Smart Sustainable Singapore: An Innovative Model for Twenty-First Century Urban Growth

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Abstract

Despite their common aims, sustainable development and smart city strategies seldom overlap. This paper argues that city leaders who combine sustainable development and smart city initiatives into one consistent and intentional urban strategy will see more resilient and responsible urban growth. This strategy, referred to as smart sustainable city development, provides a best-practice framework for municipal leaders to incorporate in their own urban environments. The city-state of Singapore, with a reputation for innovative implementation of both concepts, provides a case study for the smart sustainable model. Previous scholarly research, city data, and literature on the policies and partnerships within Singapore illustrates the breadth of affects associated with smart sustainable urban development.

Introduction

A variety of important trends have set the conditions for a new approach to urban life in the twenty-first century. Globalization, for instance, has had the important effect of making partnership and collaboration easier and more accessible. The blooming of rapid communication techniques aids to this knowledge sharing. Globalization also lends a sense of prominence to the emerging global issues of the twenty-first century, including climate change, human displacement, and economic and political relations. As more of the global population resides in urban environments, there is an increasing need for effective urban strategies.

The majority of modern city planning approaches reside within this set of circumstances. Most of these approaches can be categorized under topics such as resilient growth, acknowledging the need to consider both the short-term and the long-term effects of urbanization. Two of the more popular strategies that are emblematic of resilient growth are sustainable development and the pursuit of the smart city. Sustainable development promotes social equity, economic vitality, and ecological health with the understanding that global resources must be maintained for future generations (United Nations 1987; Joss 2015). Meanwhile, smart city initiatives offer an outlet for both the public and private sectors to engage in a form of city-building that takes advantage of the opportunities made available through information and communications technology (ICT) systems (Intelligent Community Forum 2015).

While sustainable development and smart city innovation can be wholly independent urban strategies, they share a number of similarities. Both are movements born largely in the latter half of the twentieth century, with a particular intensification in the last twenty-five years in the context of global development. Urban sustainable development and smart city initiatives target similar aspects of the built environment, particularly buildings, energy, and transportation, and the overarching visions of a ‘sustainable city’ and a ‘smart city’ both include advanced, innovative, and adaptive urban spaces. Despite the similarity of the two concepts, the majority of prominent sustainable development and smart city frameworks do not overlap (Ahvenniemi 2017, 240).

However, there is evidence that indicates that the overlap of such frameworks would yield positive results. Drawing on the example of Singapore, this paper will argue that the synthesis of sustainable development and smart city innovation into one consistent urban strategy provides a best-practice option to municipal leaders for effective twenty-first century urban development. Despite Singapore's status as a city-state, the global metropolis in Southeast Asia provides a strong case study for analyzing the potential points of intersection between 'smart' and 'sustainable.' Singapore has received global recognition, especially in the popular press, for its efforts in the areas of sustainable growth and smart innovation, punctuated by the city-state's proclamations of a Smart Nation and of a City in a Garden. After conducting an extensive literature review on the benefits of the "smart sustainable city" development model and sketching a brief history of smart city initiatives and sustainable development in Singapore, this paper will connect city data, policies and partnerships to conclude that through the utilization of sustainable development and smart city innovation in tandem, Singapore is representative of an innovative approach to resilient city-building as modern globalization continues.

Understanding the Smart City and the Sustainable City

This paper focuses on the concepts of sustainable development and the smart city. However, these terms include a certain imprecision. For instance, how do we know if a city is smart? Concurrently, what makes a city sustainable? In addition, given the broad thematic nature of the two subjects, 'sustainability' and 'smartness' have been attributed to a large number of disciplines (many of which fall beyond the domain of urban affairs) in order to create a buzz. Thus, it is important to establish proper definitions of sustainable development and smart city, as well as the trends that have made each of them relevant today, in order to provide a pathway to clear and concise research. Both smart city initiatives and sustainable development policies are viewed by some as having shortcomings due to the top-down nature of their implementation, the interests of private entities (especially in regards to smart cities) and the reality of such strategies through an equitable lens. Defining these topics will make it easier to understand in which ways they can be the most beneficial.

Sustainable Development

Industrial production cultivated an urban environment for smart city initiatives, yet it also had other long-lasting effects. Western urbanization shaped the spatial distribution of the residential, commercial, and employment sectors. They also promoted the usage of and, in many cases, overuse of natural resources. It was not until the latter part of the twentieth century that the subject of sustainability was recognized on a widespread level, when overconsumption and global equity became more burdensome issues. It is widely believed that the 1987 report of the World Commission on Environment and Development (WCED), facilitated by the United Nations, provides an original comprehensive definition of sustainable development (Ahvenniemi et al. 2016, 235). The text provided by the WCED defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations 1987, 16).

This definition is helpful because it provides an essential understanding of sustainable development that can be applied to countries along the spectrum of development. More specifically, it implies a multifaceted approach to the pursuit of sustainability. For the purpose of this research, this paper will identify social, economic, and environmental factors as the tenets of sustainable development. These trends signify the importance of people, partner, and place; only active participation from all sectors of the economy, with a declared commitment to a vibrant ecological health and a lasting social equity, will result in positive sustainable change.

Although this definition applies to developing and developed countries and urban and rural communities, sustainable development does look different in cities. Identifying social, economic and environmental factors as a type of 'triple bottom line,' Simon Joss details the variety of fields in which urban sustainability is manifested. They include, but certainly are not limited to, transport, waste, and biodiversity (environmental sustainability); competitiveness, resilience, and employability (economic sustainability); and equity, civic engagement, and cultural diversity (social sustainability) (Joss 2015, 830). The differences in density between urban and rural communities and the fact that urban spaces host the global hubs of living, culture and commerce render urban sustainable development to be more complex than general sustainability.

Figure A: Urban Sustainability Challenges (Marsal-Llacuna and Segal 2017, 87)

SO 1. URBAN CONFICLTS: Cities are potential sites of conflict between various groups and individuals with differing interests. Effective mediation from city councils between confronted parties is required so do that conflicts can be avoided.	**EC 1. GROWING URBAN POVERTRY AND UNEMPLOYMENT RATES:** One of the most pressing issues for today's urban areas is that of urban poverty and the economic divide. Social housing, employment and energy poverty strategies are two potential areas where regulations and policies have to be designed.	**EN 1. ENERGY CRISIS:** Current energy sources still rely on finite resources. Today's energy production and consumption need to be reformulated. Renewable, non-carbon generating sources are resources to leverage in. Current energy consumption pace together with the growth of population in developing countries, if not changed, will finish some of the available resources in less than forty-years.
SO 2. UNREPRESENTED CITIZEN: Smart cities, by definition, are citizen-centric. Therefore, one of the fundamentals of smart cities is citizen inclusiveness. The citizen must not only to participate but have an active role so that public consultations are not anymore validation processes but real participatory actions.	**EC 2. URBAN CRIME:** Urban crime has different degrees, from small robberies to bigger issues that can affect people's life, integrity and dignity. These problems can not be only fought with surveillance cameras and noise sensors but active educational programs and opportunities for everyone are the most powerful tool, more than any technology.	**EN 2. MOBILITY:** A more efficient and less privative mobility can be achieved with urban technologies. Public transport can be highly improved with real-time information and the increase of multi-modal connectivity. Private transport is highly inefficient, in terms of economic and temporal costs, besides all negative environmental effects which have also been demonstrated as a health threat to citizens.
SO 3. ISOLATIVE ARCHITECTURE: Smart architecture is not pretentious, just as inclusive as smart cities should be. Smart architecture is not only about technologies to make it efficient. Architectural design must be conceived as a dynamic, changing and short-lived shelter adjustable to any function. Smart architecture it is not something stuck that never disappears but that it is mobile and has infinite adaption capacities.	**EC 3. CITY MANAGEMENT:** Cities are highly complex unpredictable animals. Current city management practices go after city needs, without anticipating its behaviour. Smart city management is about strategy and vision, hence, it includes prediction functionalities, for both management of urban daily routines and for exceptional events. Data sharing also contributes into a more responsible urban living as it helps individuals to manage their daily complexity thanks to the consideration of other's choices beyond their personal priorities.	**EN 3. URBAN POLLUTION:** conventional urban lifestyle has a detrimental impact on the environment that includes the production of various urban pollutants and non-recyclable waste. New materials reusing waste need to be formulated and a more local and self-sufficent lifestyle needs to be introduced.
SO 4. INNACCESSIBLE ENVIRONMENTS: Smart cities must be accessible, not only from technology, also from architecture. In an accessible smart city everybody counts, from elderly to disabled through kids. And these disadvantageous groups count even more since they are more sensitive to barriers. Smart cities do not have barriers, not physical nor technological.	**EC 4. LACK OF RESILIENCE:** This includes disaster control, corruption detection, security and safety threats, cyber crime, and war prevention. All these urban-related issues are of extreme complexity and therefore difficult to predict. However artificial intelligence technologies, pattern recognition, and modelling and simulation have a key role as tools to increase urban resilience.	**EN 4. SCARCE GREEN SPACES:** Green spaces are efficient tools to fight urban pollution. Additionally, green spaces fight the psychological 'pollution' of urbanites. It has been demonstrated the enormous beneficial psychological effect of green areas. Experts say that citizens need to enjoy (or at least see) one small green space every day. Once a week, a bigger, wilder and uncontrolled green space, this is for the shake of a complete healing.

Fig. 1. List of main SOcial (SO), EConomic (EC), and ENvironmental (EN) challenges cities are facing today.

Furthermore, cities face issues related to sustainable development that are unique to urban spaces. Cities are responsible for approximately 70 percent of the global carbon dioxide emissions that have been attributed to human-induced climate change (Tan et al. 2016, 1920). In addition, the United Nations estimates that the world will see the global population increase by 2.5 billion people between the years 2014 and 2050 (United Nations 2014, 2). Figure A, compiled by Marsal-Llacuna and Segal, describe the issues concerning sustainability that cities are facing today (Marsal-Llacuna and Segal 2017, 87).

Smart Cities

Urban planning has always considered the relationships between industry and urban space. Ebenezer Howard's Garden City model and the stylings of the Italian futurists and the German Bauhaus movement in the early twentieth century were all hyper-aware of the effects of industrialization on rapidly growing urban spaces (Angelidou 2015, 96). Le Corbusier, a prominent architect and urban planner of the twentieth century, once wrote that a "house is a

machine for living in" (Neirotti et al. 2014, 26). These perspectives not only transcend their original era of mass production, but reflect the themes of innovation and partnership between people and technology—tenets core to the smart city ideology.

The smart city conception that we see today was made possible with the transition to a knowledge-based economy, especially over the last fifty years. Ideas of a creative class that connect the dots between economic development and technological sectors (Florida 2004) and the importance of human capital and internal production skills to the economy (Weiss 2015) have accelerated this idea. With urban areas becoming increasingly populated with members of these industries, many cities have become massive laboratories for developing technologies.

The term 'smart city' itself was first used to describe these emerging trends in 1993, in a book written by David Gibson, George Kozmetsky and Raymond Smilar entitled *The Technopolis Phenomenon* (Marsal-Llacuna et al. 2015, 612). Two years earlier, Mark Weiser of the Xerox Research Center in Palo Alto, California said that the "most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991, 94). Smart cities, in essence, aim to weave technology into city living and city planning via the implementation of ICT-based solutions. Whether it is an advanced telecommunications system, real-time information sensing, or cloud-based and other forms of big data collection, cities that are considered to be smart take advantage of modern ICT systems.

However, smart cities are not composed solely of ICT initiatives. Human capital, innovation and creative entrepreneurship and collaboration have been monumental in designing modern ways to address urban problems. In line with the knowledge-based economy, smart city solutions have been made possible not only by city governments, buy also ICT companies in the private sector. A simple Internet search of smart city initiatives conducted by IBM, McKinsey and Company, and Oracle yield a variety of technology-based solutions offered by private stakeholders, in collaboration with both municipal and national authorities. The following smart city definition combines these sentiments into a concise definition:

> "the Smart Cities initiative tries to improve urban performance by using data, information and information technologies (IT) to provide more efficient services to citizens, to

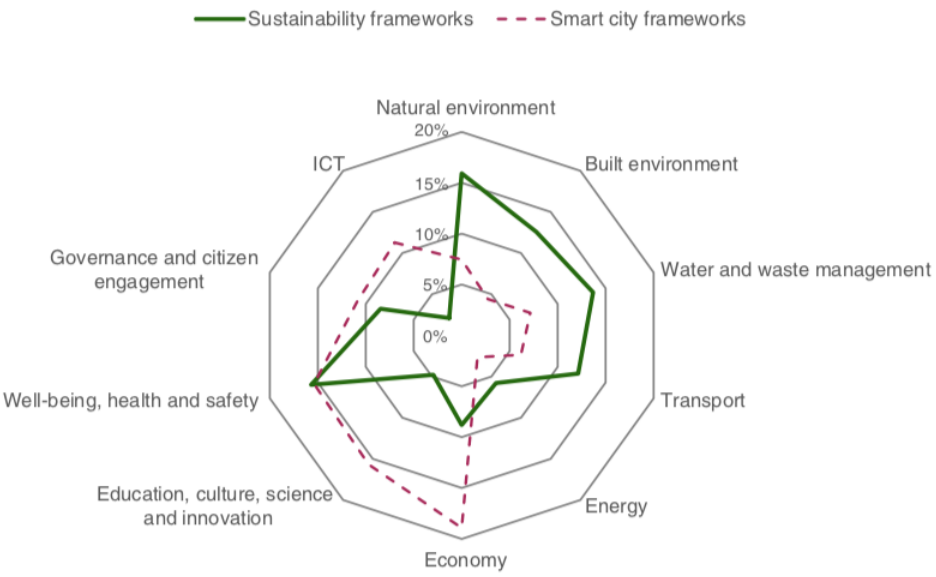
> monitor and optimize existing infrastructure, to increase collaboration amongst economic actors and to encourage innovative business models in both the private and public sectors." (Marsal-Llacuna et al. 2015, 618)

The Intelligent Community Forum has identified a variety of indicators that are valued as critical to the success of smart city projects. They include fast and powerful broadband services, a knowledgeable and specialized workforce, an interconnected and innovative economy, digital equality and equity, and advocacy (Intelligent Community Forum 2015). A combination of all of these attributes arm city government officials with the resources, partnerships, and inspiration necessary to implement proper smart city initiatives. It is worth noting that in 2015, the ICF introduced a sixth smart city indicator: environmental sustainability, implying that there are a number of frontiers that smart city applications may approach to address the ecological features of cities.

Smart sustainable city: a best-practice urban framework

While the smart city and sustainable development models share very similar goals and operate in common sectors, the two movements have not historically overlapped. Thus far, there have been very few practical applications of smart city technologies to address natural environment concerns, with the few exceptions being water supply and waste management (Yigitcanlar 2015, 32). Hannele Ahvenniemi analyzed smart city frameworks and rankings and sustainable development assessment frameworks to discern the similarities and differences between the two. Among the indicator frameworks measured include the European Smart Cities Ranking, City Protocol, LEED for Neighborhood Development and UN Habitat Indicators (Ahvenniemi et al. 2017, 237). The authors find that generally speaking, smart city indicator systems place a much higher emphasis on ICT and economic development than sustainable development systems. Furthermore, smart city indicators do not place as much value on environmental sustainability, which is a focal point of sustainable development frameworks. Figure B illustrates which sector categories are prioritized by smart city and sustainable development frameworks, showing a lack of overlap in the areas of ICT and environmental sustainability (Ahvenniemi et al. 2017, 242).

Figure B: Smart City and Sustainable Development Frameworks (Ahvenniemi et al. 2017, 242)



Division of the indicators of both smart city urban sustainability frameworks under the ten sector categories.

However, this is not to say that smart city and sustainable development frameworks *should not* overlap. Kramers et al. elaborate on this idea:

> "Despite the lack of a connection between smart and sustainable cities, it is clear that ICT has great potential for supporting the transition to more sustainable cities, both as regards the management of urban systems and offering more support for sustainable urban lifestyles" (Kramers et al. 2015, 53).

The authors further argue that "as a way of emphasizing initiatives when smartness is (also) used to promote environmental sustainability, it is proposed that the concept of 'smart sustainable city' is used" (60). The European Union has also adopted the smart sustainable city terminology as a mechanism of taking advantage of ICT solutions to reduce a city's carbon footprint (European Commission 2011).

This paper will adopt the term 'smart sustainable city' and define smart sustainable city development as an urban development framework that uses the human capital and ICT resources associated with the smart city to simultaneously address the goals of smart city and sustainable development initiatives with focus and intention. As will be described further, smart sustainable city development offers a best-practice framework for municipal leaders looking to leverage an innovation-based economy to drive responsible urban growth in the modern era.

Neirotti et al. provide a helpful framework for understanding the areas in which smart city initiatives and sustainable development may better overlap. After identifying the need for a prevalence of investment in both 'hard domains' (where ICT plays a proactive role) and 'soft domains' (where the role of ICT is more limited), the authors present a series of domains and sub-domains (described in Figure C) where smart technologies may enhance the effectivity of sustainable solutions (Neirotti et al. 2014, 28). As can be seen, there are areas underneath each domain where ICT applications and sustainable development may intersect. Smart city domains occupy areas of all forms of sustainability: environmental (natural resources and energy, transport and mobility), social (buildings, living), and economic (government, economy and people).

Figure C: Domains and Sub-Domains of Smart City Technologies (Neirotti et al. 2014, 28)

Domain	Sub-Domain
Natural resources and energy	Smart grids, public lighting, green/renewable energies, waste management, water management, food and agriculture
Transport and mobility	City logistics, info-mobility, people mobility
Buildings	Facility management, building services, housing quality
Living	Entertainment, hospitality, pollution control, public safety, healthcare, welfare and social inclusion, culture, public spaces management
Government	E-government, e-democracy, procurement, transparency
Economy and people	Innovation and entrepreneurship, cultural heritage management, digital education, human capital management

Applications of smart sustainable city development

Smart sustainable solutions can be manifested in a multitude of ways. One such example is through innovation procurement. Procurement, as an economic principle, is a demand-side tool used by states to bring various goods, services, and industry sectors into the economy. In a similar fashion to how research and development funding allows cities to become pseudo-urban laboratories for new ideas, procurement facilitates innovation in urban spaces. Procurement for smart city technologies also has a lucrative amount of partnership potential "with companies like Siemens restructuring to create an entire division dedicated to solutions which allow cities to

utilize emerging information technologies to increase efficiency and access to real-time data" (Cohen and Amorós 2014, 800). Multinational ICT companies, consulting firms, and other companies that deal with large swaths of data are investing in smart city technology. Such businesses, which are obviously concerned with upgrading their profit margins and expanding their international footprint, are entering these industries because it makes logical sense: the transition to an information-based economy build upon advanced data and technological systems, coupled with the reality of more of the global population locating to urban environments makes for intensely lucrative markets. Cities placing an emphasis on procuring these businesses, in a manner that enables business development while also providing services that assist the general public, will further weave ICT and human capital into the physical urban space.

Another opportunity for cities to leverage public-private partnerships into smart sustainable development is by setting voluntary standards. On the more localized level, implementing voluntary standards for firms and companies to follow can spur innovation in a municipality. This is an especially useful tool when it comes to industries that are directly related to municipal infrastructure and green solutions, such as LEED certification in the building industry. As Cohen and Amorós write, "we posit that technology firms with environmental solutions should collaborate with municipalities to encourage the introduction of voluntary standards and incentives as a mechanism to cross the chasm and begin to scale the market beyond the municipality" (Cohen and Amorós 2014, 803). Both innovation procurement and voluntary standards help to set the culture of innovation that makes the smart sustainable city concept much easier to implement.

In addition to the benefits of real-time data as expressed by Marsal-Llacuna et al. and the broadband services promoted by the Intelligent Community Forum, there are a large number of applications dependent on information and communications technologies that can be beneficial in promoting a sustainable city. Some of these applications include GIS, ubiquitous sensor networks, telematics, and context awareness computing technologies (Yigitcanlar 2015, 28-9). Not only are these advanced ICT technologies, but they help address what are inherently urban issues, namely, the collection, analysis and synthesis, and visualization of data in urban spaces that are becoming more and more accessible to public and private interests.

One of the most widespread information and communications technologies that provide value to urban space is geographic information systems. GIS is a computer-based set of tools and applications that makes the production and sharing of data-based maps more accessible. By using spatial data (information that is described by point, line, or polygon-based geographical features), GIS allows the user to create thematic content that addresses subjects ranging from population demographics to ecological features of a given area. As is described by the Environmental Systems Research Institute (ESRI), spatial analysis and GIS "is useful for evaluating suitability and capability, estimating and predicting, interpreting and understanding, and much more" (Harden and Brown 2017).

Another innovative form of technology that Yigitcanlar identifies as being leveraged as a smart city initiative is ubiquitous sensor networks. Sensor networks capitalizes on the idea of 'big data' which is often promoted as a fundamental way to pursue the smart city agenda. The idea is that with the vast amount of systems available that makes measuring data easier, city leaders can be more informed than ever before. Sensor networks is one of the common ways in which big data is measured. Per IBM, "smart sensors that are installed throughout the city, in vehicles and buildings, and apps and devices … inform decisions on how public spaces are designed, how to make the best use of resources, and how to deliver public services and utilities more efficiently and effectively" (Gerber 2018).

Geographic information systems and sensor networks share the similarity of being complex technological systems that use information to address what are inherently issues of the built environment. For instance, sensor networks can be used to monitor traffic congestion, waste management, air quality and pollution, and energy management, among others. In comparison, many of the modern GIS platforms that are made available via companies such as ESRI or in the public domain are empowered with a large number of geospatial analytical tools that allows the user to make a more explicit connection between information and space. Such technologies hold a high amount of potential when it comes to promoting sustainable urbanism.

A more tangible example of how technology may fuel a smart sustainable city framework is the City Performance Tool, developed by international conglomerate Siemens. While other indexes and indicator systems that were discussed earlier fail to directly mix smart cities and sustainable development, the City Performance Tool "gives guidance to a city on how to achieve their environmental targets while providing an indication on how each infrastructure-related decision will influence job creation and the infrastructure sector growth" (Siemens 2018). By conducting simulations and analysis of the city's current strategic plans, the Siemens case provides an example of smart city technology touching the economic, social, and ecological aspects of sustainability.

As is the case with most urban development strategies, smart sustainable city development does not come without its own share of challenges. These challenges include the belief held by some that cities are inherently unsustainable, that ecologically sustainable development can perpetuate inequalities, the important of technology in sustainable development, and the issue of conflicting areas of governance. Dwelling on these issues, Simon Joss offers an explanation of the problems that may arise when sustainability and technology intersect:

> "A third challenge arises from the increasingly central role placed on technology to provide solutions for eco-city development. On the surface, this is about the application of an array of green technologies … Such heavy emphasis on technological innovation and solutions runs the risk of conceptualizing the eco-city narrowly as physical infrastructure and an urban technological system." (Joss 2015, 836)

Drawing back on the work of Ahvenniemi et al., this negative effect is more likely to be a side product of an urban development strategy that does not intentionally nor adequately synthesize smart city and sustainable development, given that smart city initiatives have historically placed less of an emphasis on social sustainability. As globalization continues to influence urban inequality, this is an important area to address. More conscientious efforts by public officials to incorporate social equity into smart sustainable planning may alleviate these concerns.

Smart City and Sustainability Efforts in Singapore

Singapore's population has exploded from 1.0 million in 1950 to 5.6 million in 2017 (Rimmer and Dick 2006, 8; Kolczak 2017). There are a few defining characteristics that make Singapore

unique as a Southeast Asian city and as a global city. First, given its status as a city-state and not a nation-state, Singapore does not have multiple layers of governance; in many cases, local initiatives and national policy are different names for the same thing. Over the last sixty years, the government has closely monitored Singapore's development, implementing policies that have allowed Singapore to become the third highest-earning country by GDP per capita in the world (World Bank 2016). This section will sketch the history of sustainable development and smart city developments in Singapore, two initiatives that have earned Singapore praise in the popular press (Vaswani 2017, Kolczak 2017).

Sustainable Singapore

One of the earliest public examples of Singapore promoting sustainable living dates back to the 1960s, when Lee Kuan Yew stated that "a blighted urban jungle of concrete destroys the human spirit" and that "we need the greenery of nature to lift our spirits" (Sustainable Singapore 2015, 9). In 1968, the Singapore government launched a Keep Singapore Clean movement, one of the city's first national campaigns. The campaign, aimed at reducing littering in the city and facilitating educational activities, sought to enhance quality of life, cultivate national pride, and make the city-state attractive to tourists and foreign investment (National Library Board 2012). Other historical projects of note include the clean-up and transformation of the Singapore River in the 1980s and the establishment of the Garden City Action Committee in 1970 to make the city-state greener (Singapore would alter make the key ideological pivot from 'Garden City' to 'City in a Garden') (Sustainable Singapore 2015, 9; National Parks Board 2018). This brief passage from a 1997 yearbook of Singapore published by the Ministry of Information and the Arts moves this vision closer to the twenty-first century:

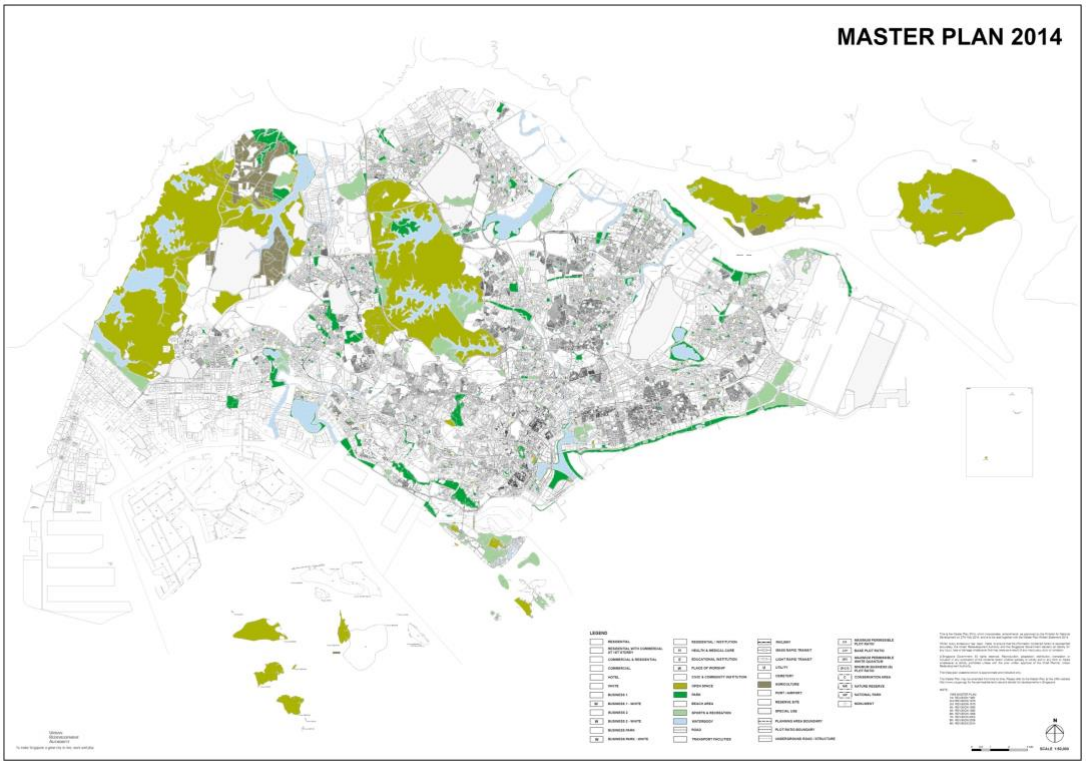
> "Vision of a Green City: The ministry's vision for this decade is to develop Singapore into a model Green City having high standards of public health and a quality environment with clean air, land and water, and a quiet living environment. Singapore will be conducive to gracious living and a regional centre for environmental technology." (Ministry of Information and the Arts 1997, 252).

Singapore's sustainable development mission today is manifested in the city's sustainability blueprint, last updated in 2015. Under the umbrella pursuits of a "livable and endearing home," "a vibrant and sustainable city," and "an active and gracious community," the blueprint lays out

focus areas and targets for socially, economically and environmentally sustainable urban living (Sustainable Singapore 2015, 3). Among the city's sustainable development targets for 2030 include a threefold increase in the amount of skyrise greenery and the length of cycling paths, 80% of buildings to achieve a Green Mark Certification from the Building and Construction Authority, and a 36% decrease in the amount of flood-prone areas (111).

Cultivating biophilic spaces is a particular focus of Singapore's sustainability efforts. In 2005 the city passed the Parks and Trees Act, to "provide for the planting, maintenance and conservation of trees and plants within national parks, nature reserves, tree conservation areas, heritage road green buffers and other specified areas" (Parks and Trees Act 2005, 1). Since the 1980s, the level of green cover in Singapore has increased from 36% to 47%, and it is a goal of the city to have 9 in 10 households be located within a ten-minute walk of a park by 2030 (Senthilingham 2016; Sustainable Singapore 2015, 111). Figure D illustrates Singapore's 2014 Master Plan for urban development, color-manipulated to show Singapore's spaces that have been explicitly dedicated to open spaces, parks, sports and recreation, water bodies, and agriculture (Urban Redevelopment Authority 2014).

Figure D: Color-Adjusted 2014 Singapore Master Plan (Urban Redevelopment Authority 2014)



Smart Nation Singapore

Singapore is recognized as one of the first nations to integrate smart city visions into its urban planning strategy (Marsal-Llacuna et al. 2015, 617). In 1999, Arun Mahizhnan of Singapore's Institute of Policy Studies published an article in *Cities* illustrating how Singapore's social, political, and economic history has leveraged the city-state into a prospective 'Intelligent Island' for twenty-first century perseverance. He describes Singapore's economy of the pre-1960s as a trading economy (with the expected effects of post-colonialism), the economy of the pre-1990s as an industrial economy in line with other nations in the region, and the emerging economy of the 1990s as a new information economy (Mahizhnan 1999, 14).

In addition to facilitating the growth of information technology and telecommunication industries in the city, Singapore took steps to weave IT education and skill-building into the populace. By 2002, in addition to the traditional reading, writing, and arithmetic competencies, Singaporean officials aimed to devote 30 percent of children curriculum to computer-based learning (Mahizhnan 1999, 15). Mahizhnan further describes innovations relating to information technology infrastructure and the bourgeoning information technology economy. He refers to *A Vision of an Intelligent Island: IT2000 Report*, released by Singapore's National Computer Board in 1992 with ambitious aims:

> "In our vision, some 15 years from now, Singapore, the Intelligent Island, will be among the first countries in the world with an advanced nation-wide information infrastructure. It will interconnect computers in virtually every home, office, school, and factory" (National Computer Board 1992).

Indeed, by 2007 Singapore had made considerable strides in advancing information technologies that, in the spirit of Mark Weiser, disappear into the urban fabric. In August of that year, for instance, the city announced a pilot partnership with IBM that analyzed data to make real-time traffic predictions in the city's Central Business District, with prediction results above the target accuracy of 85 percent (IBM 2007). This application had a long-lasting effect of increased ridership and reduced traffic congestion (Yigitcanlar 2015, 28).

Today smart city initiatives have become a cornerstone of Singapore's economic development and its status as a global city. under the flag of 'Smart Nation,' Singapore's recent strategic

projects include national digital identification for citizen-business interactions, e-Payment systems, sensor platforms that considers urban livability, urban mobility systems that enhance public transit, and government services and support (Smart Nation 2018). While some of these initiatives, such as e-Payments, do not need to be confined to urban spaces, many of Singapore's national projects establish an inherent link between smart technology and city living. These smart city initiatives address energy, transport, and public health, topics of concern in a high-density and expanding city. Singapore's efforts that cultivate the 'Smart Nation' reality are bolstered by the availability of open data, digital inclusion, start-up accelerators, and the usage of the city as a living urban laboratory for public and private research and innovation (Smart Nation 2018). The following section will analyze the manifestation of these principles in city policy, public-private partnership, innovation initiatives, and other forms of city strategy to illustrate how the Smart Nation movement in Singapore facilitates the implementation of and advances the priorities of the city's sustainable development mission.

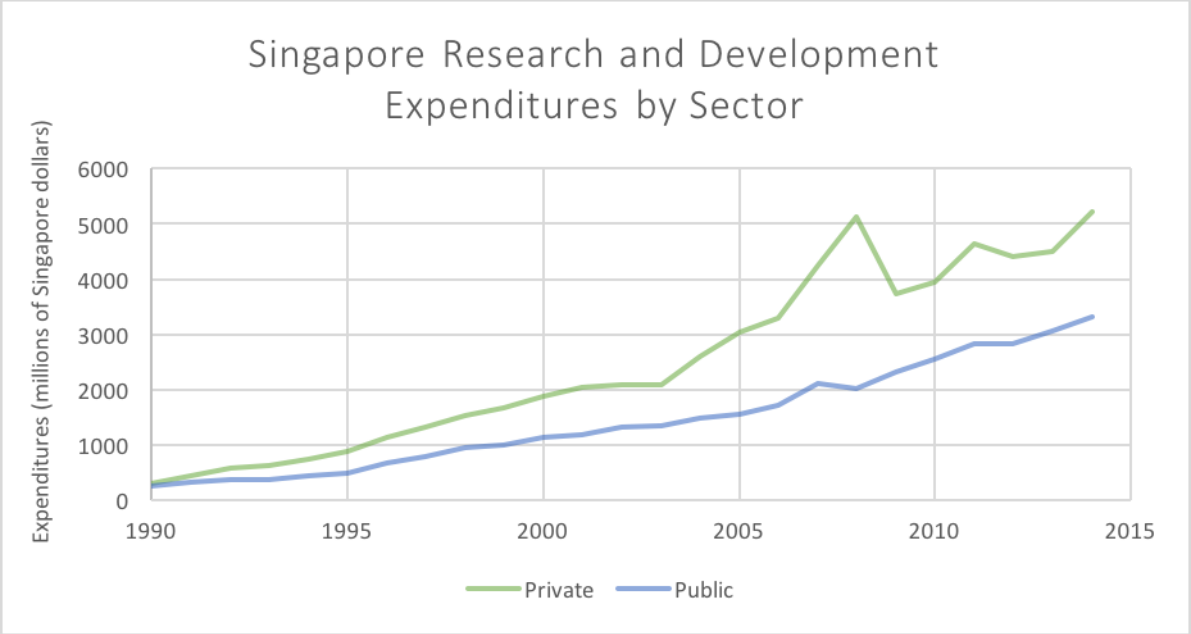
Analysis: Smart Sustainable Singapore

This section will describe the intersection points where smart sustainable development comes together in the Singapore city-state. Overall, Singapore markets their smart city and sustainability efforts as unique and individual entities, illustrated through the distinctive 'Smart Nation' and 'Sustainable Singapore movements described on official government webpages. However, this section will show that the two movements depend on each other in a number of ways, and are connected through the general themes of growth and innovation.

Figure E: Smart City and Sustainability "Movements" in Singapore

As Singapore has continued its transition into one of the world's leading urban information economies, research and development has expanded in both Singapore's' public and private sectors. Figure F details this growth; from 1990 to 2014, public and private expenditures on research and development have grown by a factor of over 12 and 16, respectively (Government of Singapore 2017). This increase in investment in a growing innovation economy has had a major impact on smart sustainable city development in Singapore.

Figure F: Research and Development Expenditures (Government of Singapore 2017)



An example of research and development making an impact on smart sustainable urban development is in Singapore's housing industry. As a result of a 2016 partnership between the National University of Singapore (NUS) and real estate developer City Developments Limited (CDL), the Smart Green Home and Tropical Technologies research laboratories have been established to conduct research on sustainable building technologies that are sensitive to Singapore's tropical climate. Per the CEO of City Development Limited, Grant Kelley, the projects will analyze engineering innovation and architectural design in-depth to "unlock the potential to create innovative products and solutions for our future homes, solutions around interiors, facades, and building materials integral to a sustainable, climate-resilient cityscape" (Thong 2016).

Singapore has also made efforts to further procure businesses that operate within the realms of technological innovation and sustainability. The city-state has made over 35 funding and incentive opportunities available for businesses whose work considers the natural environment, including grants for energy efficient technologies, Green Mark and skyrise greenery incentive schemes, incentives for shipping transport to reduce emissions, funding for research for water technologies, among others (Green Future Solutions 2015).

The water industry is a prime example of innovation procurement in Singapore, where the number of water companies has doubled from 2006 to 2013 and 470 million Singapore dollars have been committed to water research alone (Danubrata 2013). According to Reuters, "Singapore has been experimenting with reservoirs, recycled water known as NEWater, and desalination as it aims to become self-sufficient in water by 2061, when a water supply agreement with Malaysia expires" (Danubrata 2013).

Singapore's outlined plans and resources also make a direct connection between smart city and sustainable development. In a section titled "leveraging Technology to Improve our Urban Environment" on the Smart Nation webpage, the city encourages its residents to download two separate smartphone applications made in partnership between the Municipal Services Office and the National Environmental Agency. *OneService* and *myENV* offer Singapore residents the opportunity to connect with local official on municipal issues that are relevant to them, as well as access real-time data regarding weather and air quality, pollutant standards index (PSI) ratings, ultraviolet index ratings and heavy rain notifications (Smart Nation 2018).

Elsewhere in the city, municipal leaders are working to facilitate greener modes of transportation, including cleaner technologies such as electric vehicles and autonomous vehicles, and an expanded transit network (21). This is a vision that has been employed for some time, and Singapore is already seeing the positive results: the number of registered green vehicles has increased from 35 in 2003 to 11,635 in 2014, and from 2010 to 2016, the city has added 40.9 kilometers to its Mass Rapid Transit (MRT) lines, and MRT daily ridership during that period has risen approximately 49.5 percent (Government of Singapore 2017).

Beyond the community engagement and policy-centric initiatives employed by Singapore, arguably the best example of the city-state's mirroring of the smart sustainable city framework is through the city's 'eco-smart towns'. The eco-smart towns, which fall under the main "A Livable and Endearing Home" tenet of the city's 2015 Sustainability Blueprint, is in a sense a physical manifestation of the concepts associated with the smart sustainable city. These communities seek to capitalize on the domains of buildings, living, and natural resources and energy by promoting

innovative technological solutions that have ecologically sustainable impacts in Singapore's residential communities. As is described in the city's blueprint:

> "As smart technology and eco-friendly features are embedded into our towns and homes, Singaporeans will enjoy greater convenience and a better quality of life … A green lifestyle will be second nature for many, with more ways for people to save energy and water at home and with dual chutes to enable residents to segregate their recyclables easily while keeping our environments clean" (Sustainable Singapore 2015, 15).

One of the most effective examples of this model is Punggol Northshore. Located close to the Johor Strait along Singapore's north side, Punggol Northshore was listed as Singapore's first eco-smart town by the city's Housing and Development Board in 2010. Punggol represents a micro case study of Singapore's transformation at the end of the twentieth century, as the area shifted from a historical fishing and agricultural village to a community targeted by the city-state for waterfront-centric planning and sustainable design (24).

Some of the features included in Punggol Northshore range from smart car parks, smart fans, and smart sensor lighting systems to better waste conveyance systems and digital infrastructure imbedded into the area's housing (26). Among the variety of major projects that have been implemented in the Punggol Northshore eco-town is 'Treelodge@Punggol.' This project refers to a set of seven residential building blocks that weave green spaces and green building technologies into the city's public housing system under the canopy of "comfortable green living" (Housing and Development Board 2018). Other features of Treelodge@Punggol include vegetative green roofs, grey water and solar power systems, and buildings that are painted white and oriented away from the sun for energy efficiency. According to Alan Tan, the director of Singapore's HDB Environment Sustainability Research team, "Punggol Eco-Town is in fact a living laboratory for us … This is where we test bed a lot of urban solutions for us to identify which of those are workable and for us to adopt, for us to introduce more to our public housing" (Neisloss and Ko 2012).

A second example of eco-smart towns taking form in Singapore is the Jurong Lake District. Jurong Lake District includes smart sustainable features such as mixed-use spaces that allow for

pedestrians, bikers, and autonomous vehicles, as well as the requirement that all new developments in the area receive Green Mark accreditation from the Building and Construction Authority (Sustainable Singapore 2015, 35; 71). One of the major factors that sets the Jurong Lake District apart from other neighborhoods that integrate technology in Singapore and other global cities is how the Singaporean government has embraced an ideology of sustainable innovation in the city. Similar to Punggol Northshore, Jurong Lake District acts as a Living Lab for the city, and in Jurong Lake District there is incentive for private companies to partner with the government to design, develop, and test urban-solutions in the built environment (71). This is helpful not only for procuring industries to the city-state that operate in the realm of urban sustainability, but for more explicitly bridging the gap between smart city and sustainable city under Neirotti's hard and soft domains.

For instance, in the nearby Jurong Lake Gardens, the National Parks Board began work in 2016 on partnering with consulting groups on synthesizing technology and nature in the Gardens' new design. Solar photovoltaic cells, biodiversity sensors, and other forms of green technology have been presented as ways to develop a modern biophilic space that tows the line between cultivating natural biodiversity and smart spaces that are open to the public (Tan 2016).

Even some of Singapore's most well-known spaces are subscribing to the eco-smart concept, which makes sense given Singapore's attempt to leverage itself as a twenty-first century global city with globally advanced amenities. Such is the case with Marina South, home of the Gardens by the Bay and adjacent to nearby Marina Bay Sands, Singapore's architecturally sparkling resort. Similar to other areas of the city where diverse forms of transportation have been promoted in mixed-use spaces, an intentionally vast network of pedestrian and cycling paths allow residents to better engage with the space. Additionally, according to the Sustainability Blueprint, Marina South was planned in a fashion where the streets are aligned for better wind flow, and the area was designed to include smart sustainable features such as rainwater collection and grey water recycling and energy-efficient buildings (Sustainable Singapore 2015, 25).

Discussion

While Singapore does not tout a formal and fully-integrated smart sustainable city development strategy, the city is arguably the strongest example of the type of framework that smart sustainable city development represents. The city-state is internationally recognized for both its smart city and sustainable development efforts. While there is evidence of smart city initiatives in Singapore as far back as the 1990s and sustainable development as far back as the 1960s, the majority of the implementation of these concepts have occurred in the twenty-first century. When smart city and sustainable development are combined in Singapore, seen in areas such as the Punggol eco-town, transportation, water, waste, and housing development infrastructure, and innovation and partnership, Singapore sees a level of economic and ecological vibrancy that is almost entirely unique to the city-state. In many ways, the modern city is a large, intertwined network of relationships and communication, and Singapore advances an urban development model that takes advantage of this. It is not fully 'smart sustainable city development' as the reviewed literature would suggest, but it is clear that Singapore's development strategies that are emblematic of this framework yields positive results.

One of the strongest assets of Singapore's smart city initiatives and sustainable development plans are the public-private partnerships that have been cultivated in the city. Development firms, consulting firms, educational institutes and multinational technology conglomerates all have a stake in the modern city, and Singapore leverages these partnerships to bring innovation to the city. Singapore is also successful making its urban planning vision clear and communicable to both the city's residents and the city-state's global audience. This increases transparency and the ability for the city's residents to engage with and become invested in the city's sustainability goals.

It is important to recognize that Singapore may not serve as an ideal case study because Singapore operates under a set of circumstances that are unique to the city-state. Namely, Singapore's governance structure makes it easier for the city to facilitate partnerships with private companies and institute procurement practices. A city in a different country, for instance, would have to navigate both the local government and the national government (as well as a state or provincial government, depending on the country). Singapore's status as a city-state allows

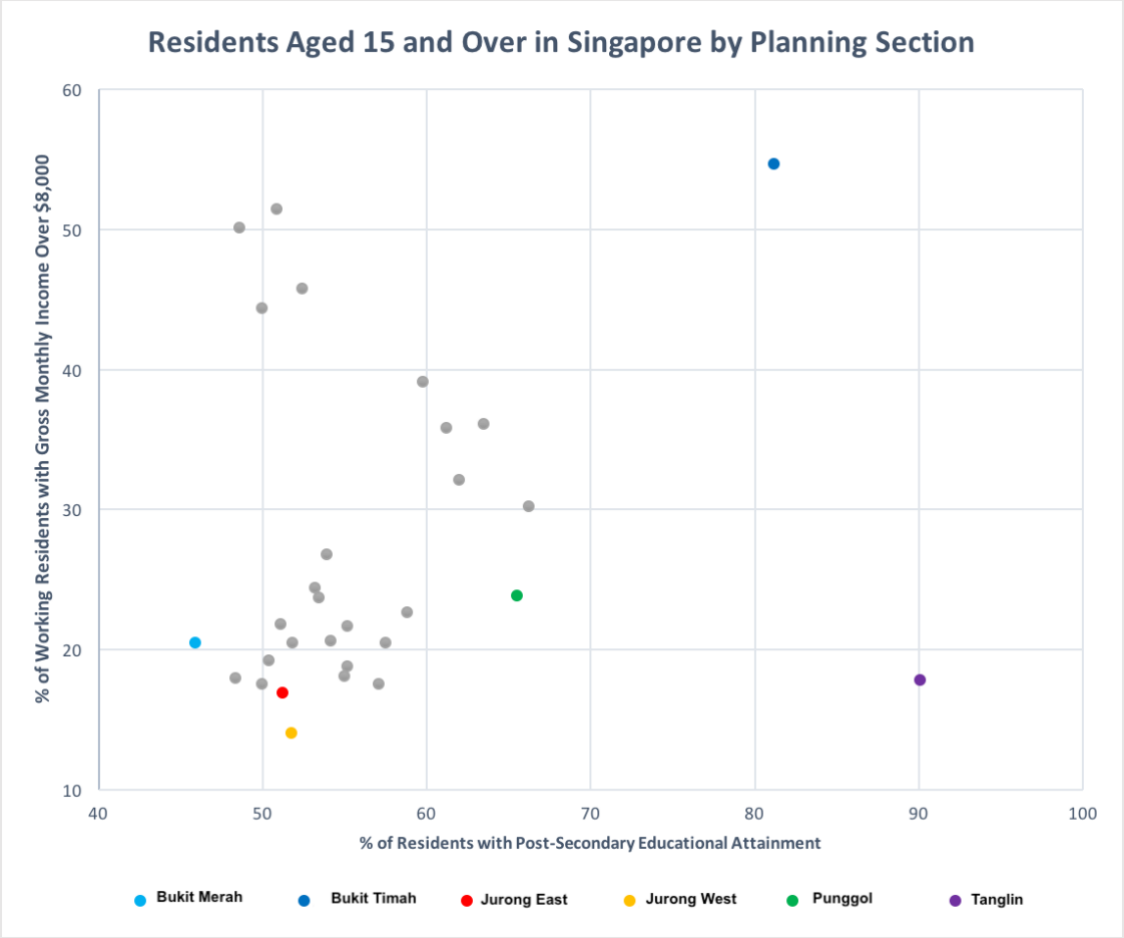
municipal leaders to avoid a lot of the bureaucratic issues associated with multilayered governance.

Another issue that is worth discussing relates to equality and equity. Some of Singapore's projects, such as increasing public transit ridership by almost fifty percent and the goal of having nine in ten households being within a ten-minute walk of a park, are emblematic of planning that considers all of the residents of the city. And while the Singapore model does include heightened community engagement and accessibility to the amenities and ICT solutions that have been introduced into the build environment, the realities of urban inequality inherently prevents some residents from reaping the benefits of any urban strategy.

This is especially relevant to Singapore, which, as a country, had a Gini coefficient (a common measurement of income inequality) of 0.459 in 2017 (Kit 2018), and, like other global cities, struggles with socioeconomic inequality. Given the breadth of potential initiatives that are associated with the smart sustainable city framework, it may be difficult to remotely measure how effective these projects are in making themselves accessible to Singapore's citizens. An analysis into the areas where some of Singapore's eco-towns exist, however, may offer some insight.

The data used to build Figure G was sourced from Singapore's Department of Statistics, which provides a variety of census and household survey results for public use. The geographic distribution of a 2015 general household survey was used, which separates data by the city-state's close to thirty planning areas. For all residents in Singapore who are at least 15 years old, the x-axis represents the percentage of workers by planning section whose highest educational attainment consists of post-secondary (non-tertiary) education, polytechnic or university education, a professional qualification or other diploma; the y-axis represents the percentage of workers by planning section whose average gross monthly income is at least 8,000 Singaporean dollars (Department of Statistics 2018). The median monthly income in the city-state in 2017 was 9,023 Singaporean dollars (Kit 2018). These two indicator measurements were used because together, they may provide a picture of which neighborhoods consist of members of lower socioeconomic classes who may be at risk of inaccessibility to the smart sustainable ecosystem.

Figure G: Education and Income Figures by Singapore Planning Section, 2015 (Data.gov.sg Open Datasets)



A few particular planning sections are highlighted in the data, including Punggol, Jurong East and Jurong West planning sections, which consist of the Punggol Northshore and Jurong Lake District eco-towns. Both Jurong East and Jurong West see some of the lowest levels of educational attainment and gross monthly income. Punggol, which has one of the highest education attainment rates among all of the planning sections, is still relatively in the middle in regards to gross monthly income. Despite the fact that sustainable buildings such as the ones seen in Punggol cost about 7% more to build than a traditional apartment building (Neisloss and Ko 2012), according to Figure G, the data is inconclusive in determining whether there is a direct correlation between eco-smart towns and the engagement of higher socioeconomic classes.

One of the reasons why this may be the case is because so many of Singapore's population—over 80 percent—live in public housing (Neisloss and Ko 2012). This means that there are heightened opportunities for mixed-income housing and mixed-income residential communities.

However, this does not necessarily indicate that Singapore sees complete digital inclusion and ecological equity. For example, according to Singapore's open datasets, only 70% of residents in the city have either owned or used a computer at any point in their life, and this number has actually slightly decreased in recent years (Government of Singapore 2017). Further research into digital access in the city may be helpful in determining whether the spread of smart sustainable city initiatives in Singapore are touching all residents.

However, these subjects do not mean that Singapore's practices cannot be replicated in other cities. The evidence shows that the convention wisdom is to consider smart city and sustainable development initiatives as separate entities, as described by Ahvenniemi et al. While Singapore has yet to roll out a fully integrated 'Smart Sustainable Singapore' framework, the efforts that the city has made thus far is a promising step in the right direction. Cities that continue to use ICT and human capital attributes to pursue sustainable development goals are more likely to be successful in their pursuit of the common principles shared by smart city and urban sustainable development. As climate-related issues, globalization and urbanization, resilience and technological innovation become more important subjects in the modern urban era, these principles will not go away, rendering smart sustainable city development a best-practice, holistic urban framework for cities looking to achieve successful and responsible growth.

Concluding Thoughts

It is more likely than not that this research has merely scratched the surface of what ought to be considered regarding the smart sustainable city framework. Both the smart city and the sustainable city are modern concepts that have been popularized beyond scholarly research into other forms of media, as well as in both the private and public sectors. Given that the amount of current research on the smart sustainable city, from a theoretical standpoint, is relatively new and still emerging, it is likely that the theory supporting such a concept needs to be further built out so that the audience may perceive smart sustainable city initiatives as not simply a convenient intersection of two individual entities, but as an intentional synthesis of ideas.

As has been stated, Singapore has yet to roll out a formally established smart sustainable city framework, but nonetheless represents an excellent case study due to its international standing as

a regional and global leader in both smart city initiatives and urban sustainable development. Given the fundamental challenges of conducting academic research from a distance, especially on topics directly concerning the built environment, further research on the manifestation of the smart sustainable city in Singapore would benefit from actual field research in Singapore to further explore topics such as eco-smart towns in Punggol Northshore and Jurong Lake District. Some of the aspects that could be considered to be missing from the current research, ranging from photographs of smart sustainable spaces to in-depth interviews with city officials, business leaders and community members who are stakeholders in these initiatives, or more specific primary evidence describing the breadth and depth of initiatives in the city-state, would be supplemented by research in Singapore.

It is also recommended that further research continues to consider the possible negative externalities associated with smart sustainable city planning. Environmental injustice, greenwashing, eco-gentrification and socioeconomic inequality are issues that concern all globally and regionally relevant cities, especially ones that are pursuing a climate and resilience sensitive agenda. Due to time constraints and the specificity of the research being conducted, this research was not able to holistically probe the potential consequences of the smart sustainable city surrounding equity and equality, which is important in providing the entire picture for such a model.

Lastly, further research of the smart sustainable city model may seek to go beyond Singapore and pursue a more comparative model. While the smart sustainable city framework currently exists, for the most part, in theory and has yet to be fully embraced by a global city in a formal manner, a comparison of similar initiatives in Singapore with another city in Southeast Asia would likely yield interesting results, as would a comparison between Singapore and a leader in smart city and sustainable development movements in another part of the world, such as with cities that adopt the European urbanism or American urbanism models. Regardless, it is clear that as these topics become more and more important relative to twenty-first century cities, the smart sustainable city framework will continue to be valuable in the form of lessons of thought and potential tangible initiatives.

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