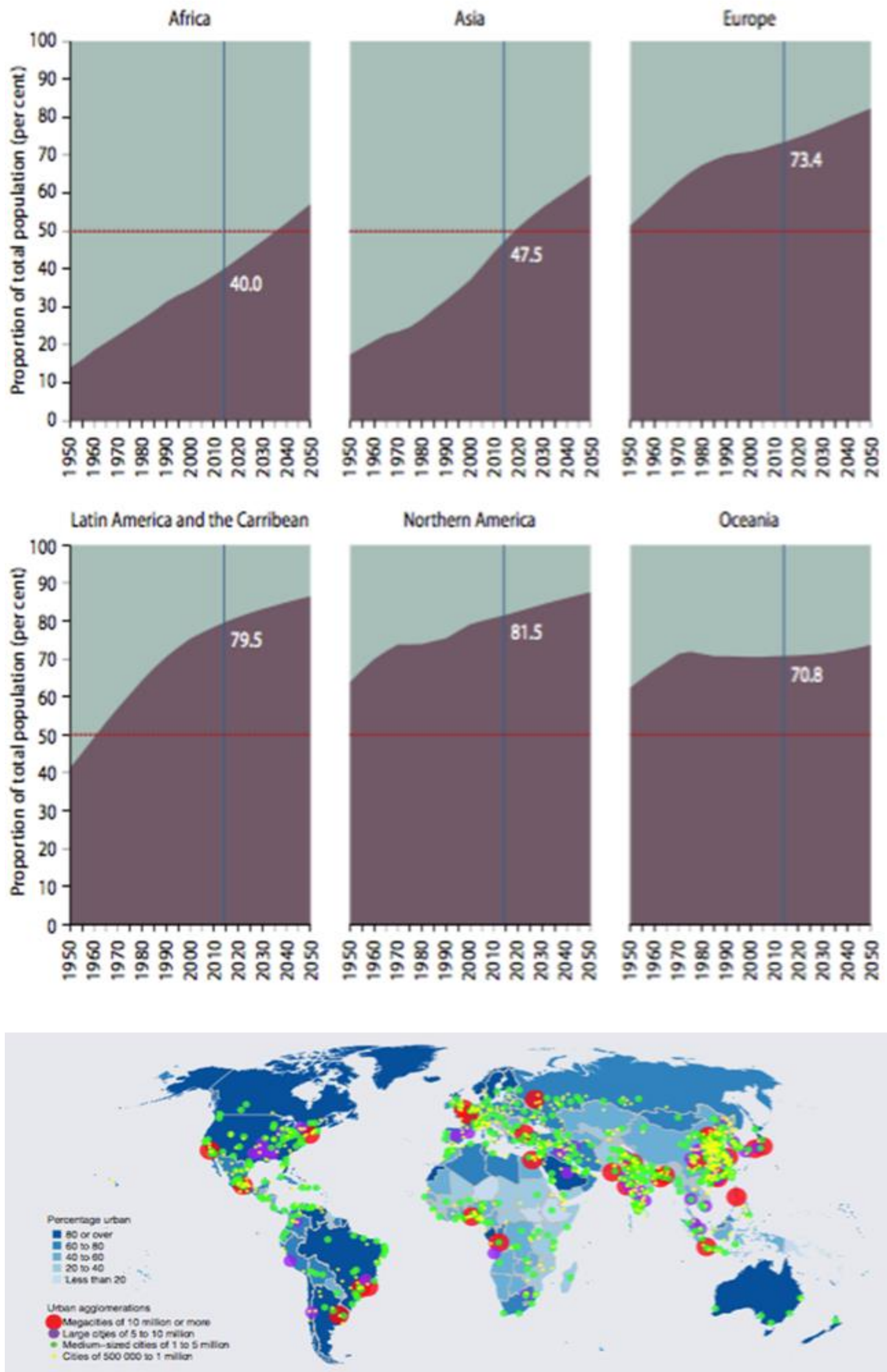

Figure 1: Proportion of total urbanized population by year and region (top). Urban proportion represented in purple, rural in green. Geographical distribution of urban population and major world cities by scale (bottom). Adapted from United Nations, 2014.

The distribution of urban populations varies across urban centers of different scales. Megacities are here defined as urban centers with 10 million people or more. In 1990 there were 10 megacities with a total of 153 million people, making up 7% of the global urban population. In 2014 however, the number of megacities has jumped to 28, with 453 million people, accounting for 12% of the world's urban population (see figure 2). The largest megacities currently include Tokyo (38 million), Delhi (25 million), Shanghai, 23 million), Mexico City, Mumbai, and Sao Paulo, each with approximately 21 million. In contrast, large cities are here defined as those with 5 to 10 million inhabitants, and currently account for 8% of the global urban population. There are currently 43 large cities globally, but projections suggest an increase to 63 by 2030, including more than 400 million people. Medium sized cities with 1 to 5 million people account for approximately 10% of the global urban population, and is expected to stay proportionally similar by 2030. In 2014 about one half of the world's urban population lives in urban settlements with fewer than 500,000 inhabitants. Finally, the report's predictions suggest that the fastest growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa. The overall picture shows that there will be a significant increase in urban populations, and as mentioned at the beginning of this section, adequate infrastructure and management will be crucial to ensure that these growing urban centers are able to keep up with the increased demands.

2.3 Smart Cities

2.3.1 Introduction

To help with facing the significant challenges imposed by rapid urbanization as described in the previous section, the concept of the "Smart City" has been put forward as a promising solution. A Smart City can basically be defined as "a place where traditional networks and services are made more flexible, efficient, and sustainable with the use of information, digital, and telecommunication technologies to improve the city's operations for the benefits of its inhabitants" (Mohanty, 2016). The international push for smart cities is meant to utilize information technology in order to effectively manage and make more efficient the various factors and interacting systems within urban conglomerates. An idealized smart city would include components such as smart infrastructure, smart transportation, smart energy, smart health care, smart governance, etc. To support these "smart" city operations and services the two closely linked emerging technology frameworks, the Internet of Things (IoT) and Big Data, are often evoked as central aspects of this new and evolving vision for cities internationally. Specific definitions of smart cities have been put forth by various authors and stakeholders that include clear sets of defining components, as will be discussed in the next section. For the purpose of this thesis however, we will borrow the broad definition of smart cities put forward by the British Standards Institution where smart cities are an effective integration of physical, digital, and human systems in the built environment to deliver a sustainable, prosperous, and inclusive future for its citizens (2014).

The development of Smart cities often includes the participation of industry partners, universities, and local government. Each of these institutions are encouraged to participate in the “triple helix” of institutional innovation, a term first coined by Etzkowitz & Leydesdorff (2000), so as to balance efficient and advanced implementation with a measured focus on servicing the public. Each stakeholder has its own specific aims but can work synergistically under this project mandate, where universities aim for research and knowledge spreading goals, industry aims for profits and new business relationships, and government for the well being of the public. It should be noted that neither state intervention nor neoliberal market solutions have been accepted as satisfactory, as the former is criticized for its managerial inefficiency, and the latter for its neglect of community interests. These institutions must work together to achieve the goals outlined in the next sections.

2.3.2 Smart Cities: The Symbiosis between cities and communication technologies

The smart city concept, despite the phrase becoming popular only recently in the 1990s, is grounded in a history of symbiotic interactions between cities and information technologies. In Anthony Townsend’s book *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia* (2013), he suggests that we can trace the beginnings of the smart city concept all the way back to the ancient world, where six thousand years ago markets, temples, and palaces emerged. In order to keep track of transactions and arrangements, buyers, sellers, and city administrators would share and catalogue written records. In this way it can be said that basic writing was the first communication technology used in the city context. Another prominent city ICT was the telegraph in all its variations, which can be historically defined as the long-distance communication of textual or symbolic messages without the physical exchange of an object bearing the message. In this way, pre-modern telegraphy took on forms like waving flags, smoke signals, beacons, etc., but did not include the physical exchange of transported written notes such as in the pigeon post.

The true precursor to the modern conception of the smart city would have to be the electronic telegraph, which was invented in the 19th century and became highly successful during the period of industrialization. The modern electronic telegraph can essentially be defined as a long-distance communication device that converts messages into electronic signals sent to a receiver via wire service. While cities like New York, Chicago, London, and others were driven by the use of electricity and steam power, these cities were in many ways enabled to grow by the new possibilities in communicating electronically over great distances. Examples of important telegraph technologies over this period include telegraphy used to organize railways, and the invention of the electromechanical tabulator, which was originally used to catalogue the results of the US 1890 census but was soon adopted by the continent-spanning enterprises of the time. Of course, the telephone must be mentioned, which allowed corporations, citizens, and government to communicate, organize, manage assets, etc., instantaneously in ways that people might have never at one time thought possible.

Finally, with the advent and beginnings of mass-adoption of the Internet in the 1990s, ICTs and cities have become more symbiotic than ever. Fiber-optic cables line nearly every livable structure and web communications are relevant to relationships between citizens, government, and industry on many levels. Smart phones are now widely used and wireless technologies are ubiquitous. Indeed it is estimated that by 2018, 2.56 billion people worldwide will own a smartphone (Curtis, 2014). George Gilder, a technology theorist in the 1990s suggested that cities were likely to disintegrate as a wired population would lead to a distributed network of people, but the opposite has in fact occured and our wired metropolises continue to grow and become more and more dense and congested. Of course, this has led to new problems related to the environment, housing, energy, social, governmental, etc., and ICTs are being proposed as the most cost-effective solution for enhancing city management. ICT companies such as IBM, Siemans, General Electric, and others are jockeying to set up contracts with cities to secure sections of the market, but the smart city concept rightly involves more than just setting up communications services as the next section will show, and is primarily focused on city management for the purpose of serving the public.

2.3.3 Smart Cities: Defining the Smart City and its Components

Defining the concept of the smart city has been a difficult problem for researchers due to the fact that different cities around the world are focused on making "smarter" different components of their cities, as well as the fact that different stakeholders have different primary interests when using the term. The genealogy of the term "smart" can be traced back to its intended use by marketers for the purpose of eliciting a user-friendly interpretation, as the term "intelligent" would seem too elitist for most people first encountering it (Klein & Kaefer, 2008). This thesis borrows the definition from the

British Standard Institution used in section 2.3.1 (2014) for its broadness and adaptability, but here I hope to offer a more comprehensive understanding of what a smart city can refer to and include.

In a review paper by Nam and Pardo (2011), they broke down the concept of the smart city into three main factors: technology factors, human factors, and institutional factors. While some purveyors may define smart cities as primarily based on the advancement of their ICT, others may focus more on the institutional policy making, while yet others care only about the characteristics of human capital and quality of life for citizens. Here I outline each category independently and describe some ways these factors can and have been instantiated in developing real world smart cities.

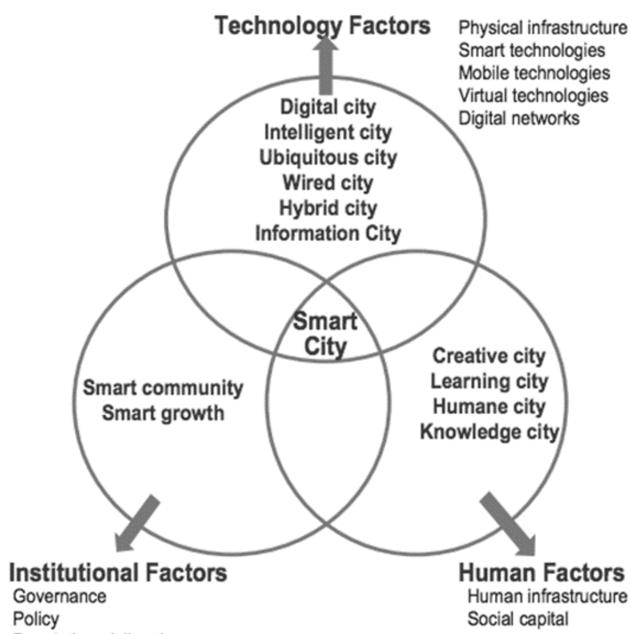

Figure 2: Fundamental components of Smart Cities. Adapted from Nam & Pardo, 2011.

Technological

Smart Infrastructure

Smart infrastructure here refers to anything physical, digital, or electrical in the city that is integrated with the smart city's ICT infrastructure. There are many examples of self-monitoring infrastructure systems such as rapid transit system, waste management system, road network, railway network, communications systems, traffic light system, office space, water supply system, gas supply system, power supply system, firefighting system, hospital system, bridges, apartment homes, hotels, digital library, law enforcement, etc. The physical ICT infrastructure can include fiber optics, Wi-Fi networks, wireless hotspots, as well as service-oriented information systems and sensors like security-cameras, meters, and other measuring devices (Mohanty, Choppali, & Kougianos, 2016). Sensor data is often fundamental in regulating these systems, centralizing their data, and keeping many of them operational through automated controls.

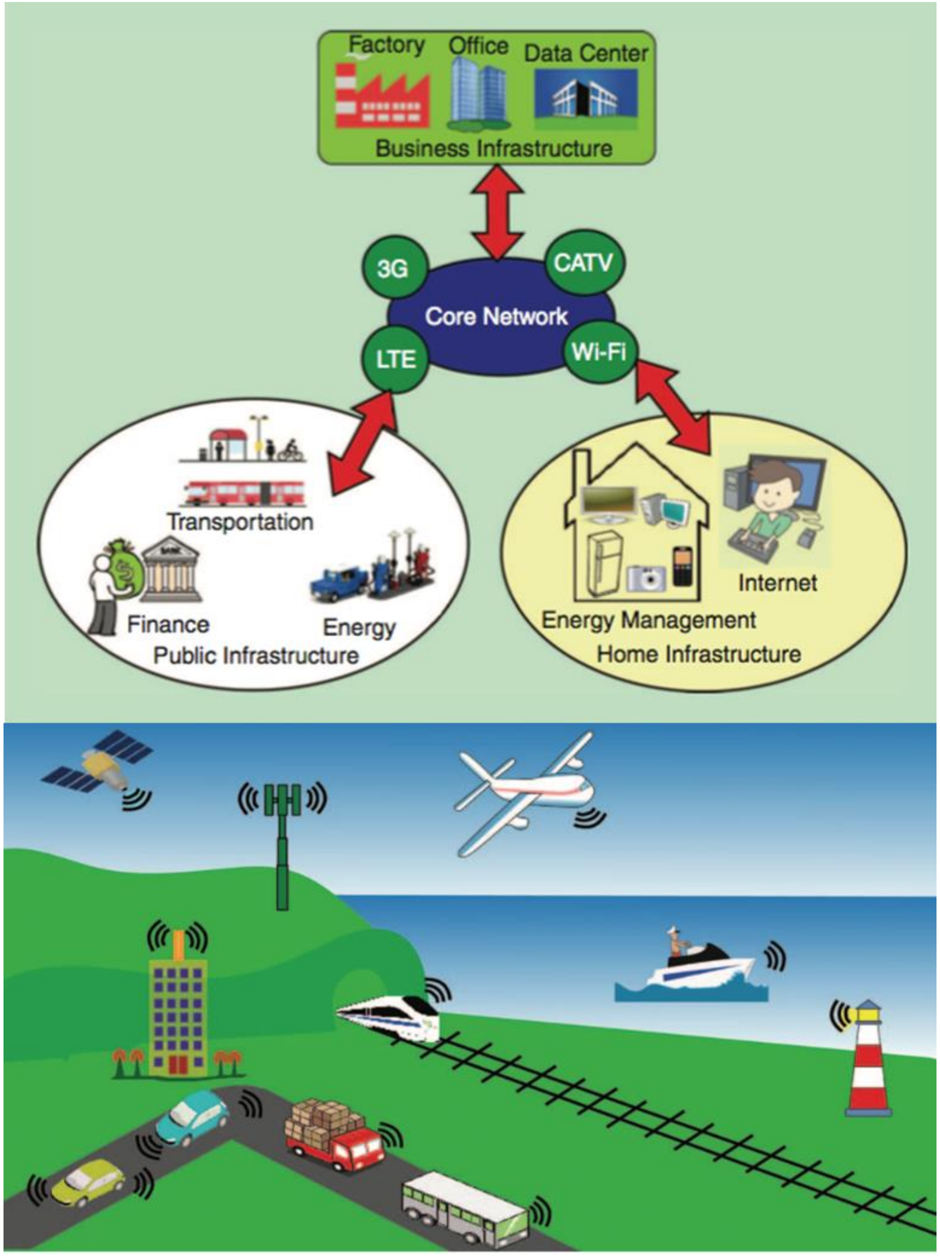

Figure 3: Depiction of smart infrastructure (top). Depiction of smart transportation (bottom). Figures adapted from Mohanty, 2016.

Smart Transportation

Improving city traffic efficiency has become a key mandate in many smart city initiatives, as the growth of cities leads to congestion, disorganization, and inefficiency of one of the most necessary functions to maintaining the success of cities. Smart transportation thus refers to transport systems in the city that benefit and offer improved services by virtue of being connected to the city's ICT system. Smart transportation systems can include railways, road transport, airline transport, water transport, etc. Smart transportation systems allow for global airway hubs, intercity railway networks, intelligent road networks, protected cycle routes, protected pedestrian paths, and integrated public transport for safe, rapid, cost-effective, and reliable transportation. These systems allow passengers to select different transportation options for the lowest cost, shortest distance, or fastest route by obtaining data from the network. Specific examples of smart transportation technology include wireless-based toll collection via radio frequency identification (RFID) for example, where drivers need not inefficiently stop at physical booths. Another example is automatic passport controls, where passengers are checked automatically.

Smart Energy

Smart energy is essentially any energy form managed through the city's ICT network. The aims of smart energy are to increase efficiency for purposes of running the city, as well as controlling energy usage so as to prevent environmental waste. Examples include controlling the consumption of energy by smart appliances like dishwashers and water heaters through automated sensor networks. Cities with smart energy are also aiming for reliance on sustainable forms of energy, as traditional forms are limited and shown to be harmful. The core of the smart energy system is the smart energy grid. The smart grid is responsible for sensing and automating energy consumption and generation in a complex network to ensure efficient, economical, and sustainable management of energy from diverse sources. The smart grid will be play an important role as city energy systems get even more complex and citizens begin to create their own energy through sources such as solar power.

Internet of Things & Big Data

The integration of the various smart technology systems produces an incredible amount of data, which when managed on this scale is often referred to as Big Data. Big data refers to the collection of large and complex data sets that would be difficult to process using regular database management. This is related to the concept of the Internet of Things (IoT), which refers to the interconnectedness of a network of independent systems and devices. In the smart city context the IoT of all the interconnected city sensors and devices creates vast amounts of data that need to be managed. Smart city big data are urban data that are often tagged in space and time and can include a large collection of sensor data, databases, e-mails, social media, and other web-behaviour. The challenges related to smart city IoT and big data include visualization, mining, analysis, capture, storage, search, and sharing, as well as the maintenance of the necessary ICT to support it.

Urban Informatics & Dashboards

Many smart cities are now using real-time analytics for city management using real-time data (Kitchin, 2014), posing the problem of how to best visualize and interpret the vast amount of updating information. To allow city administrators to make decisions grounded in real-time data analysis, the big data produced by the city's IoT can be centralized, analyzed, and presented in custom data visualization dashboards (Batty, 2015). These city dashboards are typically of two main kinds. The first kind often presents data related to weather, transit, road traffic, pollution, Twitter trends, stock market prices, utilities and local news. This kind of information can often be presented using an online data portal, and can be accessible to any user. Many smart cities around the world offer live data to the public using such portals (Batty, 2015), and this is only enhanced by the fact that many city dwellers currently own and use mobile phone technology, which conveniently offers access through wireless network. Indeed, smart city developers have embraced the mobile phone and many apps have been developed that offer data dashboards and other smart city related services (Gordon, 2014). The second type of city dashboard is the more advanced administrative control centre, where many types of data can be seen simultaneously. Some well-established examples include the Visualization Wall for the Greater London Authority, and the Rio Operation Centre in Brazil that gathers data from 30 agencies to aid in city management (Batty, 2015).

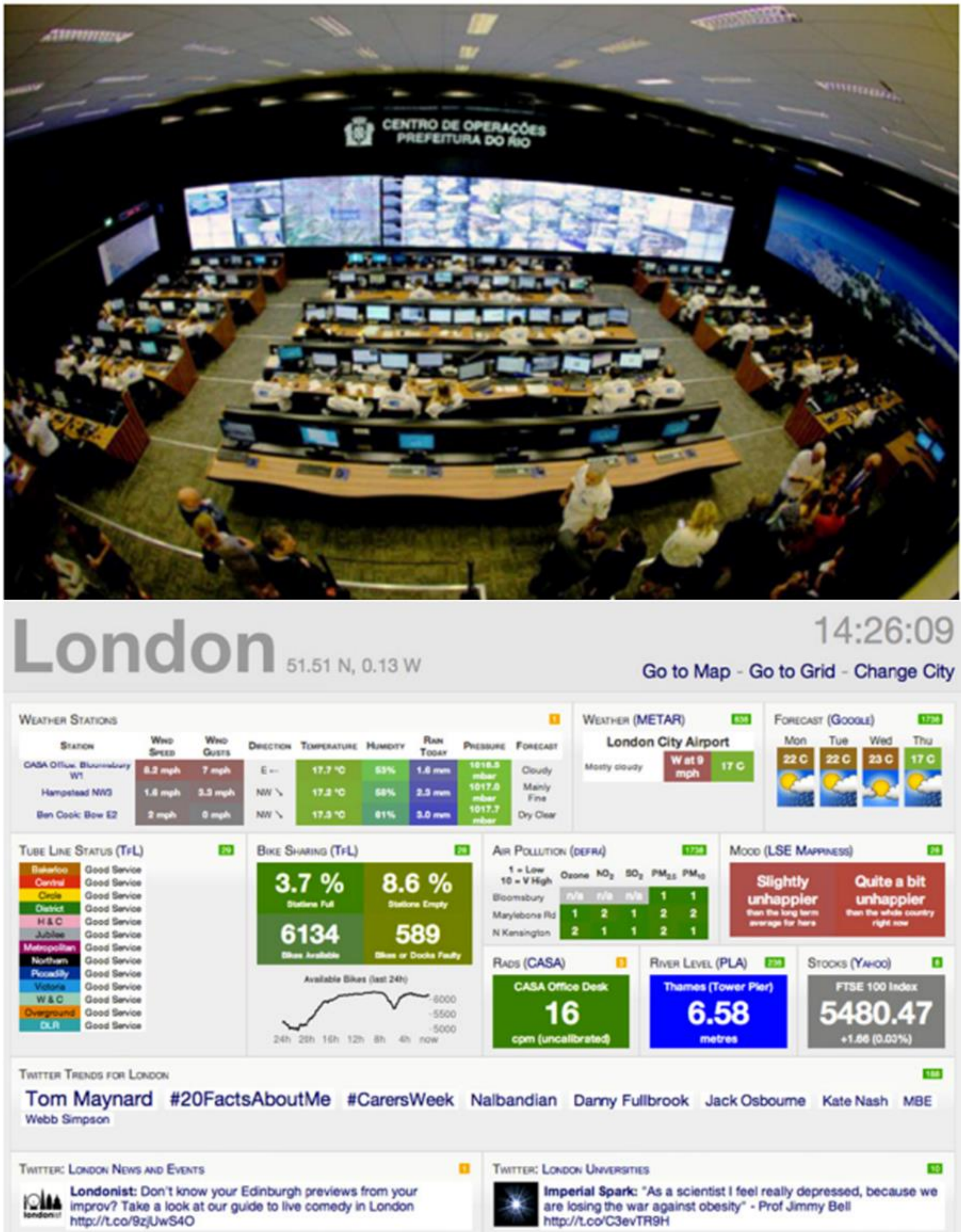

Figure 4: Urban Informatics Centre in Rio di Janeiro (top; adapted from Kitchin, 2014). City of London urban data dashboard (bottom; adapted from http://citydashboard.org/london/).

A city's spatial information is often a key component for city management, and smart cities are currently pouring resources into developing advanced methods for geomatics and 3D urban city representation. Looking beyond conventional 2D digital mapping methods, researchers are working with smart city stakeholders to encourage the development of 3D virtual models for the purpose of advanced data analytics, advanced city simulation, urban planning design, and citizen-engagement (Daniel & Doran, 2013; Roche, 2014; Hu et al, 2015). In a review article by Biljecki et al (2015), the researchers outlined some of the uses and benefits specific to 3D city representations for interpreting urban factors (see figure 5) such as visibility analysis, spatially detailed representations for understanding energy usage, population density, emergency response, shadow estimation, solar panel positioning, etc. The industry standard CityGML has been used as a common information model and XML-based encoding scheme for exchanging virtual 3D city/landscape models, and has defined international specifications such as well-defined levels of detail (LOD) for representations. Some smart city initiatives around the world are currently working to develop detailed 3D urban representations to be used as part of their advanced dashboards including the country of Singapore (Schwartz, 2016) and the city of Toronto in Canada. These interactive 3D visualizations will eventually be presented to the public, as researchers are currently working to develop web-based 3D-enabled applications (Prandi et al, 2014).

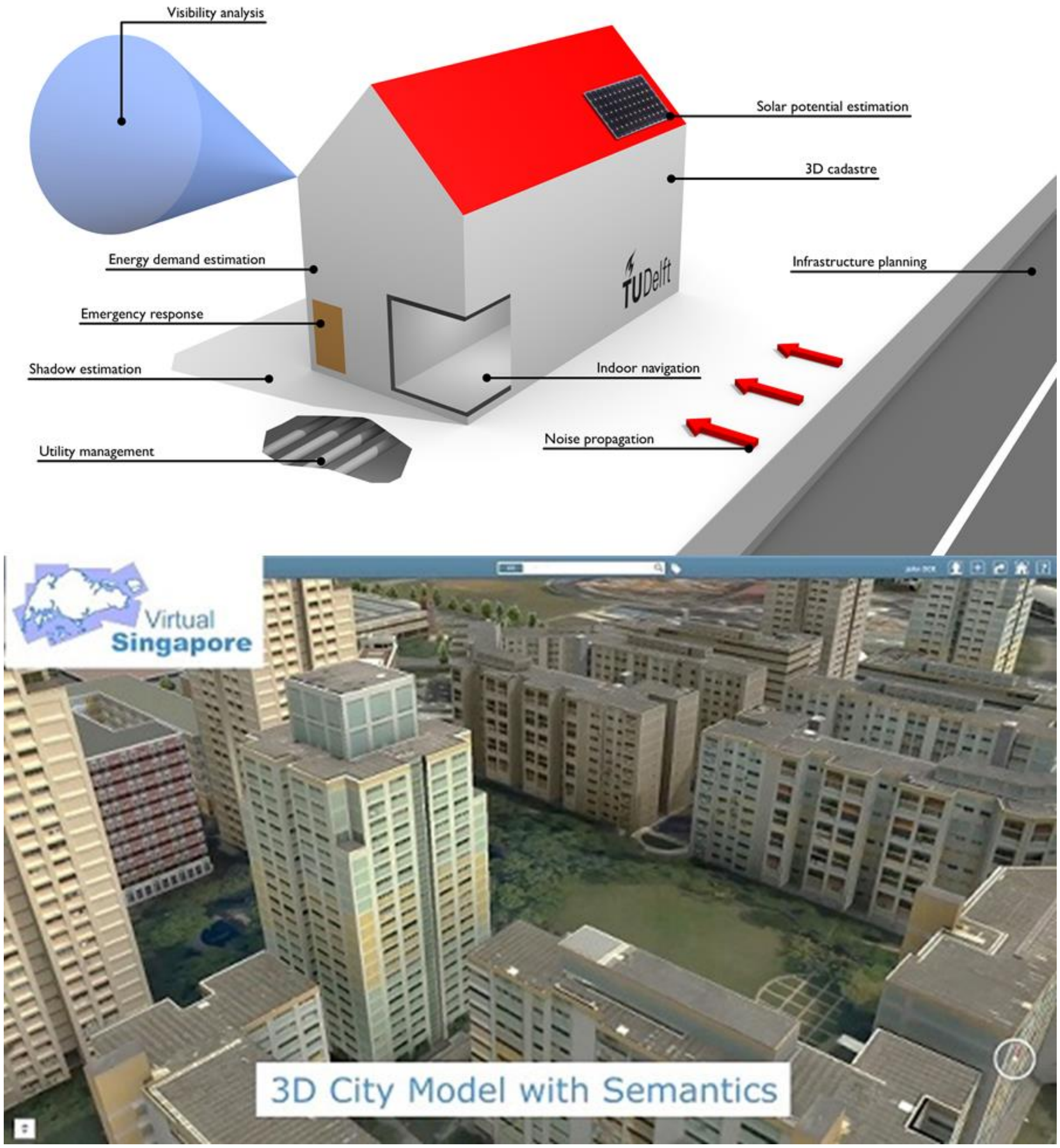

Figure 5: Examples of 3D urban model uses for representation and decision support (top; adapted from Biljecki et al, 2015). Example image of Virtual Singapore 3D urban model (bottom; source: https://www.nrf.gov.sg/programmes/virtual-singapore).

Human Factors

Concept of the citizen

The most fundamental of all smart city components is the citizen, the individuals who the government is ultimately intended to serve. The concept of citizenship in its broadest sense is ever changing and constantly debated, and so here is presented a universal concept of citizenship that is considered to be functionally useful within the smart city literature. In an article conceptualizing the concept of the citizen within the smart city, Michel (2005) presents a definition first put forward by Leca (1986) where citizenship is composed of the combination of, each to at least some extent, rights, duties, and participation. Each of these components relates to a citizen's involvement in the smart city, and plays a role to a different extent depending on the mandate of the city in question. In this sense, when a citizen is primarily defined as having "rights", they are thought of as consumers of rights and public services. When defined primarily by "duties", the citizen is thought of as a more passive agent, being subject to a set of restraints. Finally, when "participation" is given greatest value, it is taken for granted that the citizen is an active agent fully engaged in public life.

Michel (2005) further illustrates the concept of citizenship by invoking the 1958 French Constitution (Chevallier, 1999), which states that a Republic consists of a "government of the people, by the people and for the people". Two interrelated ideas emerge from this founding principle: first that citizens are manageable and "something to be governed", and second that there are different modes for the management of citizenship. When referring to a "government for the people", it again refers to the idea that citizens are consumers of rights and public services. The idea of a government "of the people" refers citizens as passive agents, where governments would have to improve the chances of success for a policy by making the citizens' adherence easier. Finally, "government by the people" emphasizes the democratic ideal, where citizens play an active process in politics. With the above definition and concepts in mind, it can be posited that the role of government in an idealized smart city is to make available beneficial rights and public services, to limit duties only to those that are necessary and beneficial, and finally to encourage and enable democratic participation of citizens in the public processes of the smart city.

Human capital and the creative class

The ideal smart city should be able to facilitate economic growth and sustain a creative class of citizens (Boulton, Brunn, & Devriendt, 2011). The creative class is typically highly educated and tends to work in creative and service-oriented industries such as science, engineering, education, computer programming, research, art & design, and media (Florida, 2002). These kinds of highly skilled knowledge workers continue to migrate to smart cities where they begin to have an impact on the local urban culture and typically promote diversity, creativity, and expanded economic opportunities (Eger, 2000). A smart population is also defined by affinity to life long learning, social and ethnic plurality, flexibility, cosmopolitanism, open-mindedness, and participation in public life (Florida, 2002). In a smart city, smart solutions to local urban problems can be solved in conjunction with a citizenry that are engaged in public life. A smart population is thus encouraged to be active participants in the Human Smart City, where their contributions are considered an important urban planning tool (Marsh, Molinari, & Rizzo, 2016). Education is critical to a fully realized smart city, and dynamic learning environments are shown to attract businesses, organizations, and diverse individuals (Boise Smart City Initiative, 2002) who then lead to a secured creative class that nurtures and further develops this economy.

Institutional

Citizen-oriented Smart Government

An important aspect of the smart city is its smart government and that it works to serve its people. An expectation of a smart city is that its government shares concepts, visions, goals, priorities, and even strategic plans with the public and stakeholders (Odendaal, 2003). Successful cities possess some common characteristics such as the concerted collaboration between different functional sectors and parties (e.g., government, business, academics, non-profits, voluntary organizations, and others), and between different jurisdictions within geographical areas (Eger, 2009). IBM offered suggestions on how a smart government should run, namely that the government must do more than just regulate the outputs of economic and social systems (IBM, 2009). Instead, governments must also play a role in connecting dynamically with citizens, communities, and businesses in real time to spark growth, innovation, and progress. Smart cities can benefit from IT-mediated governance, also known as e-governance, which offers citizens platforms with which to engage in public life through web portals. A major benefit to this digital governance strategy is that digitized data is easy to copy and distribute, and this allows for information to be available to the public through open government data initiatives that put a premium on transparency (Paskaleva, 2009). Indeed, open government data is a central aspect of this thesis project and will be discussed in detail in section 2.4.

With the advent of the smart city concept, one of the central goals of e-governance is to help facilitate citizen engagement with public life. Citizen engagement in the emerging contexts of smart cities refers to how digital media and culture allow citizens to engage with, organize around, and act upon collective issues and engage in co-creating the social fabric and built form of the city (De Lange & De Waal, 2013). Traditional forms of citizen engagement include the town-hall meeting, where citizens gather together with public representatives to deliberate around relevant issues and potential implementations concerning the city. In the modern context of social media and the ubiquity of web-based interactions, Varnellis (2012) argues that citizen engagement can take on the form of a “networked public”, which is a group of people that use digital technologies to organize themselves around collective goals and issues. Due to the advent of online culture, there has been an observed growing interest in organizing publics in this way, either to collectively map issues as part of activism, or to organize themselves around common pool resources. Michel (2005) describes this participatory process via e-governance enabling interactions between citizens and governments as one that provides the resources necessary for citizens to generate new ideas, to debate them, and to develop constructive propositions.

2.3.4 Smart Cities: International Examples and Portrait of Singapore

Since population growth and rapid urbanization are taking place all around the world, the movement for implementing smart cities has become an international one. In a recent survey by Thompson (2016), it was observed that there are currently 1119 cities that either are or are in the process of incorporating criteria that can be considered "smart". The distribution of smart and emerging smart cities across the globe includes 493 in Europe, 494 in Asia, 87 in North America, 18 in South America, 10 in Africa, and 16 in Australia. In an analysis by Forbes magazine (High, 2015), they concluded that the top five smartest cities in the world were Barcelona, Nice, London, New York, and Singapore.

Singapore is an interesting example of a smart city due to its high dependency on ICTs, and the fact that it is really a smart country. Since being bought in 1819 by the British East India Company, Singapore's economy has relied on trade and commerce as a well-positioned port. Singapore was never wealthy in terms of commodities, and so they were always dependent on its service-economy (Mahizhnan, 1999). After becoming independent in 1965, the new government realized they had to create jobs for their citizens and so embraced the then growing extension of multi-national corporations looking for strategic locations to expand their business operations. The Singapore government decided to invite the development of multinational IT companies onto their island in order to become economically competitive on a global scale. Singapore benefited economically and gradually structured their society around IT (e.g., emphasis in IT education, IT training for adults, etc.) until they reached their intended goal of becoming an “intelligent island nation”. Singapore has since become one of the first and most widely recognized “smart” cities as they have advanced technology, a creative and technologically literate population, and completely integrated smart institutions. Singapore continues to lead the way in the international movement for smart cities, but is also a case study in some of the costs associated with this movement, as will be shown in the discussion section of this thesis.

2.3.5 Critique of smart cities and the need for citizen engagement

While this thesis fundamentally promotes the benefits of smart cities, open government data, and digital culture, and assumes that rapid urbanization and socioeconomic changes can be solved through technological intervention, the concept of the smart city is in actuality far from being without its criticisms, highlighting the value of implementing efficient methods for citizen engagement. This section outlines some of the central critiques of smart cities posed in the literature in the interest of having a more comprehensive understanding of this emerging phenomenon, and the need for implementing methods for citizens to contribute to the rapid development of their cities. The criticisms include questioning the underlying assumptions of technological determinism, the effects of giving multinational organizations too much influence, and the social consequences of potentially dividing a city along techno-economical and ideological lines. This section concludes with the claim that implementing novel forms of e-governance solutions may serve to mitigate the potential negative effects outlined, as well as others, and relates back to one of the central aims of this thesis project.

The first criticism begins with questioning the primary assumption of smart city initiatives, which is that integrating ICTs can solve urbanization problems. Eger (1997) argues that there is too much faith that how cities are changing and being shaped can be attributed to implementations of ICTs and technological intervention. Eger argues that there is the assumption that the implementation of ICTs will in and of itself somehow deliver a smart city, which he views as both closed-minded and naïve, and as an example of the fallacy of technological determinism. Evans (2002) articulated this idea succinctly when he stated, "being connected is no guarantee of being smart". In Evans' view, technological implementation cannot be taken as the sole critical factor in making a city "smart". An example of the mismatch between the society and the integration of ICTs comes from the South American city of Lima. Despite increasing the amount of telecommunications diffusion in the city, the citizens of Lima did not take up or use the new smart city ICT features as expected, as it was found that for many citizens, smart-phones and internet connections were not priorities when budgeting their finances (Graham, 2002). This idea that technological intervention can usher in an improved society prima facie, may be due to clever marketing rather than real-world empirical analysis.

The second criticism builds on the last point above that smart city marketing and promotion is tied to business interests, and can expose the city to the negative effects of multinational neo-liberalism. While the rhetoric of smart cities is finely tuned to appear as a clear benefit to citizens and public institutions, it should not be forgotten that large companies that get invested in these projects have a financial bottom line, and may overlook social issues to appease stakeholders. What makes this point more salient is that many of the companies getting involved with these projects exist internationally, and therefore may have no stake in the outcomes of any particular city other than to reach their financial goals. Governments as well may overlook citizens in hopes of increasing revenue by bringing in high-profile business partners. An example of this conundrum is Singapore, which according to Wei Choo (1997) has undergone three main ideological changes since it began its smart city projects. The first phase was the integration of IT to improve public services and produce a stock of national IT professionals. The second phase was the change of emphasis from public to private where the health of the city became synonymous with the ability of IT companies to export services. And the final phase was the shift, both practical and ideological, towards Singapore becoming an "intelligent island". What is interesting about this final step is that ICTs have become embedded into nearly every aspect of a Singaporean's life, and the city/country's rhetoric emphasized almost explicitly that the well-being of the citizenry is intertwined with corporate competitiveness. This shift from public to private was gradual, but has had tangible effects on Singapore's culture, leaving some of its thinkers to consider how to preserve some of its original identity (Mahizhnan, 1999).

The third criticism is that smart city policies and ideas can also have tangible negative effects on the social fabric of cities, as smart cities require the creation of an international class of creative and smart workers and can exclude static citizens. The problem with importing too many smart workers is that it can lead to gentrification and social polarization along the lines of real estate, wealth, lifestyle, and culture (Harvey, 2000). This can be seen for instance in the vast wealth inequality in Sinagpore where the upper class makes 36 times more than the lower class (Singapore Democratic Party, nd). Effectively, the city gets broken apart along the lines of technological haves and have-nots, where opportunities to enter the IT economy are limited to anyone willing to adapt or enter the city from elsewhere. These kinds of issues are often the basis for criticism for many kinds of situations where neo-liberalism overlooks the social interests of the local population.

The above criticisms have culminated in Maros Krivy (2016) making the bold claim that the smart city is the real-world manifestation of Deleuze's concept of a *society of control*. Deleuze's idea for the society of control grew out of Foucault's discussions of how societies discipline citizens into conforming to social norms. Moving away from the traditional hierarchical and closed-system socieites of the past, the society of control is possible in a neo-liberal and technological state where people are controlled through the threat of surveillance. While members of a society of discipline are geographically static and threatened with violence if they fail to comply, citizens of the society of control can roam freely up to a point. The smart society of control then offers the sense of mobile freedom and technological convenience, but comes with the cost of being constantly monitored to at least some extent within the city network

As the above criticisms illustrate, the implementation of smart cities is not simply a neutral intervention that can be expected to solve all urban problems as they emerge, thus highlighting the need for citizens to be able to engage in public affairs and have an influence in policy making. Within the context of a democratic smart city-state, it must be assumed that citizens are themselves able to monitor and advocate for their own quality of life. In response to this, one of the central claims of this thesis is that if there is a need for citizen engagement within the context of the technologically enhanced smart city, then there is the potential to utilize specially designed methods of e-governance to aid citizens in their ability to participate in public life. This thesis thus proposes to design a novel form of e-governance tool that connects citizens with information relevant to generating new ideas, facilitating public discussion, and aiding in citizen activism.

This thesis specifically focuses on exploring the affordances and potential for creating such a democratic aid using emerging media platforms such as augmented and virtual reality. As section 2.5 reveals, these platforms have the potential to facilitate unique user interactions and show promise for mass-consumer adoption in the near future. This thesis claims that one method of facilitating citizen engagement is to make open government data communicable, accessible, and attractive to the public, in order that they can use this information to organize around issues of public interest or concern. Within the context of a transparent smart city, where it is assumed that open government data is disseminated to the public in good faith, open government data could be used to help citizens become aware of issues concerning their quality of life, as well as help justify their concerns when they are brought to the public sphere for discussion. The next section offers a detailed review of the concept of open government data and its multi-faceted value as a public asset.

2.4 The Open Government Data Movement

2.4.1 What is the Open Government Data Movement?

Two important aspects of the mandate for smart cities is that governments must both be transparent and promote innovation, and the open data movement is emblematic of how these goals can be accomplished. The open government data movement refers to the push for governments to be transparent and make available data that the city has collected. Through e-government services, these data can be made available to the public via open government data portals that are easy to implement as cloud services are currently very affordable. While governments typically offer their open data online in tabular and machine-readable formats (i.e., csv, JSON, etc.), this creates the opportunity for innovators and entrepreneurs to design solutions for making these data interpretable and useful (Kalin, 2014).

The concept of open government data is not new and the idea of governments using taxes to fund free access to public information goes as far back as the first library (Kalin, 2014). As cloud computing and IT infrastructure have become more affordable new possibilities for open data have become available. The current global push for open government data can be traced back to US President Barack Obama’s administration in 2008. On his first day in office, Obama signed the Memorandum on Transparency and Open Government that established the federal data portal data.gov (US Government, 2009). This inspired other local and global government administrators to implement their own open data initiatives, such as San Francisco in 2009, the British government in 2011, or the Open Data Charter by the European Union in 2013 (Kalin, 2014). The concept of open data has even been adopted by industry, and there are examples of businesses that offer open data to be used by the public at no cost.

Open government data typically comes in three sources: official statistics, sensor-based data, and user-generated content. Official statistics include population data, businesses, economics, jobs, crime and justice, health, etc., and can also come in geo-mapping formats such as Shapefiles or Geo-json. Sensor-based data can include real-time data from sensors such as street lighting, humidity, temperature, air pressure, traffic etc. User-generated content can often include GPS-based data from mobile devices, or user-interactions such as text input. Open government data can thus include static content as well as real-time feeds.

The open data initiative confers tangible benefits, but also risks that should be taken into consideration. The company Logica Business Consulting (2012) wanted to understand what the specific benefits of open data are and so assessed the Open Data standards of countries around the world and identified the following: increased transparency, stimulation of economic growth, improved government services and responsiveness, reuse of data, improved public relations and attitudes towards government, and improved government data and processes. It is clear that opening up government data suggests to the public that the government aims to be transparent, helpful, and trustworthy, and so can work to enhance the city’s brand. Conversely, potential risks of open data were discussed in a study by Kucera and Chlapek (2014) where they interviewed open data administrators. The most serious risks they identified included the publication of data that violates legislations (e.g., infringing someone's rights or freedoms), publication of data that reveals trade secrets that ought to be protected, publication of personal data and infringing on individual privacy, the use of data about infrastructure that could be used for nefarious reasons (e.g., terrorist attacks), and the possibility of wasted investment due to lack of users, etc. Kucera and Chlapek went on to suggest some methods to mitigate these risks such as communicating with the public to understand what data is most in demand, and assessing compliance of datasets before publishing.

2.4.2 Open Data as Engine for Innovation and Economic Growth

An important benefit of open data initiatives, and one related to the aims of this thesis, is the potential for open data to stimulate economic growth and promote innovation. Open data can be used by entrepreneurs to create new services and design outputs, and there is evidence to show that this idea has been very fruitful. Indeed, economists like Manyika et al (2013) have estimated that the result of governments around the world opening up their data to the public has a potential value of 3-5 trillion dollars per year across seven sectors: education, transportation, consumer products, electricity, oil and gas, health care, and consumer finance. Other studies have offered regional and country level estimates where the annual worth of businesses oriented around open data was 3-9 billion for the United Kingdom (UK Dept for Business Innovation and Skills, 2013), and 30-140 billion euros for the European Union (European Commission, 2011). Research by Deloitte's Insight Team identified five archetypes for how businesses use open data to increase their value, and they are: Suppliers (businesses that publish their data openly to foster customer loyalty), Aggregators (collect and analyze open data, and sell their insights), Developers (design, build, and sell web-based, tablet, or smartphone applications using open data as free resource), Enrichers (use open data to enhance their business via understanding demographics, consumer behaviour, etc.), and Enablers (charge other companies to facilitate the access and use of open data). As can be seen, open data can stimulate economic growth and aid businesses on both the scales of multinational enterprise, all the way to the individual mobile developer.

2.4.3 Citizen-Facing Open Data Digital Interfaces: E-governance, Web Portals, & Mobile Applications

As mentioned in section 2.3, e-governance allows for the optimization of public services through the use of ICTs. E-governance can thus range in quality from information provision when government organizations publish static information available to the public via the Internet, to web interactive communication and e-transactions, to fully developed one-stop integrated virtual government services (Fang, 2002). Most broadly, e-governance has been defined as service delivery enhanced by ICTs between government and any of the following parties: citizens, public servants, business, and external governments (Baum & Maio, 2000). In this thesis, and particularly in this section, we are interested in e-governance that takes place between government and citizens and are implemented via web-based and mobile platforms. In the next section, some illustrative examples of effective open government data web portals will be presented.

Many governments around the world use online web portals (i.e., interactive webpages) as a highly practical method of presenting open data to the public, but it is important to be mindful of the quality of these portals as this will impact the willingness of citizens to engage with them. In a recent study by Martin, Rosario, & Perez (2016), they performed a comparative analysis of open government data portals around the world (figure 6). They developed a Quality Index based on the following three subindices: functional subindex (FSI), semantic subindex (SSI), and content-based subindex (CSI). The FSI refers to the evaluation of the utilities and functions with which users can obtain information. The FSI score is determined by looking at the five factors of data search techniques, organizational approach to data provision, data supply, visualization, and feedback, and was inspired by work from Alexaopolous et al (2013) and Kalampokis et al (2011). The SSI refers to the arrangement of the data through both simple flat structures and complete linked ones. The SSI score is determined by looking at the four factors of SSI including level of metadata, level of open data, multilingualism, and data format. The SSI was inspired by Berners-Lee (2010) and the Interoperability Solutions for European Public Administration (2011). Lastly the CSI refers to the relevance of the information provided by the portal. The CSI was determined by looking at multiple factors including data accuracy, completion, consistency, timeliness, types of information, categorization, data filters, total data volume, and number of agencies involved. The CSI was inspired by work from Polillo (2012). To determine the QI, they took the sum of scores for all items, divided them by the total number of scoring factors, and multiplied by one hundred to represent the value as a percentage score. The researchers used this metric to evaluate all the open data portals linked to via the US data.gov “International Countries” category.

Compiling scores of all countries, the QI scores reveal some interesting findings regarding open data portals in general. Overall, the FSI scores were the highest of the subindices with 61%, compared to 51% for SSI scores, and CSI scores with 43%. Taking a closer look at the FSI performance of all countries, 94% present simple lists with data search by categories, and keyword search. In contrast, data search using interactive maps was used very little with only 11%, and when information was presented via interactive map, the portals included a digital tool to optimize geo-information searching. Just over half of the portals gave users the opportunity to both view data online as well as download it. Where data was viewable online, 61% was offered as image, 56% as text, and 3% as audio. Another FSI was the ability for feedback, and the most common methods were forms (67%), email (47%), and telephone (22%). Some example findings from the SSI were that 14% of countries offer multiple language translation, and the most common data formats were XLS, CSV, XLM, and the least common were GIF, JPEG, and ODS. Finally, in terms of CSI some findings were that 23 countries were developing specialized applications for web and mobile for user access to open data. Some outstanding findings regarding specific countries are that Canada overall had the highest QI with a score of 78, China and the US provide the most data volume, and the US had developed the greatest number of interactive web and mobile applications based on the open government data.

	Functional Aspects	Semantic Aspects	Content Aspects	Quality Index
Australia	78	71	46	65
Austria	75	75	49	66
Bahrain	80	13	39	44
Belgium	37	82	32	50
Belize	70	53	30	51
Canada	80	97	56	78
Chile	67	31	32	43
China	63	0	39	34
Costa Rica	73	48	41	54
Denmark	40	64	33	46
Finland	23	6	0	10
France	70	46	49	55
Germany	63	60	46	56
Ghana	83	40	22	49
Greece	65	31	37	44
Hong Kong	60	53	32	48
India	53	77	37	56
Ireland	43	13	35	30
Italy	73	71	65	70
Japan	73	67	42	61
Kenya	80	45	46	57
Morocco	40	14	25	26
Netherlands	67	59	39	55
New Zealand	50	53	51	51
Norway	50	61	47	52
Philippines	53	58	35	49
Portugal	80	49	45	58
Saudi Arabia	43	15	29	29
Singapore	57	48	45	50
Slovakia	73	50	47	57
Spain	43	96	18	52
Sweden	40	64	33	46
Tunisia	73	41	30	48
United Kingdom	77	63	44	61
Uruguay	53	53	33	46
United States	57	67	64	63
Mean	61	51	39	50

Figure 6: Open data quality index scores by country. Adapted from Martin, Rosario, & Perez (2016).

Many open government data portals have been developed for mobile application, both by local governments and engaged citizens. Indeed, some believe that the only way for smart cities to be fully realized is through the development of mobile applications as described in the *Apps for Smart Cities Manifesto* (2012). In this paradigm, mobile apps would allow for ubiquitous government and create more possibilities for citizen participation as mobile apps afford the use of camera, immediate feedback based on live experience, location based functions, etc. In a study by Mainka et al (2015), they performed a broad survey of mobile apps based on open government data from cities all around the world. Their analysis of 471 apps worldwide revealed the following six main types based on their services (figure 7 top): Mobility/transportation, points of interest (e.g., tourism), education, health, public safety, and information awareness (e.g., public statistics, local news, etc.). The most common types were single-topic points of interest apps, transportation apps, and various information awareness apps. Their research also revealed the specific functionalities of these apps; where the most common were GPS, map presentation, and real-time data feeds. They also showed the proportion of apps created by government vs. non-government developers by country as can be seen in (figure 7 bottom). Some cities with the greatest proportion of apps developed by government vs. non-government developers appears to be New York, Barcelona, and Hong Kong, where Hong Kong has the most mobile apps for open government data overall. The authors conclude their paper noting that the development of specialized apps for open government data is still in its infancy and that increased technical literacy in city populations will lead to new non-government developed applications. In the next section, some specific examples of open government data web portals, mobile applications, and specific functionalities of interest will be briefly reviewed.

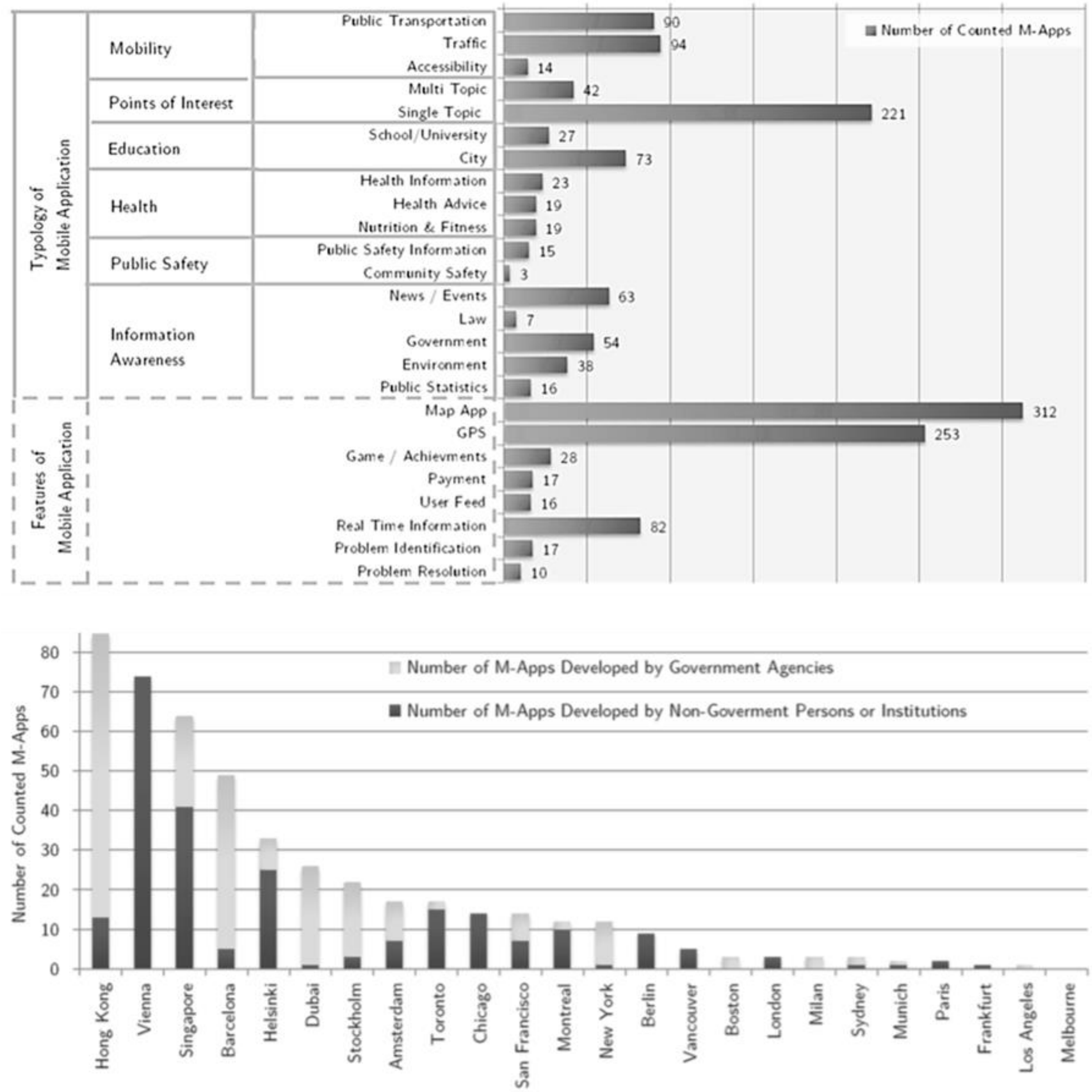

Figure 7: Types of open government data mobile apps by country (top; adapted from Mainka et al ,2015). Proportion of apps developed by government vs. non-government developers by country (bottom; adapted from Mainka et al, 2014).

2.4.4 Illustrative examples of Web Portals from Singapore, New York, and Toronto

In this section, some illustrative examples of open government web portals are presented in order to review the current state-of-the-art and thus create context for developing new and experimental methods of presenting Toronto's public data. Figure 8 shows open data web portals from Singapore, Toronto, and New York, as well government- and non-government-developed web-applications based on Toronto's public data.

While all three of the presented web portals are high quality, they have varying strengths and weaknesss. While all three present a wide-range of publically available data, Singapore's data portal is notable in that data sets are visualized into charts and graphs using web applications built into the site. Indeed, the homepage of Singapore's portal looks like a dashboard until one digs deeper to search for specific data sets. In both the New York and Singapore portals, when specific datasets are selected, previews and visualizations are offered for quick reference. All three portals offer keyword search to navigate to data sets of interest while also offering clickable categories. All three portals offer galleries to web applications and data visualizations developed from non-government actors. Both New York and Toronto portals offer access to built-in map applications (figure 8) that allow users to geographically visualize various datasets, while Singapore does not appear to have one comprehensive map application for this purpose. Singapore and New York's portals offer special developer support, with code examples for accessing web portal APIs while Toronto has only a handful of API supported datasets and live-feeds but no pages for specific developer support. The web application shown in Figure 8 is one such example of an app based on live-feed data, where the availability of rentable bikes around the city is visualized in real-time.

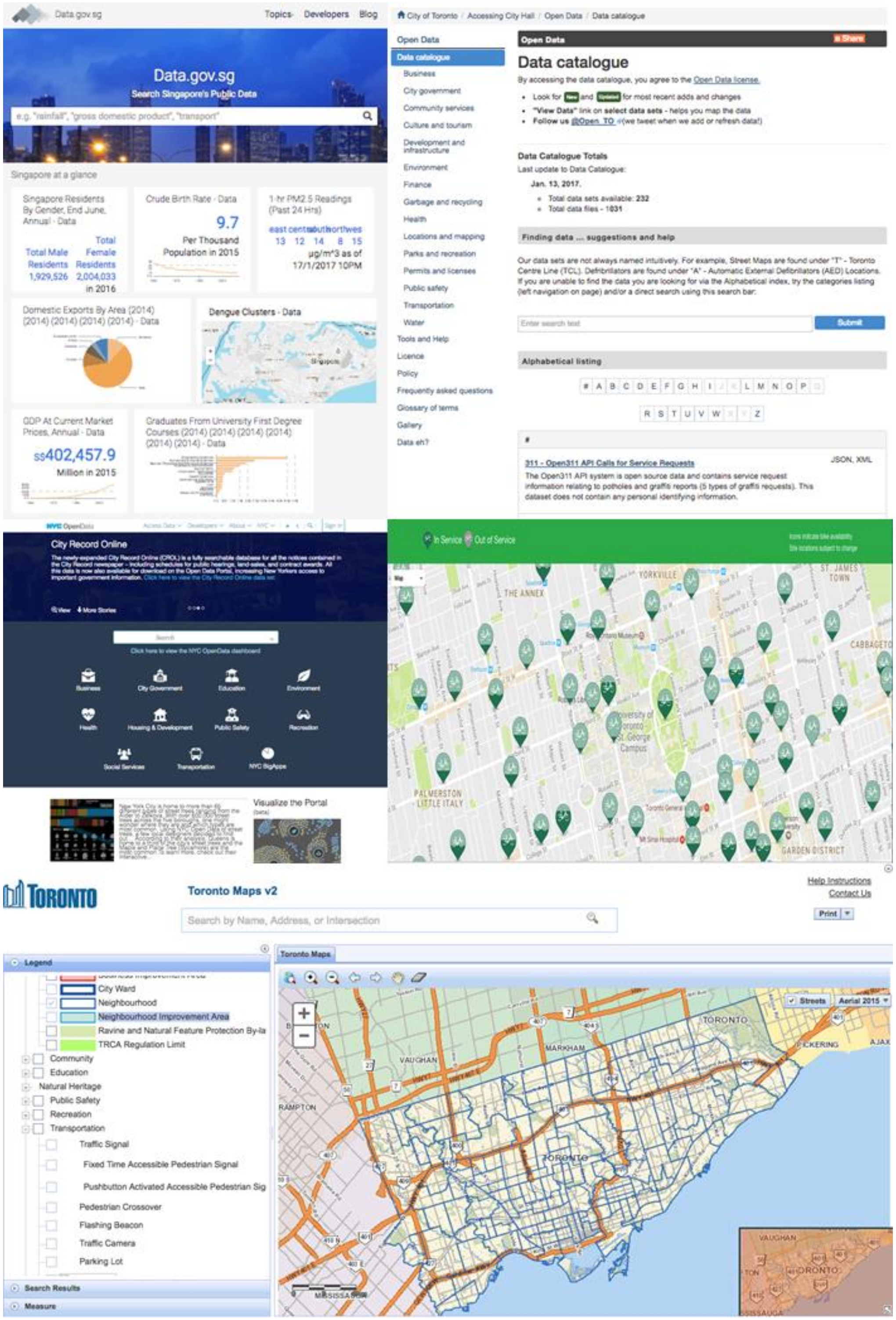

Figure 8: Open government data web portals from Singapore (top-left), Toronto (top-right), and New York (middle-left), as well government- (bottom) and non-government-developed (middle-right) web-applications based on Toronto's public data.

2.4.5 How can the city of Toronto benefit from presenting public data through novel and experimental forms of media?

I argue that given the context of the continuing growth of smart cities and the increasing availability of open government data, the City of Toronto, as well as smart cities in general, can benefit from developing open government data portals and applications using experimental and emerging media platforms. As shown in section 2.4.3, Canada is ranked first in terms of the quality of its open government data portals, and by continuing to push the envelope on this movement, which promotes government transparency as well as economic opportunities for citizens, Toronto is in a position to be a world leader in this area. In this way, Toronto can enhance its reputation internationally as a growing smart city by empowering its creative citizens as well as maintaining its reputation for democratic ideals.

Toronto currently has a strong brand internationally, and can benefit from taking advantage of smart branding opportunities. Both New York as well as Singapore have had official public demonstrations that promote their smart city image that includes showcasing what is being done with their public data. New York was recently awarded the title of smartest city of 2016 in Barcelona as part of the World Smart City Awards (Smart City Expo World Congress, 2016), and they have also created an exhibit titled New York at its Core, which provides a multi-media experience explaining the city's origins, how it solved the problems of growing and sustaining such a complex metropolis, and how it is becoming smarter in order to solve the problems of the near future (Museum of the City of New York, 2016). Similarly, Singapore has a history of presenting its smart city accomplishments for the purpose of world recognition as exemplified by its exhibit LIVE Singapore! in 2011, where participants could observe real-time data visualizations based on Singapore's incoming sensor data in a national museum setting (Singapore Art Museum, 2011). Toronto in contrast has not had these kinds of smart city exhibitions but it does have a strong open data portal that can be utilized to develop new and innovative open data applications and experiences to showcase. It should be noted that Toronto was named the most livable city in the world by both Metropolis and Forbes periodicals, and Toronto's brand itself ranked as one of the best in the world by Resonance Consulting group in 2017. I argue that Toronto's reputation can only be improved by showcasing cutting edge and innovative applications that are a direct benefit of the city's transparency and service provision.

Promoting the development of open data applications via experimental media platforms may also benefit local citizens, both for educational as well as financial reasons. For one, having standout open data media can draw attention to open data, as many citizens may be unaware of the fact that the government has made all this information available. Furthermore, this can lead to awareness of the smart city concept itself, especially if these media present data that are real-time and reveal the city's integration with IoT and various sensor systems. Citizens should be given the opportunity to gain awareness of the smart city movement for sociopolitical reasons that were discussed in section 2.3.5. Next, experimenting with open data and new media raises awareness for developers to utilize open data for their own financial empowerment, as projects based on open data were shown to stimulate economic growth in section 2.4.2. In this way, using open data with new media platforms, such as virtual reality and augmented reality, has potential to stimulate economic growth and innovation as these platforms show promise for rapid development and mass-adoption, as will be elaborated on in the next section.

Overall, creating advanced digital prototypes using open data is in line with the idea of a smart citizenry as described in section 2.3.3, and may create new techniques for advancing citizen engagement pertaining to city issues as Toronto becomes a more fully developed smart city. These new media platforms offer new possibilities for e-governance communication due to the specific affordances that these platforms enable. If citizens can interact with open government data that is presented through experimental new media, there is the potential for new forms of democratic processes and citizen engagement

2.5 Virtual Reality, Augmented Reality, and Mixed-Reality Media Platforms

2.5.1 Introduction

Virtual reality (VR) and augmented reality (AR), while becoming popular concepts on a mass-scale only recently, have a longer and deeper history and theoretical background. The grandfather of both VR and AR is often considered to be Ivan Sutherland, who described the *ultimate display*, a theoretical technology that would allow a person to experience a simulated multisensory reality that could be non-discernable from subjective experiences in the real world (Sutherland, 1965). Sutherland is credited for having created one of the very first VR head-mounted displays nicknamed the Sword of Damocles in the late 1960s (HMDs). Through the 1970s and 1980s, various researchers made technical projects that combined human interaction with computer generated overlays often as artistic installations (Schmalstieg & Hollerer, 2016).

Through its early history to today, virtual reality has developed rapidly through much iteration, leading to a wide range of potential applications. Beginning in the same period as Sutherland, Myron Krueger was a prominent virtual reality researcher and explored user experiences in “artificial reality” and responsive environments (Krueger, 1991) by developing computer generated worlds. He created a VR experience where multiple users could communicate from far away distances while sharing the same virtual environment. The term virtual reality was coined in 1987 by VR researcher John Lanier who created his company the visual programming lab. Since this period VR has been used and experimented with as a media platform in many disciplines including education (Sinclair, 2016), engineering (Cencetti et al, 2016), architecture (Ibrahim, Dimick, &

Joseph, 2017), health (Henriksen, Nielsen, Kraus, & Geng, 2016), entertainment (Zyda, 2005), etc.

Augmented reality has seen similar growth from its early experimentation stages to a technology with a broad scope of applications. In 1993, Feiner et al introduced an AR system that instructed workers on technical and repair work. A user with an HMD could see overlaid schematics on working objects and gain insights to aid in their work. In 1994, State et al created a compelling AR application that allowed users to view unborn fetuses inside a pregnant woman's belly by looking through her skin into a CGI re-created version of her uterus. In the mid-1990s Steve Mann developed a range of wearable AR technologies such as the WearCam, a mobile visual display that could augment the visual output and allow the user to interact with the explored environment in experimental ways (Mann, 1997). Aided by the growth in smart-phone and tablet technologies, AR has been implemented in a wide-range of applications including education (Foster, 2016), engineering (Agarwal, 2016), architecture (Chi, Kang, & Wang, 2013), medical (Cutolo, Parchi, & Ferrari, 2014), entertainment (Pucihar & Coulton, 2013), etc.

Both VR and AR are examples of mixed-reality (MR), a higher-level classification that adds a broader theoretical framework to understanding these evolving media platforms. Mixed-reality can be simply defined as a display experience that merges elements of the real world with elements of the virtual world along the "virtuality continuum" as depicted in Figure 9 (Milgram & Kishino, 1994). The virtuality continuum refers to the possible set of experiences that come from direct interaction with the real world, to fully simulated experiences that are conditioned entirely by a technological virtual world. VR is thus on the virtual end of the spectrum, but AR is an example of MR and exists somewhere in the middle of the virtuality continuum, where experiences with the real world are augmented to a degree via the overlaying of simulated elements. MR can also include augmented virtuality (AV), where a user is experiencing a virtual world yet has elements of the real world superimposed into it. There is a range of mixed-reality experiences that do not necessarily fit well-defined areas like VR or AR, and so MR offers a broad scope with which to look at this field as a whole.

Figure 9: The virtuality continuum. Adapted from Milgram & Kishino, 1994.

2.5.2 Virtual and Augmented Reality: Definitions and key-concepts

As described in the previous section, virtual reality is essentially defined as an experience where the user is immersed into a virtual environment, to the point where they lose their sense of contact with the real world (Milgram & Kishino, 1994). This leads to the two concepts of immersion and presence, where immersion essentially refers to the degree to which the technology creating the virtual experience engulfs the user's sensorimotor apparatus, and where presence refers to the user's psychological sense of “being in the virtual world”. Hoffman et al (2004) suggest that the immersion of a participant into a VR system makes it possible to shift their attention from the real to the virtual world. This shifting of attention away from the real to the virtual world is how some authors have succinctly defined presence (Waterworth et al, 2004). Thus the quality of immersion enhances presence, and the quality of immersion is determined by many complex factors including multisensory richness as well as the quality of interactivity (Sheridan, 1992; Fuchs, Moreau, & Guittion, 2011).

Whereas VR places a user inside a virtual world, AR aims to present information that is registered to the real physical world. AR bridges the gap between the real and virtual worlds, both spatially and cognitively. The most widely accepted definition of AR was presented by the researcher Azuma, from his 1997 survey paper. According to his definition, AR must have the following three qualities: Combines real and virtual, interactive in real time, virtual object is registered in 3D physical space. To implement these three characteristics, an AR device must include a tracking component, a registration component, and a visualization component (Schmalstieg & Hollerer, 2016). The goal of these systems is ultimately to give the user the perception that the virtual elements exist within the real world space and interacts with real world objects, thus offering a compelling and unique experience with the virtual content.

2.5.3 Examples of VR and AR applications presenting urban open government data

In this section I review some state-of-the-art virtual reality and augmented reality applications used for presenting city open data to citizens. Both virtual and augmented reality are still in their early stages as consumer-facing media, and so the aim here is to gain some perspective on how these media platforms can be used to present open government data in creative ways. Some proprietary virtual reality city analytics applications will also be presented, and these will highlight the large gap in quality between what is available to citizens and what is available to enterprise-level users.

The first example is an interactive augmented reality application named TunnelVision, which is designed for users commuting in New York City's subway system. TunnelVision allows users to point their phone at one of the many New York City transit maps and explore city open data that is overlaid onto the physical map (figure 10, top). Users can explore city Census data such as income levels by region, real-estate prices, etc., and can also observe real-time data such as the number of commuters entering train stations by activating a visualization of New York's smart transit data feeds. I think this is a very clever AR application that solves the problem of boredom in train stations while offering users an educational experience that allows them to see their local transit maps in an intriguing new light. TunnelVision is available on the AppStore and more details are available at http://www.tunnelvisionapp.com/.

The next example is a virtual reality application designed for mobile and Google cardboard which allows users to fly-through a simple 3D virtual map of New York and activate various data visualizations to explore (figure 10, middle). The low visual detail reflects the fact that mobile-phone web applications can only render a limited amount of 3D content without experiencing performance issues. An interesting aspect of this application is the unique way the author visualized racial demographics by region. To represent percentage distributions of the local population by race, a particle-system was created where the proportion of floating colored particles relative to others represented how many people of each colour lived in the area being observed. The camera height was fixed such that users can only move forward, backward, left, or right but never up or down. This gave a limited feeling to the exploration, but was a clear compromise to prevent users from veering away from the locally loaded geographic area and losing the sense of immersion from the low-polygon city. I think this kind of interactive fly-through city map with data visualizations is very successful except for its limited functionality. The fact that this virtual reality experience can be accessed on mobile using only a browser makes it effective as a potential e-governance tool. More information on this application can be found at http://povdocs.github.io/webvr-cities/?viz=income#MOjwAk9FWGitHdYu http://www.vizworld.com/2016/07/dataviz-in-virtual-reality-using-open-data/#sthash.VFerCb2y.dpbs.

Another example of a customer-facing virtual reality open data exploration tool is one developed by Nirvaniq Labs for Oculus Rift, which offers users a user interface for exploring open data concerning all of Canada (figure 10). This group developed an application that uses a head-mounted-display as well as handheld controllers to query a virtual world map of Canada to retrieve conventional data charts such as 2D pie-graphs, line-graphs, etc. displaying Canadian economics data pertaining to each province or local area. One strength of this application is its animated interactions, its polished overall look, and the breadth and scope of data. One can curate their environment by placing the charts around oneself however one wishes. The main drawback of this application however is that it is effectively a simple dashboard translated into three dimensions when two dimensions would suffice. The immersion aspect is based on the feeling that one is in an informational control room, but the user does not gain any specific advantage from the added immersiveness when compared to a conventional screen-based geographical visualization. More information on this open data application can be found at https://nirvaniq.com/.

The VR and AR market for consumer level open data applications is smaller than I expected, and I think part of this expectation came from the fact that there are incredible modern media applications currently being developed that relate to digital geomapping and data visualization. Google Earth for HTC Vive and Oculus Rift, while not a data visualization application but rather a tool that lets one explore high-definition 3D renders of real-world geographical and urban scenes, is at the forefront of immersing users in virtual scenes based on the real-world. If Google Earth were to incorporate open government data visualization into its virtual platform, I argue that this would be one strong solution to the design problem described in this thesis. There are indeed other virtual visualization platforms for specific industry purposes such as DRiVEDecisions (https://open-data-apps.socrata.com/catalog/drivedecisions/), which visualizes a 3D urban cityscape with data pertaining to making decisions related to real estate (https://open-data-apps.socrata.com/catalog/drivedecisions/), and multi-purpose virtual geomapping such as the work done at the Environmental Sciences Research Institute (ESRI). There currently appears to be very little available to consumers in the way of citizen-facing open government data portals using AR and VR and practically no examples of VR or AR e-governance public services. This gives design researchers the opportunity to explore a future-oriented novel problem that is free from limiting preconceptions.

Figure 10: Examples of VR and AR applications presenting open government data to citizens. Augmented reality New York subway map Tunnel Vision (top). VR New York flythrough for Smartphone and Google Cardboard (middle). VR Canada open data exploration for Oculus Rift. Sources can be found in section 2.5.3.

2.5.4 Potential for growth in consumer-level VR/AR

While VR and sometimes AR take criticism from forecasters for having not yet been mass adopted, market predictions are very positive that this is a growing industry. In a forecasting report published by Golden Sachs, Bellini et al (2016) discuss VR and AR as the current potentially game-changing new form of computing display. They predict that both platforms will grow into large markets that will be adopted in the areas of videogames, live-events, retail, real estate, healthcare, education, military, and engineering, to various capacities. They suggest that the hardware is finally catching up to the conception of its profitable implementation and that these platforms might enjoy similar patterns of growth as compared to the personal computer as well as the smartphone. They report that the venture capital investments to VR and AR in 2014-2016 totaled 3.5 billion overall, and that Facebook aggressively purchased Oculus for approximately 2 billion dollars. This forecasting team has predicted that the VR and AR market could grow up to an 80 billion dollars industry by 2025. This is thanks to a combination of HMD prices dropping through more efficient economies of scale, as well as the combination of growth for smartphone-based VR and AR growth (e.g., Google Daydream) and new technologies like OculusRift, HTC Vive, Meta2 AR Headset, and new models that come out. This projected growth includes both consumer level adoption of technologies, as well as more advanced enterprise level projects.

Chapter 3: Research Methods and Prototype Development

3.1 Research Approach

To develop prototypes used to engage citizens with open government data using AR and VR platforms I will be using the research approach of practice-based research. Practice-based research is an approach that emphasizes the process of discovery through the act of creating project artifacts (Candy, 2006). What makes practice-based research a research approach rather than merely the act of pure practice, is that the research outcomes are intended to provide general insights rather than solve only particular instances of a creative problem (Scrivener, 2002). Through the act of creating prototypes to solve the research question insights are garnered that are then integrated into further iterations. This process continues until the artifact can itself be used to demonstrate creative insights that offer a potential solution to the initial research question. In practice-based research, both a representation of the artifact as well as articulation of creative insights combined is considered final output.

I chose this research approach because my project is focused on creating tangible user-facing artifacts with experimental media to solve a novel research question. The practice-based research approach gives me the freedom to explore the media platform in a tangible sense, while generating insights that could be used by practitioners in future projects. By experimenting with these currently non-ubiquitous but contemporary media platforms, whose real-world affordances have not been fully understood yet, discoveries can be made regarding how users interact with them directly for the purpose engaging with open government public data.

3.2 Early Development of VR and AR prototypes

3.2.1 Introduction

The goal of my early prototyping was to become acquainted with creating simple VR and AR mockups so that I could get a concrete sense of what is possible with these media. From this point of understanding the possible AR and VR experiences that I could realistically develop, I could then begin to focus on creating an artifact that I believed would best solve my research question. Once I had envisioned the ideal prototype that I would focus on, I could begin the process of iteration and re-iteration until my creative output approximated this ideal. As will be shown in this section, after first creating some simple VR and AR “paper-prototypes” I decided to focus the remainder of this thesis project on developing an interactive AR map of the city of Toronto.

3.2.2 Overview of Digital Design Tools

In developing my early AR and VR prototypes I discovered that I could develop for both of these media using the same basic design software tools, which greatly simplified the technical learning curve. The software tools that I used to develop my AR and VR prototypes included the video game engine Unity, the geographical information systems software QGIS, the urban procedural modeling software ESRI CityEngine, and various 3D editing software like Rhino3D and Sketchup.

Unity is a cross-platform game engine used for developing video games for PC, consoles, mobile devices, and web browser. By importing various standard development kits (SDKs) one could develop for different platforms including both VR (SteamVR SDK) and AR (Vuforia SDK). As a game engine, Unity development is primarily graphical user interface (GUI) based, where game objects are spatially localized in a game scene and can be assigned behaviours and interactions by attaching behavioural program scripts to them. All the interactive cross-platform application prototypes that I developed through this thesis were built and deployed using the Unity engine.

QGIS (Quantum GIS) is an open-source geographical information systems (GIS) software that offers data viewing, editing, and analysis capabilities. QGIS works with geographical spatial data, where spatial axes are defined by their longitude and latitude within specifically defined coordinate systems. QGIS can work with spatial data comprised of points (pair of latitude and longitude coordinates), lines (points to points), and polygons (closed shapes of three or more lines). Attached to these spatial data can be attributes that represent quantitative or qualitative data. QGIS can be used to create, edit, and export these geo-spatial data and their associated attributes in various file formats.

ESRI CityEngine is a 3D urban procedural modeling software that allows users to generate detailed 3D landscapes and models from GIS data. CityEngine is often used by architects, geographers, spatial data analysts, and game designers to create virtual representations of either real-world or fantastical environments. Similar to Unity, CityEngine uses both a GUI interface as well as its own *computer generated architecture* (CGA) scripting language. By applying CGA rules to 2D geo-spatial objects, comprised of points, lines, or polygons one can generate complex textured 3D models. The base 2D geo-spatial objects, as they are represented in CityEngine's GIS coordinate map, can have data attributes that the CGA rules can use to specify how models are generated (e.g., generate a specific type of tree at a point representing local tree locations of different species). CityEngine can thus be used as a powerful 3D data visualization tool by generating 3D models with specified visual variables from data attributes associated with the geo-spatial base objects. With the above three software in mind, the general workflow of my prototyping efforts was to prepare GIS files in QGIS, which were then imported into CityEngine for 3D procedural modeling, and then finally imported into Unity where user interactions could be developed (figure 11).

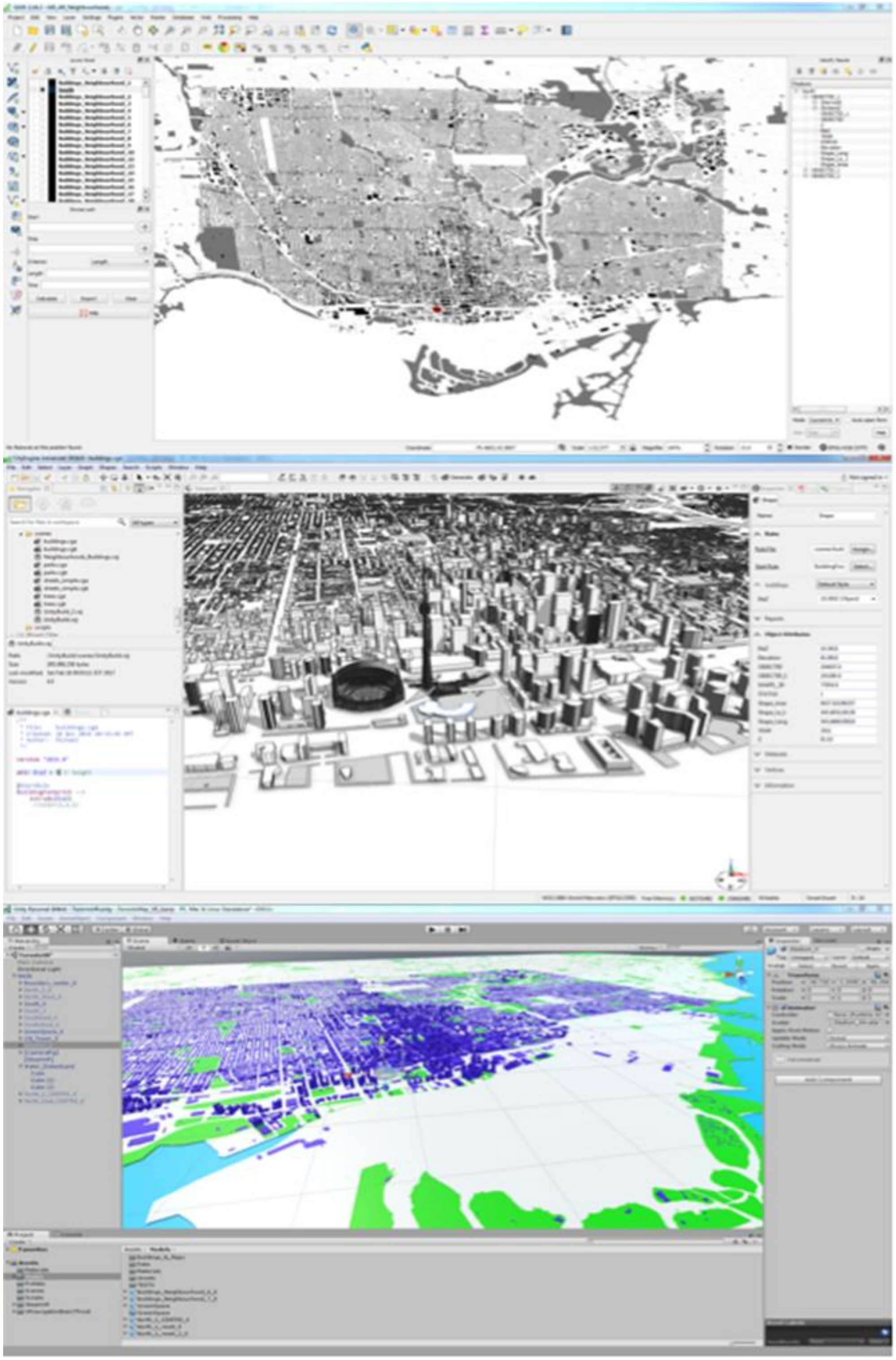

Figure 11: General workflow for prototyping work. Geo-coded data are brought into QGIS for analysis, editing, and file conversion (top). Exported data are brought into CityEngine for 3D geo-modelling and data visualization (middle). Curated assets are brought into Unity for interaction design (bottom).

3.2.3 Overview of Open Government Data and digital assets

Since this thesis is about presenting open government data using new media all digital assets used as content for creating my prototypes were taken from the Toronto open data website. From Toronto's open data portal I was able to find a number of GIS data files including city streets represented as lines, city parks represented as polygons, building footprint polygons, neighbourhood boundaries, street tree locations as points, police station locations, etc. These GIS files could be downloaded as shapefiles (.shp) and opened and modified in QGIS in order to later be used in developing the spatial components of my VR and AR applications. Other spatial data available on the Toronto portal are the high-polygon 3D models of Toronto buildings and cityscapes, offered as AutoCAD, Sketchup, and even 3D GIS files. Because of the greater level of detail, these files are much larger than the GIS files mentioned above. There is also a wealth of tabular quantitative data representing topics such as city demographics, economics, community-centre participation, health and well-being, etc. These data can be visualized and incorporated into the VR and AR applications in order to create engaging interactions with city data.

3.2.4 Early VR Prototype

While I ultimately decided to focus on AR as the central artifact of my thesis, my early prototyping efforts were geared towards building a VR application, which is described here, as well as some of the processes necessary for creating my thesis prototypes in general. Taking stock of the assets I had available to me, the most intuitive path to creating an engaging open government data exploration experience was to give users the opportunity to explore a 3D virtual map of the city of Toronto and present data visualizations to them within this space.

To build an explorable 3D virtual city representation of the city of Toronto, I would need to create a game environment that included geographically accurate representations of key city features such as buildings, streets, land elevations, city boundaries, etc. For the sake of simplicity and computational performance however, I focused only on buildings, parks, and the city's boundary. Since the open data GIS files for buildings contained 2D footprints for each building, as well as an associated data attribute for height, I could use ESRI CityEngine to extrude these polygons into simple veridical 3D shapes. From there I could export these shapes as 3D models of buildings, parks, and the city boundary and upload them into Unity to begin creating an interactive experience. One problem I quickly realized was that due to the city's size and density, CityEngine could not process the 3D shapes for the entire city at once. This forced me to first import the 2D geo-information into QGIS and export the 2D building polygons as multiple smaller regions to then be imported into CityEngine for modeling. Importing the 3D building models as multiple regions was necessary as well for Unity due to the large file sizes. Thankfully, CityEngine is designed with a built-in feature specifically meant to export 3D models for Unity, where models are spatially referenced to each other such that importing them places them in their correct relative positions within Unity. This saves the trouble of having to manually resize and reposition all the separate pieces of the city and avoids spatial inaccuracies.

While the lo-fi geographical map of Toronto was data in and of itself, I wanted to present to users some tabular data that could be visualized, as this best illustrates the advantage of presenting Toronto open government data to users that would likely otherwise not casually engage with it. On the open data website I found various tabular data but chose to stick with variables concerning city economics, as I thought these would be the most socially neutral and interesting to the widest general audience. Since I was placing data within a virtual map context, I needed data that could be geographically defined. I noticed that in the Toronto economics spreadsheet there was a column associating economics variables and values to Toronto neighbourhoods. If I could visualize the quantitative data by neighbourhood, I could make the data geographically meaningful and place the visualization within my virtual map for users to explore. I thus found GIS files on the portal that represented Toronto neighbourhood boundaries, and used QGIS to attach the data attributes from my economics spreadsheet onto them. Of the various economics variables in the spreadsheet, I chose to visualize average home price by neighbourhood, as this is currently a hot topic in Toronto that affects very many people.

To create a data visualization that could exist within the 3D map environment, I exported these neighbourhood boundaries from QGIS and imported them into CityEngine. To visualize the data I extruded the neighbourhood boundary polygons based on the quantitative house price value, and mapped the opacity of each region from 0-1 based on the minimum and max price values. I then exported this coloured 3D model from CityEngine and placed it over the Toronto city model that I had constructed in Unity for data exploration.

Once the virtual map was created, and I had 3D data visualizations that could be placed in Unity, it was time to focus on the user interactions (figure 12). In order to create a virtual reality experience, I obtained an HTC Vive and configured it to work with Unity using the freely available SteamVR SDK. The affordances of the HTC Vive include 3D spatial tracking of the wired head mounted display (HMD) and two wireless hand-held controllers within a limited user defined region (about 2 x 3 meters). The advanced 3D spatial tracking of the Vive HMD offers the user the ability to explore content by moving their heads amongst objects in the proximal virtual scene, while also navigating to distal virtual distances typically using commands from the two controllers.

Since I wanted to create an immersive experience I gave users the ability to manually fly-through the virtual city. To do this I used the freely available VR self-movement library for Unity titled “VR navigation basic thrust”. This library allows the first-person user to thrust their first-person viewpoint in the direction that they aim their HTC controller when they press the thrust command. Based on the user’s voluntary button press, the 3D house price data model would also appear or disappear from the map and users could explore them by moving about them as they pleased. At this point I had finally reached my goal of creating my first VR prototype entirely out of open government data assets, an explorable 3D virtual map of Toronto showcasing city data as a unique and engaging data visualization.

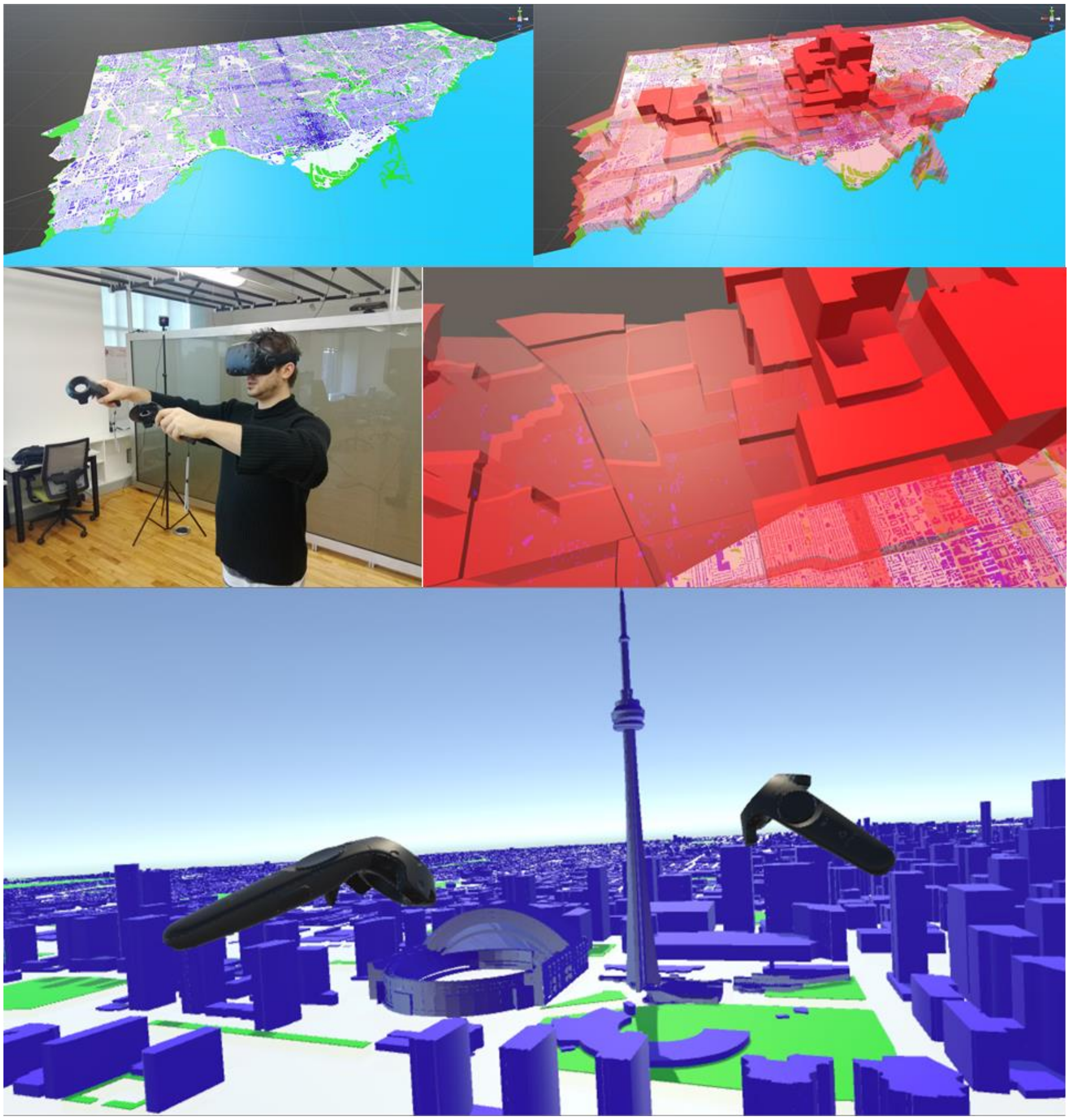

Figure 12: VR prototype development in Unity. Fully constructed virtual map (top-left). Virtual map with house price data visualization overlaid (top-right). HTC Vive setup (middle-left). First person view of virtual city flythrough (bottom). Performance issues using VR, noting that map elements can only be rendered within a limited range from the camera (middle-right).

3.2.5 Early AR Prototype

As mentioned above, my main goal with creating my early prototypes was to gain insight into what is possible with AR and VR media so that I could envisage a final artifact that I could ultimately iterate towards. As such, I created a handful of simple AR prototypes that utilized different kinds of open government data. The processes involved in this AR prototyping work shared much overlap with the development of my VR prototype described in the previous section.

In creating my first AR prototype, I decided to follow the popular convention of using a mobile device's camera to visually recognize a target image that then activates spatially correspondent digital content. I chose this method, as opposed to something like GPS activation, for its relative technical simplicity, it's focus on the immediate environment, as well as the fact that most people are familiar with it. To develop an AR prototype that utilizes image recognition I used the popular Unity AR SDK Vuforia. With Vuforia's online web application, a developer can create digital packages of custom image targets. This package of image targets can then be imported into Unity, or other app development environments, where targets can be associated with digital content that is activated when the target is visually recognized.

Taking stock of the different kinds of open government data that I had available, I designed three unique AR experiences as an exploration. The three different kinds of content included the GIS data of city buildings and parks, citywide tabular data visualization, and complex 3D models of Toronto buildings. I thought these could make for unique and engaging experiences, and I wanted to explore and get feedback for each set. For the GIS buildings, I isolated the Waterfront neighbourhood in QGIS and made only this set of buildings and parks into a 3D model for import into Unity. For the target image, I chose to use the GIS building and park footprints of this neighbourhood so one could easily identify the relationship. For the citywide data visualization, I used the same visualization model constructed for the VR application, average house prices by neighbourhood, and spatially matched it to an image target of the city's boundary with the neighbourhood boundaries also outlined. Since the data visualization shows the neighbourhood boundaries extruded into 3D space relative to the average home price of that neighbourhood, I thought this target image made the relationship between image target and digital content clear and interesting. Finally, for the complex building model I chose to specifically present the AGO, 100 McCaul OCADU building, and the surrounding buildings along McCaul street. I used Sketchup to isolate these 3D building models from the larger 3D model of downtown Toronto they were initially housed in. For the associated target image I chose to use the OCADU logo due to the associated semantic meaning, as well as a sense of skittish pride.

With these digital models and target images I could then build the AR prototype in Unity. This prototype was very simple and had no UI elements. Quite simply, if one pointed their mobile device's camera at any of the target images, their associated digital models would appear above the image and the user could move the mobile device about them, always with the target image at least partially visible, to investigate the models (figure 13).

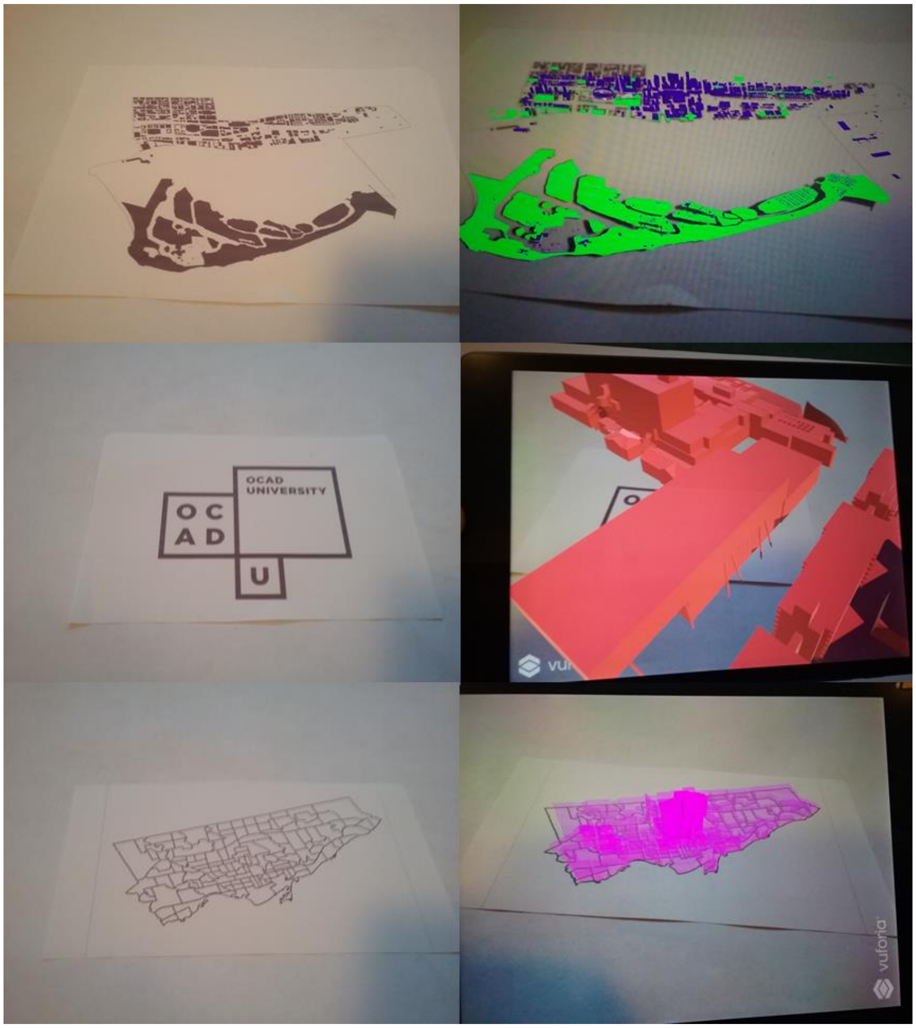

Figure 13: Early AR prototype. Image targets to be recognized by AR applications (left column). Activated digital content (right column). The top AR content is the Waterfront target paired with digital buildings, middle is OCADU logo paired with detailed building model, bottom is map of city neighbourhoods paired with housing price data visualized.

3.2.6 Reflections on early prototypes and decision to pursue AR

After having created these first VR and AR prototypes I had to review what I had discovered from them and make a decision on what kind of thesis artifact I should ultimately pursue going forward. After taking everything into consideration up until this point in my thesis and discussing my progress with my primary supervisor, it became clear that I did not have the time or resources to produce both a fully fleshed out VR as well as AR project as I had initially set out to do, as this was too ambitious. To make the decision between fully pursuing either VR or AR I looked at a combination of factors including my own subjective impressions of these experiential prototypes, a survey of technical considerations, the opinions of others through informal user feedback, a comparison of the creative merits and affordances of each medium, and most importantly which approach would most help me to answer my research question.

My own subjective experiences from interacting with my VR and AR prototypes were that while the VR experience was personally more interesting from a technical point of view, the AR experience was more novel, intriguing, and charming. The VR experience was certainly immersive and I felt that I was present in the virtual map. Bringing up the 3D data model was interesting as I could move into and about the information in a way I had never done before using conventional data visualizations. Some unsolved technical problems however became clear in that the performance of rendering the entire map at once was impractical, and the experience was choppy and suffered for it. Also, visualizing the entire map at once was not possible with my current configuration, and this made the citywide data visualization much less useful and satisfying than it should be. These technical problems were specific to the computational demands of VR, as translating this prototype into a traditional PC keyboard and mouse setup operated smoothly.

The AR prototype in contrast already showed promise of being a complete experience. Something about introducing meaningful 3D digital content into the real world was just naturally very intriguing. Being able to look at and explore the digital content by physically moving around it was in and of itself engaging. Of my three AR mockups, the ones with the GIS buildings and the house price data visualization were the most interesting because the relationship between the image targets and the resultant digital content was visuospatially meaningful. Furthermore, in these cases, the target images themselves were informational, and the AR activations worked to enhance the already useful visual forms. Despite the considerably greater amount of work that went into implementing the VR application, the AR experience quickly proved to be the more engaging subjective experience.

To support my qualitative inclinations, I showed my projects to a handful of peers and academic superiors to gauge their responses. This was work that I did informally, with no experimental controls or measures. Also since it was cumbersome to transport an HTC Vive to potential users I re-deployed the VR application as a first-person laptop videogame with keyboard and mouse for controls and asked users to imagine the experience in VR. The unanimous response even from those who did experience the full HTC Vive VR, was that the AR experience was much more interesting and had more potential. Traversing a virtual city even in VR was considered less original than the AR experience. Ultimately I agreed with this sentiment, as other applications like GoogleEarthVR already masterfully present VR fly-through experiences of realistic virtual cities. Even though my VR project also presented visualized open government data, the AR project seemed to elicit a more pleasantly surprised and curious response from people.

When comparing these media in terms of inspiring citizens to engage with open government data the AR prototype had some important advantages. The first major advantage is that while most people have smartphones that can deploy AR applications, most do not have modern consumer level VR hardware like the HTC Vive. Second, a major advantage of AR is that it is more compatible with social activity, where multiple people can observe digital content through the same smartphone and discuss what they find. Indeed, when I showed my AR prototype to peers multiple users would crowd around to share the experience, and some users even began to share their thoughts on house prices in the city. VR in contrast appeared to be an isolated experience, and seemed to lack this kind of immediate social dimension. Taking all of the above factors into consideration, it was clear to me that for the purpose of creating a public and accessible artifact that would encourage citizens to engage with open government data, augmented reality showed the most potential. I therefore chose to direct my creative efforts to realizing a more developed AR project.

3.2.7 Iterating towards the final AR artifact

Having decided to focus on developing an AR application that would engage users with city public data I had to use the insights gained from my previous prototyping efforts and ideate a final AR artifact to work towards. From my original three AR mockups, I found the GIS buildings and house price data visualization to be the most effective due to the clear and meaningful relationships between the target images and their associated digital content. Furthermore, I thought it was interesting that the buildings represented information at the local level, while the house price data visualization concerned the whole city. If I could integrate these two levels of city data into one curated AR application, it would be a unique and compelling experience.

Next I had to decide on what form the AR experience presented to users would take. I was originally considering creating an interactive AR book with Toronto as its theme with image targets on pages similar to the targets of my original prototype. This could have been a successful option, but it did not seem original or experimental enough. To gain inspiration I reflected on my city data assets and found I admired the aesthetic quality of map-based depictions of the city in its entirety. The map of Toronto itself, quantized into simple GIS readable points, lines, and polygons really stood out as an eye-catching and sentimental form. Such a complex form however would be too detailed for the small size of a typical book, but would be perfect as a large poster print. Using this kind of large scale I could create image targets both on the local city level as well as the citywide level. The entire city image could function as the citywide target image, and then singled-out regions of the map could serve as local image targets. I thus proceeded to create the central AR prototype of this thesis through the iterative process described below.

Iteration 1: To create a large-scale print of the GIS Toronto map I used QGIS to layer the three shapefiles for buildings, street centerlines, and city parks. To get a sharp looking print I exported the image as a PDF vector file. I wanted the print to be large so that the local visual forms would be distinct enough that Vuforia's AR image recognition algorithm would function properly. I also wanted the print large enough that it was physically impressive but a manageable size to move around. I thus printed the image at approximately 7 x 3 feet (figure 14).

To create the image targets at the citywide level I exported the whole map from QGIS as JPEG. For the local level I used QGIS to crop sections of the map delineated by neighbourhood. exported the cropped neighbourhoods, extruded them in CityEngine, and put all of these assets into Unity to build the application.

The first prototype was very simplistic and recognized both the citywide and local levels. A user could see a data visualization 3D model of house prices for the whole city if they got the whole map into camera view, and they could see different neighbourhoods pop up in 3D if they came close enough for Vuforia to recognize the neighbourhood image targets.

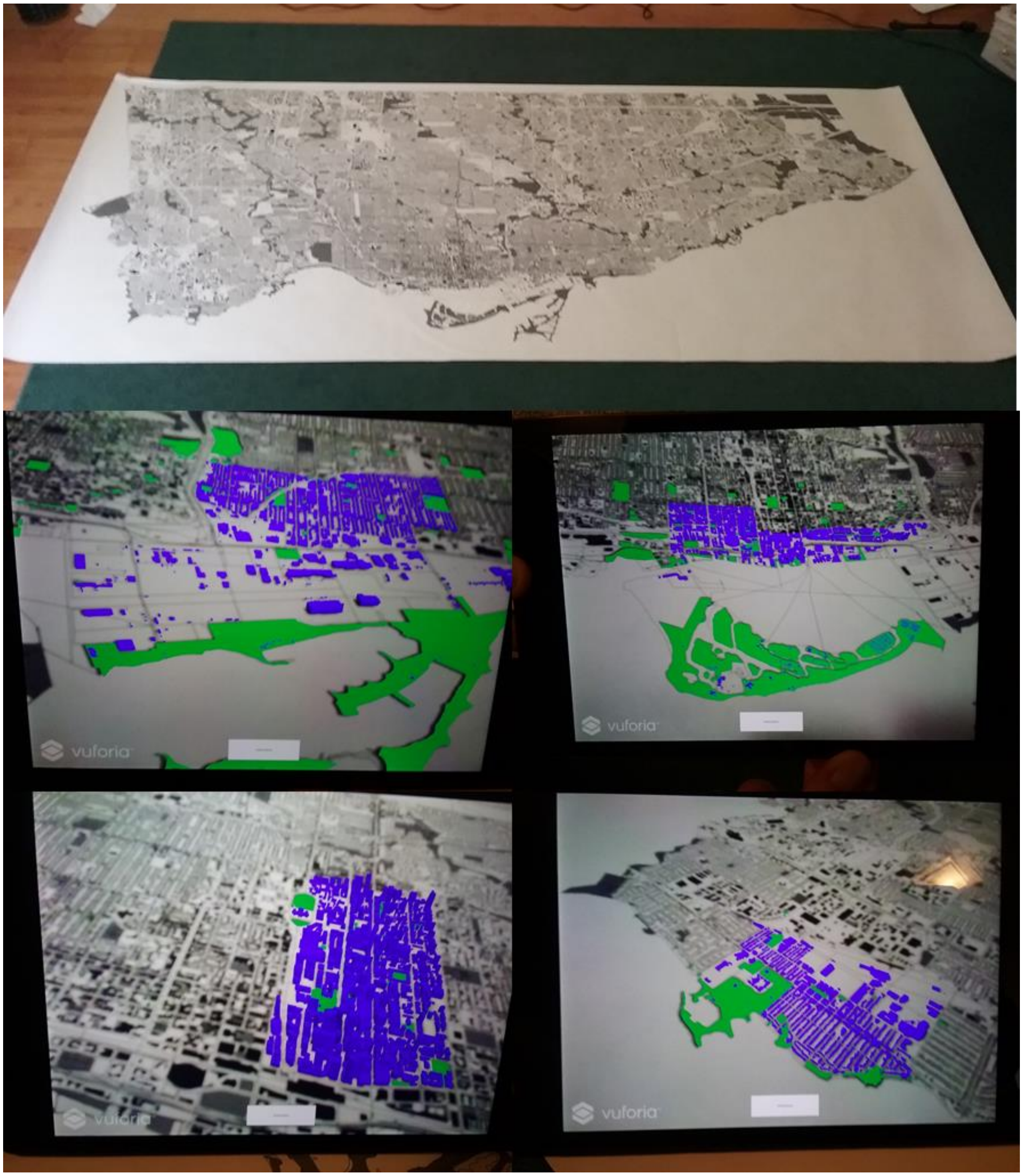

Figure 14: Printed Toronto AR map, approximately 7 x 3 feet (top). Various AR content activated visualizing 3D neighbourhoods of city (bottom).

Iteration 2: For this iteration, I added user interface elements to the map using Unity's canvas feature, as well as the ability to switch between different citywide data models using onscreen buttons. Along with the average house prices model, users could choose to look at degree of employment by neighbourhood, or bare outlines of the neighbourhood boundaries. I also added a menu button, which pops up instructions on how to use the application. I also added 3D data axes for each citywide dataset so users could estimate what the height of each data visualization (values represented as extruded height) represented in absolute numeric terms. Finally, a distance scale representing 10 kilometers was added as well (figure 15).

Figure 15: AR activated content at citywide level. Average house prices by neighbourhood (top-left). Estimated employment by neighbourhood (top-right). Neighbourhood borders with names (bottom-left). Data scale and kilometer scale (bottom-right). Note the buttons on the left and right of the screen switch between data visualizations, and the bottom-middle button pops up a simple instructional panel.

Iteration 3: For this iteration, I focused on unifying the AR experience between the local and citywide levels. Up until this point, users could either look at the citywide level to see the data visualizations, or the local level to investigate 3D renders of individual neighbourhoods, but these data levels remained disconnected and left the AR experience appearing incomplete. Furthermore, while the data axis was useful for estimating data values, it was impossible to determine actual values. To solve both of these problems I implemented a two-stage process that allowed users to move from a citywide data set of their choice, to the local level and see the corresponding data values represented as explicit numbers spatially adjacent to the 3D neighbourhood. Choosing different data visualizations would change the corresponding neighbourhood values. With this two-stage AR mechanic implemented I felt that my project was finally becoming a cohesive and engaging experience that creatively utilized some of the unique properties that are possible with AR (figure 16).

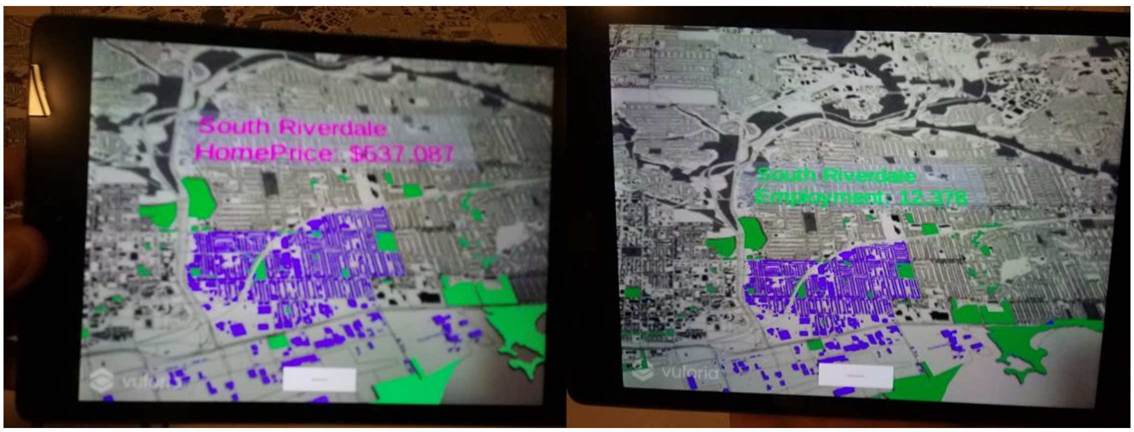

Figure 16: Text-based data activated by first activating the citywide data level, and then investigating specific neighbourhoods. Data presented depends on if last citywide dataset activated was house prices (left) or employment (right).

Chapter 4: Use Test Study

4.1 Introduction and Purpose

After developing the Toronto Augmented Reality Map final prototype as described in the previous section, it was time to evaluate the effectiveness and viability of the design by observing users interacting with the work in a structured environment. During the various phases of prototype development, there were many informal instances of presenting my work to colleagues and friends where I received their feedback, but these occurrences were random and had no consistent testing protocol. Here I present a use test study of my final AR prototype iteration that employed consistent testing methods in order to ensure observations of user interactions and responses were valid. The purpose of this use test study was to answer the following questions: (1) Are users able to use the prototype as it is intended? (2) How do users intuitively interact with the system? (3) What improvements can be made to the prototype based on user feedback? (4) Can the prototype be effective with multiple users interacting with it simultaneously? (5) What are users' attitudes towards new media technologies and the possibility of public installations based on open data?

4.2 Use Test Design and Methods

Since I wanted to gather observations of users' ability to interact with the prototype, as well as gain insights regarding their attitudes towards concepts surrounding my thesis project, I tested users with both the methods of explorative usability testing and structured written interview. The detailed instructions given to subjects for this usability test and structured interview can be found in the Appendix of this thesis document.

The study consisted of observing users interact with the prototype through a series of structured steps. Users were guided through the ordered set of interactions as the study was meant to evaluate how well users could interact with the different functionalities of the prototype. For this usability test, pairs of users were tested simultaneously and given identical instructions, in order to evaluate the effectiveness of the prototype when multiple users engage with it simultaneously. After being given a brief demo on how the prototype works, pairs of users were expected to complete the following set of interactions: Investigate each of the 3 citywide level data sets, investigate the map at the neighbourhood level to view 3D buildings, use the two-step process to identify the neighbourhood with the highest employment rate, and to find the specific data value for that region. Pairs of users were given one tablet with the TOAR application to share as they completed the tasks.

After the pair of users completed the usability test, they were given a written structured interview to complete. This was meant to probe users on their qualitative experience of the device, as well as get a sense of what potential they think this project has as a tool in general. The interview questions included how they would rank the usability of the system from a scale of 1-5, what improvements could be made, whether the system is good for multi-user interactions, what is the future potential of AR, and how could this tool be made available to the public? For both the usability test and the structured written interview, users were given as much time as they needed to complete the tasks. Three pairs of users conducted the study, resulting in six sets of responses as structured interview.

4.3 Results and Discussion

Explorative Usability Test

All users were able to complete the various functionalities of the explorative usability study, but nonetheless their interactions revealed insights regarding technical and design issues that could be resolved and implemented. In terms of technical issues, the major problems were citywide image target recognition and camera-focus. The citywide image target can be made more augmentable by changing grey-scale tones on the printed map into a pure black and a white representation. Unreliable camera-focus however is a technical issue related to the interactions between the Vuforia plugin library and the specific drivers of different mobile devices. The device I tested on was very fast at rendering 3D content, but could not allow for in-app camera re-focus. This may warrant testing on different specific mobile devices to isolate this issue.

In terms of design issues, probably the most salient observation was that almost all users intuitively attempted to pinch the screen in order to zoom the camera on digital content. Since this is an application designed for mobile device, specific interactions afforded by the platform should be reviewed and potentially implemented if they would enhance the interactive experience for users. Users also complained that discovering neighbourhood image targets was difficult as they had to move the mobile device around randomly to find 3D neighbourhoods. This can potentially be solved either by adding visual cues to the application, or even to the poster itself. Other users had an issue with how text-values regarding neighbourhood specific data were presented as free-floating numbers. They felt it was hard to determine which text referred to which neighbourhood. This could potentially be solved by showing text values not as floating 3D text within the scene, but rather as presented as part of the user-interface using Unity's UI Canvas function.

Finally, the multi-user aspect of the usability test proved to be fruitful, as users interacted not only with the prototype itself but also with each other. The prototype seemed to effectively elicit social interaction between users with the prototype as conversation piece. Users discussed both the employment and house price data with each other as they discovered it. This was particularly true with users who were native to Toronto. Some users freely walked around the device together and treated the experience as one to be shared. This would have shown very different results if VR was used, and this highlighted the usefulness of AR as a multi-user platform.

Written Structured Interview

Overall the written responses were positive and offered useful feedback. The six users rated the usability of the prototype as 3.6 on average (5 being the most usable), where the biggest issues were related to image-target recognition and the need for physical movement to observe data. In terms of suggested improvements, users stated that more mobile device functionality would be appreciated, including camera-zoom and the ability to tap on data objects to get further detail. Some users also felt that viewing the entire map at once was difficult to maintain, suggesting that a smaller physical map may be preferable. All users reported the concept was very interesting and felt a strong level of engagement with the prototype. Other users were very intrigued with the fact that they could walk around the entire digitally enhanced landscape.

All users except one felt that the device is very effective as a multi-user interface, and is able to facilitate discussions with others in the immediate vicinity regarding city metrics. In terms of making this prototype into a publically available project, users suggested to create a website, downloadable app, installation in public venues, or sell a high-fidelity version of the map as an augmentable poster. Most of the subjects replied that they do not use AR very much at all other than as cute entertainment applications, and for that reason they were very impressed that the TOAR application is a promising attempt to create a valuable and practical use for the platform.

Chapter 5: Discussion

5.1 Reflections on using AR and VR to enhance citizen engagement with open government data

Through user-tests and the process of creating the AR and VR prototypes for this thesis, insights were gained regarding how these platforms might be used to engage citizens with urban open government data. The most revealing insights were that AR excels in the social context of multiple user experiences, that users found AR to be an engaging and attractive experience, and that AR shows more potential for near-future mass-adoption.

The Toronto augmented reality map demonstrates that multiple users can interact with this medium simultaneously in a common physical setting. Because the content of the project is entirely composed of urban open government data, social communication regarding current issues of the city is made possible. While this data is publically available through Toronto's open data web portal, where some conventional visualizations already curated for use can be accessed on mobile devices via web browser, the Toronto AR map installation enhances social multi-user engagement because the content being investigated appears to exist in the users' common immediate physical space. The AR experience gives users the sense that they are investigating the same real-world interpretable object that they view from their own physical and individual perspectives. I claim here that multiple users encountering the same physical installation is a much more engaging and social experience as compared to looking at conventional charts, graphs, and tables presented through web browser. This is partly because experiences on the web are abstracted and disembodied compared to the spatiotemporal experience users can share in the real-world using AR.

When compared to VR, AR appears to be more attractive to general users and shows more potential for reaching a wider audience. Based on my informal use testing experiences with VR, users did not appear to see a tremendous amount of extra value in experiencing city data with this platform. The VR experience is currently viewed as socially isolating, the head mounted display can be heavy and impractical, the technology expensive, and the immersive experience can be disorienting. Some of these issues could be mitigated using smartphone-based VR experiences such as the one described in section 2.5.3, but the immersion and user interactions here are limited and thus may not warrant a dedicated application specifically for experiencing Toronto open data. There may still be uses for VR in the smart city context given the proper design and purpose, but the above issues are drawbacks that should be addressed when considering mass-adoption by the public.

In contrast, AR is socially enhancing, lightweight, technologically ubiquitous, not physically discomforting, and the technology itself offers many possibilities for user interaction. Because smartphone and tablet use is already widespread one can gain access to this application simply by downloading it onto one’s mobile device and being in proximity to the TOAR map image target. Physical proximity to image targets is an important issue with image-recognition based AR being used to communicate public information however, as unlike other media platforms the experience requires a physical installation to interact with that may not be readily available.

5.2 Ideas for making available the Toronto augmented reality map to the public

If one wishes to produce an image-recognition-based AR application for use by the general public, an important issue that needs to be addressed is the availability of the physical image targets to audiences, and how they are presented. In the case of the Toronto augmented reality map, the size of the designed physical target image needs to be taken into account when proposing market-contact solutions. Below I propose a handful of potential solutions to this problem by offering the physical component of the AR application to the target audience using both public and private strategies. The corresponding digital application would be made available through the web.

The first option would be to make the TOAR map available to the general citizenry as a public installation. In terms of creating a democratic tool that could be used by the general public, this would be the most immediate and conceptually consistent solution. The physical map, interesting in and of itself as a visual form, could be made into an installation as an interactive tabletop, or even as a wall-mounted high-quality poster. A tabletop installation would be preferable, as the 3D digital buildings that appear would be spatially congruent with the horizon. The advantage to producing this as a poster however, is that there would be less restrictions due to physical space. Toronto has many public spaces such as libraries, government offices with open space, subway stations, community centres, etc. Another possibility, would be to take an already existing

Toronto map, such as the tangible 3D Waterfront model in City Hall, or common subway maps (similar to the AR project presented in section 2.5.3) and augment it.

As part of the Digital Futures graduate student exhibition, I had the opportunity to present the TOAR map in such a public venue. To present the printed map and application in a usable and aesthetically pleasing way, I placed the map horizontally on a custom-built plinth (dimensions of approximately 0.5 high x 7 x 3 ft) with custom frame similar to the idea of a tabletop design (see figure 17). The exhibition setup was intended for people of any height to comfortably walk up to the artifact, observe the naked map, and then use the AR application in such a way that they could walk around the map and digital content and explore the medium's physical and spatial aspect. The exhibition presentation was quite successful, and the TOAR map drew the curiosity, inquisitiveness, and amazement of many faculty and casual patrons.

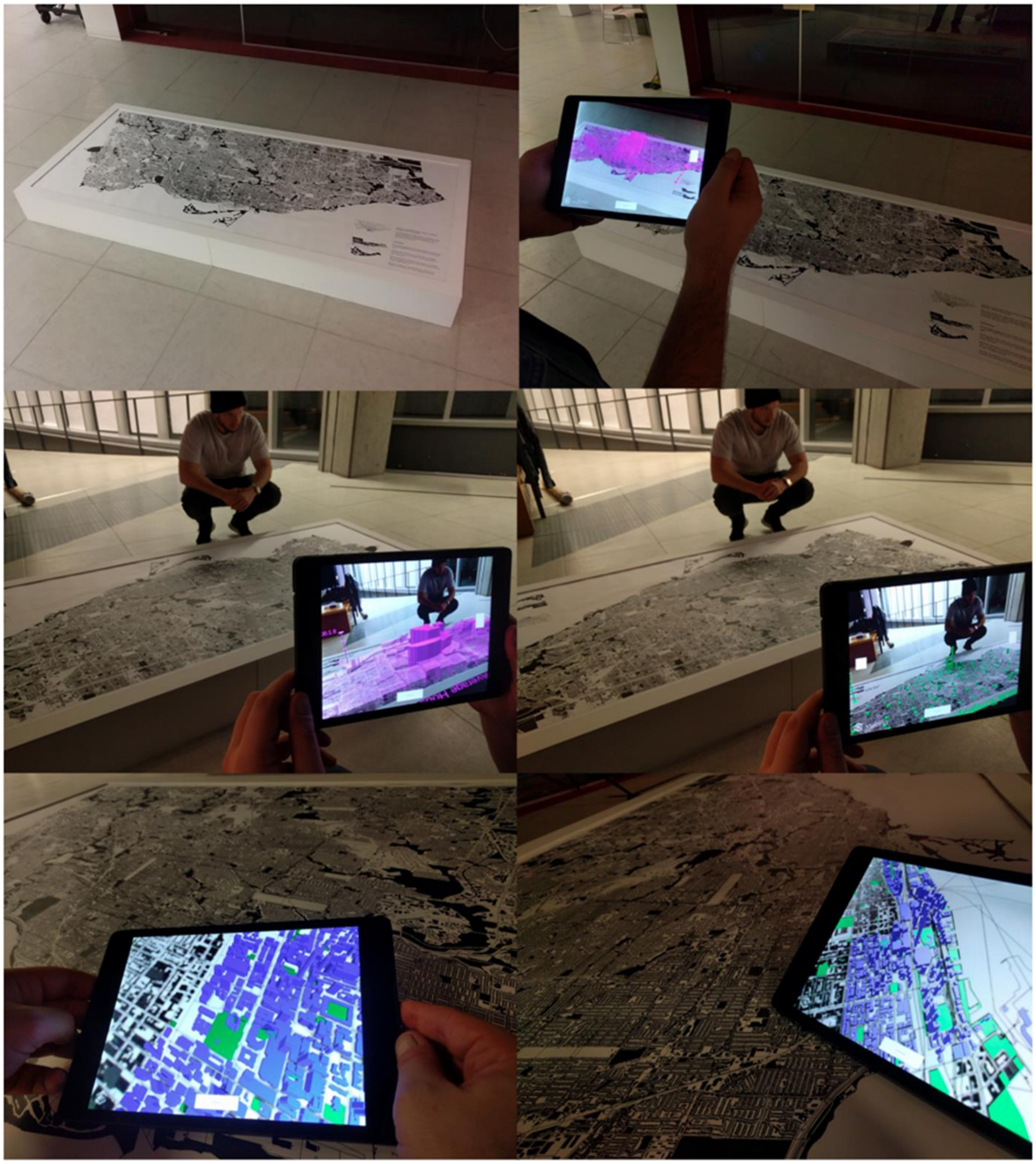

Figure 17: TOAR map presented on custom-built plinth at the Digital Futures graduate student exhibition.

The advantage of presenting this work as a public installation is that it could function as a community artifact that stimulates discussion among citizens on issues supported by public data. This work could also serve as an intriguing public work to tourists. As far as my current knowledge goes, there are no government supported public AR installations to serve the purpose of presenting open government data. Such a public artifact however has the potential to communicate in an attractive way Toronto's present values as a technologically forward smart city that promotes social and entrepreneurial progress. Figure 18 shows some possibilities for how an AR application like the Toronto AR map could be placed in city of Toronto venues.

The second strategy of public dissemination would be to independently offer the Toronto AR map to the public as a privately sold product. This could take the form of either a simple product that could be produced and sold en-masse, or a special boutique item, or both. To reach a wide audience, the simplest and most affordable form would be as a well-printed poster to be hung on a wall. I believe the possibility for reaching an acceptably large audience would come from Torontonians wanting to express pride in their city, which would be enhanced by the fact that the AR application would make for a unique and interesting conversational piece. As a boutique item, this map could made into a tabletop image. To manage the factors of physical size, and image size requirements for image target recognition, a specific region of interest (e.g., Waterfront) could be focused on rather than the entire city as it is now. This could serve as a remarkable coffee table piece. Another option would be to rework the entire project into the format of an AR booklet.

What makes the private distribution option attractive, is that if this could work as a successful business opportunity in Toronto, this model could be fairly easily reproduced for cities around the world, as many smart cities and open data movements already exist. This option is also philosophically congruent with the aims of smart cities as presented in the literature review of this thesis paper, as entrepreneurial pursuits based on open government data not only already exist, but are actively promoted by the mandate of the smart city and open data movements.

Figure 18: Public venues where AR installation could be placed. Toronto Reference Library as a wall-mounted poster (top). Toronto City Hall as a tabletop installation (bottom-left). Already existing tangible Toronto map in City Hall that could be augmented (bottom-right).

5.3 Potential improvements to Toronto augmented reality map and future work

Based on user feedback from usability testing, informal discussion, exhibition presentation, as well as discoveries made during the process of developing the Toronto AR map prototype, the following possibilities for improvements and future work are proposed. The simplest improvements that could be made are cosmetic such as improved user-interface elements such as color themes, custom UI buttons, panels, screen, etc. Changes to the user-experience would include further interactivity such as a camera zoom feature. On a number of occasions, it was observed that users they instinctively tried to manipulate the screen with two fingers in order to zoom the camera view closer to the digital content. Animations would also likely improve the user experience. By animations here I imply both animated content such as the ability to see a transit bus model drive through the city, and also cosmetic improvements such as data sets growing out of the map rather than appearing suddenly.

The application could be further improved by adding more data content and a wider scope of data interactions such as tapping on certain regions of the city to sift through various data. The most significant improvement would be to integrate the application with IoT functionality. If live-feed information, such as transit updates weather, and other monitored city variables could be visualized in the AR application live, this would add another dimension to how engaging and useful the application could be. If the application were to truly be deployed, cloud integration would play a big role in making the program light-weight enough to be downloaded, as well as add the opportunity for consistent updates in visualized data and city information. Finally, connecting the TOAR map to the cloud could create the opportunity for user-generated content, where citizens could potentially upload their own visualizations to share with the public, leave text-based comments and other communicative media, where they could help focus public attention to specific concerns. The TOAR map could in this sense remain as a living fixture within the city, where citizens can offer their views on issues as they arise, and organize around them by having a physical yet digital common place of public discourse.

5.4 Final Conclusions

To conclude this thesis, the initial research questions from section 1.2 will be revisited and responded to with the core findings of this project. In response to the first question, open government data can be presented through AR and VR as interactive map-based representations overlaid with information visualizations, but AR proved to offer special properties and affordances that are more viable in the context of enhancing citizen engagement in a democratic smart city. AR proved to be more accessible for mass-adoption and more effective for multi-user interactions, which lends itself to democratic collaboration. The city of Toronto, which is currently undergoing rapid development as a smart city, can benefit from open government data AR applications by acting as a publically available democratic aid, a potential platform and context for economic growth, and as part of a larger context in developing Toronto's reputation as a rapidly evolving technologically and socially progressive city. AR applications that communicate open government data to the public have the potential to aid the democratic process by offering citizens the information they need, in an accessible and social context, to create and justify concerns related to public life. Such a public AR application and installation could have the implicit effect of raising awareness to citizens that they can in fact participate in the democratic process, and that their city is an ever-changing and evolving environment of which they are an integral part.

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Appendix A: Exploratory Usability Test

Usability Test – Toronto Augmented Reality Map

Testing Summary and Confidentiality Agreement

In this usability test, pairs of users are given the opportunity to use the TO AR Map in order to perform its basic functions as instructed. After the testing session, each user will be given a brief set of questions to gather qualitative information relating to their user experiences.
There are no predicted negative effects to users from performing this study. All recorded user and testing information is strictly confidential. Users can choose to leave the study session at any time for any reason.

Date: ___________________

Participant 1 Name: __________________ P1 Signature: ______________________

Participant 2 Name: __________________ P2 Signature: ______________________

Prototype Instructions

The Toronto Augmented Reality (AR) Map gives users the opportunity to explore Toronto Open Government Data at both the citywide and neighbourhood levels.
With a mobile device camera, users can activate AR content by putting either the entire map, or individual neighbourhoods into the camera view. When image targets are recognized AR content will appear.

- Users can cycle through 3 different citywide datasets.
- Users can activate 3D building models by getting up close to the map and focusing on building footprints grouped as Toronto neighbourhoods.
- 2-Step Process: By first activating one of the 3 citywide datasets, users can then activate a neighbourhood to see its name and specific data-value from the last citywide dataset activated.

Usability Test Instructions

Two users will be tested simultaneously, each given their own tablet to perform the test independently. Users can freely interact with each other throughout this usability test.

1) Investigate each of the 3 citywide level datasets.

2) Investigate the map at the neighbourhood level to view 3D buildings.

3) Use the two-step process to identify the neighbourhood with the highest employment rate (waterfront), and to find the specific data value for that region.

Appendix B: Written Structure Interview

Post-Test Interview Questions

Participant Name: __________________ P Signature: _______________________

Questions

1) On a scale of 1-5, how usable is this system? Why?

2) What improvements could be made to this system?

3) Did you find this to be an engaging or unique way to explore Toronto open data? Why or why not?

4) Do you think this system is useful as a single-user platform, multi-user, or both? Why?

5) How do you think this kind of system could be made available to the public?

6) Do you use any AR platforms, and if not what is your impression of the future of this technology?