Chapter 7
Resilient Smart Cities: Contributions to Pandemic Control and Other Co-benefits

Maria Rebecca Quintero and Ayyoob Sharifi

Abstract The COVID-19 pandemic disrupted daily lives and operations in many parts of the world. Being home to more than half of the world's population, cities were particularly hit hard by the pandemic. Different socioeconomic, institutional, and technological measures and policies have been adopted by cities in their efforts to control the pandemic. This chapter is focused on those measures and policies enabled by smart technologies and solutions. COVID-19 was the first global pandemic that occurred after digital revolution. It was, therefore, no surprise that smart technologies and solutions have been deployed at a large scale to deal with it. It is argued that this has even accelerated adoption of such technologies and solutions. By focusing on the planning, absorption, recovery, and adaptation capacities, this chapter discusses how smart solutions and technologies have contributed to resilience against the pandemic. In terms of planning, it is discussed that planning and existence of smart city infrastructure have enhanced different resilience characteristics such as connectivity, innovation, and resourcefulness that have helped some cities be less affected by the pandemic. These characteristics and availability and deployment of smart infrastructure have also enabled cities to absorb the initial shocks through, among other things, better tracing and tracking. Smart solutions and technologies have also enhanced resilience characteristics such as connectivity, creativity, agility, flexibility, and inclusion, thereby helping cities to resume their functionalities in a more timely manner. This, for instance, has been achieved through teleworking, telemedicine, automatic operations, etc. Lastly, contributions to adaptation had fostered connectivity, learning capacity, and flexibility. It is expected that the use of technology will lead to positive behavioral changes that may last even after the pandemic. Despite all these positive contributions, there are concerns about privacy and digital divide that need to be duly considered and addressed for more effective uptake and implementation of smart city solutions and technologies.

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7.1 Introduction

7.1.1 COVID-19 Pandemic and Its Global Impacts

A novel coronavirus, identified as SARS-Cov-2, brought about the Severe Acute Respiratory Syndrome—Coronavirus Disease 2019 (COVID-19) pandemic (Lal et al. 2020). The earliest documented case of COVID-19 was from Wuhan, Hubei province, China on the 31st of December 2019 (Shi et al. 2020), initially identified by the Chinese Center for Disease Control and Prevention (Li et al. 2020). The symptoms varied from mild to severe such as, but not limited to, signs comparable to the common cold or flu, interminable chest pains, respiratory problems, confusion, and pale or bluish lips, nail beds, or skin (CDC 2020). It is a highly infectious disease in which lack of intervention had spread the SARS-Cov-2 from a patient to a median of three people, higher than the infectivity rate of two for Ebola and one for the common flu (Liu et al. 2020). Although the numbers of infected by SARS-Cov-2 were higher, its mortality rate was 3.44%, which was lower than other coronaviruses such as, the 9.19% rate of SARS-Cov and the 34.4% rate of MERS-Cov (Khanna et al. 2020). However, the upsurge in the number of infected cases and deaths globally, and the absence of human's pre-existing immunity to the virus, expeditiously turned this outbreak into a pandemic (Thomson 2020; World Health Organization 2020). On the 30th of January 2020, the World Health Organization (WHO) announced that COVID-19 is a Public Health Emergency of International Concern (PHEIC) (World Health Organization 2020) and was declared a pandemic by the 11th of March 2020, as it had proliferated to 113 countries (Sułkowski 2020; Khanna et al. 2020).

Moreover, COVID-19 had adverse economic, health, and social repercussions globally (Oldekop et al. 2020; Sułkowski 2020). Consequently, the outbreak had severely disrupted systems and processes such as, but not limited to, public health, the economy, global supply chains, demand for goods and services, transportation, virtual communication, and international travel and tourism (World Trade Organization 2020; Khan et al. 2020; Sułkowski 2020). Among the courses of action for the risk reduction of the COVID-19 pandemic were strict lock downs, isolation, social distancing, case detection, human contact tracing, quarantine, and widespread travel ban (Long and Feng 2020; Khanna et al. 2020). Worldwide, the drastic measures that countries and regions have adapted to limit the effect of the outbreak were diverse and have absolutely altered the way people live within a short length of time (Thomson 2020; Sułkowski 2020). Furthermore, the challenges faced due to COVID-19 have emphasized the importance of global strategy for development in which the focus deals with problems collectively to achieve equitable and sustainable solutions (Oldekop et al. 2020).

As of 8th of September 2021, WHO reported 221,134,742 COVID-19 confirmed cases and 4,574,089 confirmed deaths (World Health Organisation 2021). To date, COVID-19 vaccines have been already rolled out in which 5,352,927,296 doses were administered (World Health Organisation 2021). However, it has been argued that the response to the pandemic would be much improved by comprehensive partnership and collaboration in prioritizing the necessity of strengthening measures in the containment of the infection in communities, expeditious vaccination, and the call for the International Monetary Fund (IMF) and multilateral development banks to provide more emergency funding, with the agreement of the G20 member countries (Sachs et al. 2021).

7.1.2 Impacts of the Pandemic on Cities

Undoubtedly, the spread of COVID-19 in our globalized society meant that the novel disease not only affected countries in general, but devastatingly impacted people's lives in cities as well (UN Habitat 2020). As social beings, humans benefitted from cities through interactions, knowledge and information exchange, and cooperation (Kang et al. 2020). However, this pandemic provided a different challenge compared to diseases caused by other coronaviruses, such as the SARS-Cov and MERS-Cov, because these viruses were transmitted to humans through certain animals (Abe and Ye 2013), while SARS-Cov-2 was extremely infectious and transmissible between people, that everyday social interactions posed a high risk of further spread (Kang et al. 2020).

Aside from the medical response to this biological disaster, the protective social approaches such as, but not limited to, contact tracing, social distancing, travel bans, and lockdowns produced secondary problems, namely, the reorientation of communities' social structure in terms of work and everyday life, unstable housing costs, drastic economic changes, and concerns about privacy (Kang et al. 2020; Honey-Rosés et al. 2020). In fact, recent studies have identified socioeconomic impact as one of the categorical issues from this pandemic. While other impacts were determined from categories such as environmental quality, management and governance, and transportation and urban design (Sharifi and Khavarian-Garmsir 2020).

Moreover, cities have the highest number of confirmed COVID-19 cases, comprised of more than 90% (Pomeroy 2020). However, it was observed that the high density of the population of an urban area does not directly correlate to the increase in the number of cases. In fact, overcrowding and the management of urbanization were identified as factors which increased the likelihood of risk of infection in major urban areas such as Lagos, Lima, London, Madrid, Milan, New York, Paris, Sao Paolo, and Tokyo (UN Habitat 2020). Furthermore, the economic recession and the predicted decline of local government revenue by 15 to 20% meant less financial resources for urban development projects and services such as, but not limited to, public transport, poverty reduction, public healthcare, affordable housing, water, and sanitation

(Wahba et al. 2020). In addition, people who lived in overcrowded informal settlements and slum areas experienced further vulnerability due to inadequate, sometimes even non-existent, basic services and support that made it impossible to implement social distancing and follow recommended hygienic practices to counter the spread of the infection (Wahba et al. 2020).

Also, lockdown measures drove people to increase the use of technology and the internet for online schooling and working remotely. However, the pandemic also highlighted existing inequalities. For instance, the work from home approach succeeded with white-collar employees but, not for the workers in the informal sector who relied on their day-to-day income to survive (de Waal 2020). Additionally, students from poor families lack the technological amenities that were necessary for their online lessons and essential learning (UN Habitat 2020).

7.1.3 Urban Planning and Management Gaps and Difficulties

There are currently more people living in urban areas compared to rural areas (Carmichael et al. 2019; Lerner et al. 2018). The increasing global population is predicted to be absorbed by cities in the coming decades. To elaborate, in 2015 urban areas accommodated 54% of the total human population, and by 2036 it is estimated that it would rise up to 62% (United Nations 2018; McDonald et al. 2020). Studies have shown that the upward trend in urban population had critical consequences on land use (Angel et al. 2012), air quality (Cole and Neumayer 2004), water quality and security (Flörke et al. 2018), climate change and energy use (Rodríguez 2007; Güneralp et al. 2017), food security (Regmi 2001), and health and well-being (Carmichael et al. 2019). Furthermore, the strengthening recognition of the connection between these multidisciplinary factors demonstrated the value and the crucial role that cities and urbanization play in addressing international, national, and local development issues, resilience, and sustainable development. Also, as rapid urbanization and urban population continue to proliferate, the need for effective planning and management for cities become more significant (UN Habitat 2020).

However, urban planning and management is a multidisciplinary field, which deals with different sectors to implement extensive tasks and objectives, that would aid the community in attaining their development goals; so, there are numerous and complex challenges in it (Boarnet and Takahashi 2005). First, the knowledge and tools for planning and managing urban areas remains fragmented, which makes the approaches and solutions unreliable and confusing for cities (Polidoro et al. 2012). Second, research focus, data, and analysis about the urban environment, which urban planners could use for knowledge source, policy decision-making, and governance remain segregated (Duhr et al. 2020; Shwartz et al. 2014; Huang et al. 2018). In fact, it was argued that the incompatibility of data format, timescale, and resolution is more the reason for the disengagement between researchers and planners, and not data unavailability (Duhr et al. 2020). Third, the development policies from the national level down to the local level of governing bodies are disassociated, and there is a lack of essential key stakeholder consultation and participation (Huang et al. 2018). Fourth, the need for more comprehensive and effective master plans with strong spatial analysis that consider factors such as, but not limited to, urban sprawl, rapid unplanned urban growth (Polidoro et al. 2012), vital infrastructure aside from roads, appropriate locations for commercial and industrial sectors, and identification of unplanned areas (Huang et al. 2018). Additionally, political intervention and corruption in cities are concerns because it had an impact on the planning, implementation, and level of autonomy for planners in urban development projects (Polidoro et al. 2012). Moreover, the limited understanding and consideration for climate change and various disaster hazards and risks, such as this pandemic, are also a challenge that needs to be grappled with (Huang et al. 2018).

Against this background, the main objective of this chapter is to examine how smart city solutions and technologies have contributed to resilience against the COVID-19 pandemic. Before elaborating on this issue, we discuss some theoretical concepts related to resilience and smartness in the next section.

7.2 Theoretical Concepts

7.2.1 Resilience

Resilience is a concept that is extensively used in current literature, policy documents, reports, and decision-making, as complex interactions between and within various systems further acknowledge the relevance and necessity of maintaining their functions despite of internal and external shocks (Connelly et al. 2017). The term resilience first came from physics, which denoted an object's reaction from the impact of an extrinsic force (Peng et al. 2017). Then, studies in ecology from the 1970s used the term to pertain to a system's capacity to anticipate and recover from any external disturbances (Holling 1973; Cai et al. 2012). Moreover, in the context of urban areas, resilience was referred to as the capability of a city to absorb disruptions from its usual operations and still be able to revive and resume its operations regardless of the changes and disturbances (Lhomme et al. 2011; Alliance 2007; Folke et al. 2010; Wikström 2013; Sharifi et al. 2017).

Furthermore, there are differing ideas and definitions about resilience. Indeed, there is a lack of a unifying concept partly due to various technical languages used in different disciplines, which impede the effective sharing of ideas (Connelly et al. 2017). Even in the context of urban areas, contradictory definitions of resilience exist. This was derived from factors such as, but not limited to, various perspectives from social and ecological research, methodologies, dissimilarity on base ideas, and the ways of thinking and reasoning about it (Rezaei and Bastaminia 2016). Table 7.1 shows the different definition and concepts of resilience of cities, collated by Rezaei

Table 7.1 Definitions and concepts of resilience of cities (Rezaei and Bastaminia 2016)

Author	Definition
Holling (1996)	Urban resilience is further capacity or the ability of a city to digest disturbance or is the amount of disturbance that a system can digest it before the system structure is changed by changing variables
Buckle et al. (2000)	Quality of people, communities, agencies, and infrastructure reduces vulnerability. Not only lack of vulnerability but the capacity to prevent and reduce damages and then at the next stage maintenance of ideal conditions in cities as much as possible in case of incidence of harms, and then in third stage to recover from the effects
Gunderson et al. (2002)	The severity of disturbance that a city can absorb it before structure of cities to be converted to a different structure through change in variables and processes that are controlled by behavior
Cardona et al. (2003)	Capacity of damaged cities or ecosystems to digest the negative effects and rehabilitate them
Manyena (2006)	Capacity of a city at risks to become adjusted, resist, or change in order to reach an acceptable level of operations and structure and its continuation. This is determined by a degree that the social system is capable of organizing and increasing capacity, learning from past disasters and improving assessments of reducing the possibility of its own risk
Cutter et al. (2010)	Urban resilience is called to absorption capacity and basic and special performances, as well as capacity of recovery, "Return to Balance", after disaster
Pelling (2003)	Urban resilience is the ability of biological systems and organisms to resist or return to normal status against shocks, disasters, diseases, and other changes
Birkmann et al. (2013)	Urban resilience is considered capacity of damaged communities or ecosystems to digest the negative effects and rehabilitate them
Turner (2014)	Change process of strengthening the capacity of population, communities, organizations, and forecasting, prevention, recovery and change of cities after the occurrence of shock, stress, and changes
Kärrholm et al. (2014)	The severity of disturbances that a city can absorb it before structure of the system to be converted to a different structure through change in variables and processes that are controlled by behavior
Hodson and Marvin (2014)	Resilience is called the capacity of cities to absorb disturbances and to keep necessary and inherent feedbacks, processes, and structures of the city

and Bastaminia (2016). Despite the definitions from various authors, the study had identified two common properties from their analysis, which were: first, resilience was regarded more as a means rather than an end goal. Second, urban resilience was more effective when it was flexible to change and less resistant.

Moreover, as different definitions of resilience were explored, there were prevailing features that were present. These features were critical functions or services, thresholds, time and scale, and memory and adaptive management (Connelly et al. 2017). In addition, published literature have identified capacities of resilience which were absorptive, adaptive, and restorative (Lhomme et al. 2013; Proag 2014; Fiksel 2003; Rose 2007; Tongyue et al. 2015; Sharifi 2016). Also, in urban and disaster studies, the planning and preparation capacity was deemed crucial in decreasing the impact of disasters and was linked closely to adaptive capacity (Rose and Liao 2005). More to the point, the features that were analyzed from the definitions of resilience by Connelly et al. (2017) and the resilience capacities discerned by various studies were presented in Table 7.2, which shows the relationship of how resilience was perceived and its application in different disciplines.

To elaborate, the ability to plan and prepare is strongly related to the critical functions of a system (Connelly et al. 2017). In fact, the key stakeholders determine the scale, connectivity, and the level of priority of these critical functions when considering the vulnerabilities, hazards, and risks that would possibly disrupt the system (Cumming et al. 2006). Then, the absorption capacity is linked to thresholds due to the robustness of the critical functions and the system (Connelly et al. 2017) and has significant influence on its adaptive capacity (Fath et al. 2015). The threshold serves as the system's limitation from disruptions and once this is exceeded, the unrecovered changes in the system are adapted and different function emerges (Dakos et al. 2008). Additionally, the recovery ability of resilience correlates to the amount of time it takes to recover the critical functions and the scale of the impact of the disruption (Allen et al. 2014). Ideally, agility in recovery is deemed important to restore the system's services with no change or as little change as possible (Connelly et al. 2017). Also, the adaptive capacity places emphasis on the flexibility of the system, not just on the known external shocks but, on the uncertain possibilities of other disturbances as well (Fath et al. 2015). Moreover, foresight is also an essential resilience characteristic in envisioning alternative solutions and investment on planning and preparing for future disruptive events (Park et al. 2013; Sharifi and Yamagata 2016).

7.2.2 Common Smart City Solutions

As the urban population grows and cities are perceived as essential for the economy, there is also an increase in the demand for basic public services, healthcare, education, water, energy, and sanitation (Rao and Prasad 2018; Ramaprasad et al. 2017; Neirotti et al. 2014). The aim to improve the population's quality of life is a race with the rapid urbanization and complex system of cities, and one of the ways to handle such

Table 7.2 Resilience features common to socio-ecology, psychology, organizations, and engineering and infrastructure, which are related to the temporal phases from the National Academy of Sciences (NAS) definition of resilience (Connelly et al. 2017)

NAS phase of resilience	Resilience feature	Description by application domain			
		Socio-ecological	Psychological	Organizational	Engineering and infrastructure
Plan	**Critical functions (services)**	A system function identified by stakeholders as an important dimension by which to assess system performance			
		Ecosystem services provided to society	Human psychological well-being	Goods and services provided to society	Services provided by physical and technical engineered system
Absorb	**Thresholds**	Intrinsic tolerance to stress or changes in conditions where exceeding a threshold perpetuates a regime shift			
		Used to identify natural breaks in scale	Based on sense of community and personal attributes	Linked to organizational adaptive capacity and to brittleness when close to threshold	Based on sensitivity of system functioning to changes in input variables
Recover	**Time (and scale)**	Duration of degraded system performance			
		Emphasis on dynamics over time	Emphasis on time of disruption (i.e., developmental stage: childhood vs adulthood)	Emphasis on time until recovery	Emphasis on time until recovery
Adapt	**Memory/adaptive management**	Change in management approach or other responses in anticipation of or enabled by learning from previous disruptions, events, or experiences			
		Ecological memory guides how ecosystem reorganizes after a disruption, which is maintained if the system has high modularity	Human and social memory, can enhance (through learning) or diminish (e.g., post-traumatic stress) psychological resilience	Corporate memory of challenges posed to the organization and management that enable modification and building of responsiveness to events	Re-designing of engineering systems designs based on past and potential future stressors

Table 7.3 Comparison of key attributes in the first- and second-generation smart city paradigms (Trencher, 2019)

	Smart city 1.0	Smart city 2.0
Focus of vision	Technology and economy	People, governance, and policy
Role of citizens	Passive role as sensors, end-users, or consumers	Active role as co-creators or contributors to innovation, problem-solving, and planning
Objective of technology and experimentation	• Optimize infrastructures and services • Serve demand-side interests and spur new business opportunities • Address universal technical agendas (energy, transport, economy)	• Mitigate or solve social challenges • Enhance citizen wellbeing and public services • Address specific endogenous problems and citizen needs
Approach	• Centralized (privileged actors) • Exogenous development	• Decentralized (diverse actors) • Endogenous development

challenges is to make the city smarter and efficient (Rao and Prasad 2018; Sharifi 2019, 2020).

There is a lack of common definition for a smart city (Rao and Prasad 2018; Ramaprasad et al. 2017). When its concept started in the last part of the twentieth century, the focal point was on the development of infrastructure and technology (Woetzel and Kuznetsova 2018; Ramaprasad et al. 2017; Neirotti et al. 2014; Trencher 2019). However, the current evolution of the idea also focuses on its effects, such as, quality of services, sustainable development, and improvement on the lives of the residents (Anthopoulos 2015; Woetzel and Kuznetsova 2018; David and Koch 2019; Papa et al. 2013; Trencher 2019). In Table 7.3, the development of the concept of smart cities shows through the differences between Smart city 1.0 and Smart city 2.0 in terms of vision, citizen role, objectives, and approach (Trencher 2019).

Additionally, it is argued that for a lot of cities, being a smart city is a complex challenge and an aspiration (Ramaprasad et al. 2017). Aside from being an aspiration, the interpretation of the concept varies per city or region and is contingent on a city's resources, development, and preparedness for the transformation of some of its systems and processes (Rao and Prasad 2018; Neirotti et al. 2014).

Primarily, one of the basic requirements for a smart city is the information and communication technology (ICT), as it integrates and manages all the factors in the system. In fact, ICT enables connectivity, which is fundamental to utilize and coordinate multiple resources within the urban system (Rao and Prasad 2018; Westraadt and Calitz 2018; Papa et al. 2013). However, it is argued that investment in ICT alone could not transform an area into a smart city but, it would also need its citizen's learning capacity and innovation to promote change (Neirotti et al. 2014). In addition, the internet of things (IoT) is another solution which makes it possible to link together control and monitoring devices such as, but not limited to, actuators, sensors, RFID tags, mobile devices, and cameras, which are used to collect real-time data to be utilized and actioned appropriately (Rao and Prasad 2018; Westraadt and Calitz 2018). For instance, the smart home is a popular example of IoT, in which an infrared module is applied to control home machines and appliances (Jeong and Park 2019). Moreover, big data analytics is also a smart city solution, consequently from off-line and online datafication, and could even be obtained from cloud computing (Westraadt and Calitz 2018). Big data refers to the huge amount of information and details gathered about the citizens, potentially utilized for the management of urban systems and processes (Bibri and Krogstie 2020; David and Koch 2019). Additionally, the synthesis of data analytics, real-time monitoring, event management, and participatory technology aims for effective and well-organized delivery of public services and governance (Westraadt and Calitz 2018).

Moreover, it is argued that solutions for a smart city are not found only in the tangible elements or hard domains, and that the intangible elements or soft domains are also essential (Papa et al. 2015; Neirotti et al. 2014). Table 7.4 summarizes the hard domains, which are the infrastructure- and technology-focused solutions, while soft domains refer to the public services necessary to improve institutional position and social environment (Neirotti et al. 2014).

7.2.3 Framework for Enhancing Urban Resilience Through Smart Solutions

As urban areas are rapidly changing and expanding, the risks from disasters in cities have increased as well. Cities have experienced, and continues to experience, the consequences of climate change, unsustainable practices, and numerous hazards that hinder their development. In addition, existing socioeconomic problems have added to the burden of finding solutions to urban issues. With the consensus that cities play a critical role in global development (Rao and Prasad 2018), there is an urgent necessity for enhancing their resilience against any disruptions.

While cities have made efforts to enhance resilience, there has also been growing interest in smart city initiatives. The smart city concept was developed with the goal of improving the quality of life of citizens (Woetzel and Kuznetsova 2018; David and Koch 2019). Smart city solutions have a wide range of scope, which aim to enhance systems and services. Through the years, these types of solution have evolved and have focused on addressing different urban problems.

In relation to the points discussed, the authors developed a framework for enhancing urban resilience with the utilization of smart city solutions. The framework is illustrated in Fig. 7.1. The framework revolves around four major resilience abilities/stages, namely, planning, absorption, recovery, and adaptation (Sharifi et al. 2021).

To elaborate, the framework builds on the concept of urban resilience as a process, instead of a goal, and emphasizes adaptation to changes (Rezaei and Bastaminia

Table 7.4 Classified literature on the domains of a Smart City (Neirotti et al. 2014)

Prevalence of investment in:	Domain	Main objectives	References
"Hard" domains	Energy grids	Automated grids that employ ICT to deliver energy and enable information exchange about consumption between providers and users, with the aim of reducing costs and increasing reliability and transparency of energy supply systems	Chourabi et al. (2012), Correia and Wünstel (2011), Mahizhnan (1999) and Steria-Smart City (2011)
	Public lightning, natural resources, and water management	Managing public lighting and natural resources. Exploiting renewable resources such as heat, solar, cooling, water, and wind power	Accenture (2011), Correia and Wünstel (2011), Dirks et al. (2009), Hughes et al. (2013), Nam and Pardo (2011), The Climate Group et al. (2011), Think (2011) and Toppeta (2010)
	Waste management	Applying innovations in order to effectively manage the waste generated by people, business and city services. It includes waste collection, disposal, recycling, and recovery	Accenture (2011) and The Climate Group et al. (2011)
	Environment	Using technology to protect and better manage environmental resources and related infrastructure, with the ultimate goal of increasing sustainability. It includes pollution control	Atzori et al. (2010), Caragliu et al. (2009), Chourabi et al. (2012), Inayatullah (2011), Nam and Pardo (2011), Tiwari et al. (2011)

(continued)

Table 7.4 (continued)

Prevalence of investment in:	Domain	Main objectives	References
	Transport, mobility, and logistics	Optimizing logistics and transportation in urban areas by taking into account traffic conditions and energy consumption. Providing users with dynamic and multi-modal information for traffic and transport efficiency. Assuring sustainable public transportation by means of environmental friendly fuels and innovative propulsion systems	Atzori et al. (2010), Caragliu et al. (2009), Correia and Wünstel (2011), Dirks et al. (2009), Giffinger et al. (2007), La Greca et al. (2011), Munuzuri et al. (2005), Nam and pardo (2011), Steria-Smart City (2011), The Climate Group et al. (2011), Think (2011), Toppeta (2010) and Washburn et al. (2010)
	Office and residential buildings	Adopting sustainable building technologies to create living and working environments with reduced resources. Adapting or retrofitting existing structures to gain energy and water efficiency	Accenture (2011), Steria-Smart City (2011), The Climate Group et al. (2011), Think (2011), Washburn et al. (2010)
	Healthcare	Using ICT and remote assistance to prevent and diagnose diseases, and deliver the healthcare service. Providing all citizens with access to an efficient healthcare system characterized by adequate facilities and services	Accenture (2011), Atzori et al. (2010), Correia and Wünstel (2011), Dirks et al. (2009), Nam and Pardo (2011), The Climate Group et al. (2011) and Washburn et al. (2010)
	Public security	Helping public organizations to protect citizens' integrity and their goods. It includes the use of ICTs to feed real-time information to fire and police departments	Accenture (2011), Dirks et al. (2009), Nam and Pardo (2011) and Washburn et al. (2010)

(continued)

Table 7.4 (continued)

Prevalence of investment in:	Domain	Main objectives	References
Soft domains	Education and culture	Capitalizing system education policy, creating more opportunities for students and teachers using ICT tools. Promoting cultural events and motivating people participation. Managing entertainment, tourism and hospitality	Accenture (2011), Dirks et al. (2009), Mahizhnan (1999), Nam and Pardo (2011) and Washburn et al. (2010)
	Social inclusion and welfare	Making tools available to reduce barriers in social learning and participation, improving the quality of life, especially for the elder and disabled. Implementing social policies to attract and retain talented people	Atzori et al. (2010), Bakıcı et al. (2013), Caragliu et al. (2009), Chourabi et al. (2012), Correia and Wünstel (2011), Giffinger et al. (2007), Mahizhnan (1999) and Toppeta (2010)
	Public administration and (e-) government	Promoting digitized public administration, e-ballots and ICT-based transparency of government activities in order to enhance citizens empowerment and involvement in public management	Accenture (2011), Bakıcı et al. (2013), Caragliu et al. (2009), Chourabi et al. (2012), Correia and Wünstel (2011), Dirks et al. (2009), Giffinger et al. (2007), Odendaal (2003), Steria-Smart City (2011), Think (2011), Toppeta (2010) and Washburn et al. (2010)
	Economy	Facilitating innovation, entrepreneurship and integrating the city in national and global markets	Bakıcı et al. (2013), Caragliu et al. (2009), Chourabi et al. (2012), Correia and Wünstel (2011), Giffinger et al. (2007), Mahizhnan (1999) and Toppeta (2010)

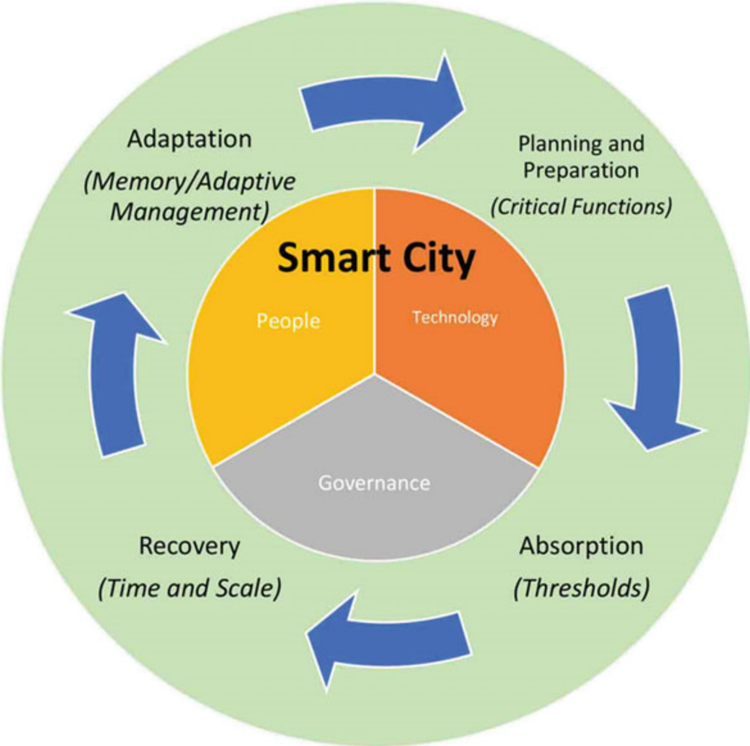

Fig. 7.1 Smart city solutions enhancing urban resilience (by author)

2016). The idea of resilience as a process and its flexibility to uncertainties are shown through the cycle of arrows. This is a nonlinear process, and each phase is dependent on the features of resilience that were impacted by disturbances on the system.

In planning and preparation, the critical functions are determined by key stakeholders. These stakeholders decide which services will be prioritized in case of disruptions. In the event of a disaster, absorption is the phase in which thresholds determine the limit on how much a city could withstand disturbances. Then, once the threshold is exceeded, recovery would be the next process. In this situation, the scale of the damage and the time it would take the city to resume its impacted critical functions would determine its recovery. However, there are cases in which recovery is impossible and adaptation would be the ideal process instead. In adaptation, it would be based on how the city learns from previous disasters and implement better processes for the future. Additionally, due to the cyclical process of resilience, adaptation links back to planning and preparation. This reflects that the knowledge gained from adaptation is strongly considered in planning for future uncertainties of disaster risks.

Moreover, the framework shows that the smart city is composed of different factors. These factors are technology, people, and governance (Skouby and Lynggaard 2014; Woetzel and Kuznetsova 2018; United Nations 2018). This builds on the concepts of previous studies that smart cities are not only about advancements in technology but, comprised of the people and effective governance as well. For smart city solutions to be beneficial, it is necessary to apply a comprehensive understanding of the system instead of addressing just individual urban problems and disruptions.

Furthermore, the framework demonstrates that at the core of the urban resilience as a process is the smart city and its solutions that enhance it. By adopting the nonlinear process of resilience and placing emphasis on the different factors of what makes a city smart, it strengthens urban resilience and fosters sustainable solutions for the future.

7.3 Contributions of Smart Cities to Resilience

7.3.1 Contributions to Planning and Preparation

Unexpected disasters and other catastrophic events, such as the COVID-19 pandemic, have drastically impacted cities (Yao and Wang 2020). Numerous endeavors and research were made to prevent, mitigate, respond, and recover from disasters. However, there is still a lot of work to be done to be able to successfully manage such difficulties (Shahat et al. 2020). Moreover, the increasing popularity of smart cities brought specific consideration on the function and effects of information and technology (ICT) in planning and preparation for dealing with disaster risks (Papa et al. 2013). Additionally, big data and ICTs are proving to be essential in disaster mitigation and support timely recovery (Yao and Wang 2020). Also, the population's capacity to learn from previous disasters not only resulted in further innovation of technological pursuits, but also strengthened the key role of human capital in a connected and inclusive city (Papa et al. 2015).

In the context of urban resilience, connectivity and innovation are major characteristics that have developed extensively through smart city solutions. Innovation brought about not only new technologies, products, and tools but, new courses of actions as well (UN Habitat 2020). Connection and exchange of information and data between citizens and governing bodies have aided decisions on what to plan and prepare for in times of crisis (Johnson et al. 2020; Yao and Wang 2020). In fact, cities that have effective systems for infectious disease surveillance through data analytics could reduce mortality rate by 5% (McKinsey Global Institute 2018). Predominantly, the cities that were a step ahead in preparation for the COVID-19 pandemic were those that had better connectivity, adoption, and inclusive system (Costa and Peixoto 2020).

Moreover, the adaptive learning applied from previous disease outbreaks due to experience has exhibited the resourcefulness of some cities in their preparation for another crisis like the COVID-19 pandemic, and the use of IoTs was in the forefront. For instance, the South Korea Digital Health was one of the initiatives from the country's adoption of the smart city concept years ago (Costa and Peixoto 2020; Whitelaw et al. 2020). Smart city solutions, such as Artificial Intelligence (AI), consumer health electronics, big data, block chain, and telemedicine were utilized in withstanding the COVID-19 outbreak (Whitelaw et al. 2020). In addition, a website with a Corona map gave information to people on which areas had confirmed cases. Also, apps such as Corona 100 m and a self-quarantine app were used to let citizens be aware of their proximity from infected areas and make sure they were following quarantine protocols, respectively (Wray 2020; UN Habitat 2020; Söderström 2020).

Similarly, Singapore's preparation for this pandemic was due to the SARS outbreak they had more than a decade ago (Costa and Peixoto 2020). The country had the TraceTogether app in place, which was part of their Smart Nation program. This program utilized various new technologies to provide smart solutions and improve the residents' quality of life. For instance, with the TraceTogether app installed in mobile phones, it helped detect people who were in close contact with confirmed cases and shared that data with the Ministry of Health for easy identification (Tandoc Jr and Lee 2020; Söderström 2020). To elaborate, the Bluetooth signal exchange in residents' mobile phones, when they were in close proximity from each other, would be data that was registered and kept for 21 days, and the public health department had access to it for their tracking of cases (Whitelaw et al. 2020). In addition, websites and messaging apps were used by the government to educate and inform the people in managing COVID-19 (Costa and Peixoto 2020). Similarly, a company in Romania developed an app called CovTrack, which utilized the same Bluetooth technology to track and trace people that have been infected (Tešić et al. 2020).

Additionally, Germany had used big data collated from a smartwatch application they developed to track people's health condition digitally, as one of their pandemic responses. This smart technology made it possible for the government to record an individual's sleep pattern, pulse, and temperature, and applied that data in analyzing the country's collective risk and status of COVID-19 infection situation, and planning for the best appropriate approach (Busvine 2020).

Another case is Taiwan, in which their well-prepared and efficient action to control the outbreak resulted in low number of infected cases and deaths (Wang et al. 2020). Big data was used ubiquitously as immigration and health insurance records were integrated, checked, and analyzed, which helped in contact tracing and identified people who needed to be tested (Whitelaw et al. 2020).

The application of several smart city solutions for the planning and preparation of urban areas to deal with disease outbreaks has aided in fighting the spread of COVID-19. However, the advantages from smart solutions in functions such as tracking, screening, and contact tracing to manage the infection have also presented some disadvantages. It has been argued that privacy, data security, lack of management and regulation, high production and maintenance costs, limited information on asymptomatic carriers, and unequal opportunity for people that have no mobile device or internet connection are some potential trade-offs that need to be taken into account (Whitelaw et al. 2020).

7.3.2 Contributions to Absorption

Aside from connectivity, smart city solutions have enhanced the robustness, flexibility, and resourcefulness of cities during the pandemic. Additionally, smart city solutions were crucial in maintaining connections and kept people productive while in lockdown or physically apart (UN Habitat 2020). The COVID-19 outbreak has facilitated the advancement in technology and the population's adoption of it (Xiao and Fan 2020; Chagoury 2020; Berg 2020). In fact, the drastic effect on communities, economy, and healthcare system has made the people and local governments more accepting of digital and technological tools to contain the spread of the disease and continue their city's critical functions as much as possible (Chagoury 2020). The smart city solutions that rapidly developed during the pandemic lockdown and physical distancing were in ICT and IoT systems such as digital and contactless payments, telehealth, remote work, online learning, robot deliveries, online shopping, and online entertainment (Xiao and Fan 2020; UN Habitat 2020).

Due to the infectious nature of COVID-19, along with the strict lockdown and social distancing measures, flexibility and resourcefulness of some regions were clearly demonstrated in the use of smart technology for telemedicine, with the aim of reducing the burden on clinics, hospitals, and health professionals in dealing with the pandemic (Wang et al. 2020; Whitelaw et al. 2020). It was reported that in the United States, almost half of the number of patients have utilized communication services such as Skype and Facetime to consult with a medical professional (Stokel-Walker 2020; McKinsey Global Institute 2018). In another case, Canada has recorded that from February to May 2020, the number of patients who consulted doctors through video conference calls increased from 1000 to 14,000 visits per day (Whitelaw et al. 2020).

Moreover, remote work and online learning have shown that resilient cities have robustness due to the aim of maintaining critical functions for the benefit of the economy and education. In this context, smart solutions such as, but not limited to, virtual meetings, virtual reality, AI-enabled robot teachers, virtual private networks, cloud technology, work collaboration tools, 3D printing, and facial recognition tools were enabled to mitigate the impact of the lockdowns as much as possible (Xiao and Fan 2020). However, the smart city technologies also reinforced the existing inequalities within cities as considerable number of the population lacked access to such innovations and faced difficulties with remote work and online learning (UN Habitat 2020). In fact, prior to the pandemic, it was recorded that high-income regions still had better conditions in terms of internet access, mobile phones, and wearable smart devices compared to both middle- and low-income regions (Bahia and Suardi 2019).

Additionally, the use of smart city solutions was not only identified through government initiatives. As a response to the lockdown, a case study has identified that some people from the tourism sector have utilized the digital sharing of copyrighted photos and videos, along with Google Maps, to continue their work through virtual tours despite the situation (Costa and Peixoto 2020). Furthermore, heritage sites and museums provided virtual tours as well, as just some of the numerous entertainments available online (Xiao and Fan 2020).

Moreover, in the case of Brazil, the lack of coordination of the national and local governments, along with overcrowded population and poor living conditions, has drastically increased the infected cases and exacerbated the impacts of COVID-19 in the country (Costa and Peixoto 2020). Due to the inaccurate reports of the public sector about the numbers affected by the pandemic, with the support of academic and scientific institutions, some groups utilize big data and IoTs for gaining better knowledge of the conditions and providing some solutions for the citizens (Urban and Nakada 2021). Smart solutions such as real-time maps of reported COVID-19 infection and open data source were readily accessed by the population to provide information of high-risk areas. In addition, several universities in the country developed a system that integrated all the pandemic data and executed statistical analysis of the population and the impact of the disease in the context of unemployment, education, violence, and poverty (Costa and Peixoto 2020). Such situations exhibited the modularity or self-organization characteristic that was decentralized and initiated locally.

7.3.3 Contributions to Recovery

In urban resilience, recovery is a capacity that is determined by the time it takes to return to normal conditions. This is influenced by the state of preparation and also the scale of a disruption (Connelly et al. 2017). Big data analytics and real-time information about a disaster could enhance the agility, connectivity, creativity, flexibility, and participatory characteristics of resilience. For example, the use of early warning systems provides cities with relevant data about the disaster and enables them to conduct more comprehensive analysis for better decision-making, damage assessment, relief efforts, and re-establishment of critical functions (Zhu et al. 2019; Yao and Wang 2020; Woetzel and Kuznetsova 2018).

The advancement of AI and its application in scientific research tools, robots, smart homes, toys, and medical diagnosis has been crucial in the development of services that affect our daily lives (Skouby and Lynggaard 2014). During the pandemic, robot-based delivery was one of the smart city solutions implemented as an answer to contactless delivery. In China, the increase in online shopping has encouraged major companies to deliver their service by robots (Xiao and Fan 2020). Additionally, drones were used to deliver essential supplies, provide alerts and information during lockdown and quarantine, and sanitize areas. Similarly, in Hong Kong (Costa and Peixoto 2020) and Nigeria (Chagoury 2020), the use of robots was considered safer in disinfecting public buses and trains and presented no risk in spreading the infection (Costa and Peixoto 2020; Scott and Coiera 2020; Chagoury 2020). These types of approaches showed that implementing smart technologies enhances creativity and agility and facilitates rapid management of the pandemic impact. Additionally, in Denmark, robots that used UV light to sanitize were positioned strategically in airports, hotels, offices, universities, government buildings, and hospitals to provide less burden to frontline workers (Bedi 2020).

Smart city solutions also had a positive contribution to the COVID-19 vaccine development. The efficient collation and sharing of data about every new disease provided more critical information and knowledge that was made possible by ICT-enabled systems (Rabi et al. 2020). Traditionally, the development of a drug for the treatment of a new disease could take years, or even decades, due to the overwhelming amount of data and necessary experiments to be done. In the case of the COVID-19 vaccines, AI had already sorted out the essential data and conducted calculations at a rapid pace (Smart City 2020; Ibrahim 2020). In fact, deep-learning based algorithms facilitated the recognition of potential SARS-CoV-2 protein structures just in several weeks (Malone et al. 2020). Also, an open data source, known as the COVID-19 Open Research Dataset (CORD-19), provided access to scientific research groups to a large number of documents on coronaviruses, including SARS-CoV-2 (Scott and Coiera 2020).

7.3.4 Contributions to Adaptation

The uncertainty and complexity of the impact of the COVID-19 pandemic worldwide reinforced the importance of a multidisciplinary approach to finding sustainable solutions (Pan and Zhang 2020). The capacity of cities previous to learn from previous disasters, and this novel coronavirus outbreak, had accelerated the trends toward utilization of smart city services (Chagoury 2020). Indeed, this crisis had demonstrated the rapid response and behavioral change of the urban population in terms of economic and business model, security, data privacy, and management of information (Davison 2020).

In the case of the Pimpri-Chinchwad Smart City, located at the region of Pune, the Pimpri-Chinchwad Municipal Corporation (PCMC) officials had adapted the smart technology and facilities into an Integrated Command and Control Centre (ICCC) to manage the COVID-19 outbreak in their locality (Costa and Peixoto 2020; Guha et al. 2020). The application of IoTs such as CCTV, real-time dashboard, GIS mapping, monitoring, and big data analytics had helped in dealing with the impact of the pandemic. Aside from the COVID-19 tracking and tracing functions, PCMC also implemented the SARATHI (System of Assisting Residents and Tourist through Helpline Information) which was an assistance platform to receive complaints or assistance requests from the population and was responded accordingly through smart analytics and categorization. In addition, the flexibility and learning capacity of other cities were demonstrated in the establishment of 45 more ICCCs across India. The crucial role that the ICCCs played in urban governance and management of the current disaster were recognized, which made the adaptation of such approach an essential consideration for future disasters (Guha et al. 2020).

Additionally, the public transport and freight sectors had experienced massive economic losses during the pandemic. The severe restrictions and lockdowns have suspended all transportation that posed a high risk for the spread of infection (Amir et al. 2020). Despite the drastic disruption, smart technology had fostered innovation, foresight capacity, and flexibility in developing solutions that adapted to the changes and uncertainty that this biological disaster had caused. For instance, the reduction in air pollution and improvement of air quality due to the halt in travel during the lockdown have strengthened the interest and investment of some cities in the UK for smart public transport. There is a massive plan to launch 3000 hydrogen buses in the cities of London, Aberdeen, Bimingham, Brighton, Liverpool, Manchester, Belfast, Glasgow, and Edinburgh, in partnership with the companies, Wrightbus and Ryse Hydrogen. This is in line with the goal to maintain the improvement of air quality even when the pandemic is over (Barrett 2020).

In India, the ride-hailing app Efleet had partnered with auto-rickshaws in the city of Jammu. The safety precautions such as installed protective screen between the driver and passenger areas, daily temperature checks for drivers, and provision of essential safety supplies such as face masks, sanitizers, and gloves were adapted to ensure hygienic transport (Amir et al. 2020). The use of the app provided an ease of transaction between consumers and the company and assured proper hygiene and safety measures for everyone. A case such as this reflects the prioritization of health approaches and related functions as one of the guiding principles in the adaptation and resilience of cities from future uncertainties (UN Habitat 2020).

Moreover, the connectivity between citizens and government was reinforced through smart technologies and has redefined the population's role as direct or indirect contributors to the urban resilience (Johnson et al. 2020). In fact, the important roles of citizen participation and the bottom-up approaches in smart cities are increasingly recognized. For instance, urban labs were established as collaborative efforts between cities, universities, tech companies, and local communities that aim to address urban issues. Some of the urban labs worldwide are MIT Senseable City Lab, University of Chicago's Urban Labs, Hyderabad Urban Lab, C4D Lab (University of Nairobi) and iHub in Nairobi, Laboratorio de Innovación Quito (LINQ), LABcapital in Bogotá, and the Laboratorio para la Ciudad in Mexico City (UN Habitat 2020). Furthermore, open data portals and open calls for innovative solutions could aid in improving public services and foster urban development. However, such approaches have also raised concerns about the standard, structure, and trustworthiness of the open data, which are challenges that need to be examined (McKinsey Global Institute 2018).

7.4 Discussions

The infectious nature of SARS-Cov-2 and the rapid spread of the COVID-19 disease worldwide had escalated it into a pandemic in a short amount of time. Its global impact had drastically affected systems and processes such as, but not limited to, the economy, global supply chains, transportation, and public health. Moreover, as centers of economic activities and other processes, cities were also severely impacted by the disease outbreak. Additionally, this biological disaster had highlighted existing urban planning issues and even exacerbated these issues in some instances. Undoubtedly, the necessity for effective response and management of this disaster and future disasters is crucial for the resilience of cities. In fact, it is argued that the pandemic has offered an unprecedented opportunity to learn lessons for improving urban resilience (Sharifi 2021).

In this chapter, the concepts of resilience and smart cities were explored. The definition of resilience, in the context of urban areas, was discussed with its phases of planning and preparation, absorption, recovery, and adaptation. Also, the definition of the smart city, along with the common smart city solutions, was reviewed. The smart solutions initially discussed were Big Data Analytics, Information and Communication Technology (ICT), and Internet of Things (IoTs). However, it was identified that smart city is not just all about advancements in technology and data. Furthermore, a framework for strengthening the resilience of urban areas due to smart city solutions was developed and analyzed.

Moreover, the contributions of smart city solutions to urban resilience were explored. These discussions were categorized according to its contribution to the phases of resilience. Also, some actual cases of smart city solutions were reviewed, and these are in the context of various cities response to the COVID-19 pandemic.

There is no general definition for resilience. In the urban context, resilience is understood as the ability and process of a city in dealing with external and internal shocks, and its flexibility to unknown disturbances. Resilience was analyzed in this study as a process in terms of its capacity to plan and prepare, absorb, recover, and adapt. Each phase had features which helped define it. Planning and preparation were based on the system's critical functions. Absorption depended on the threshold present in absorbing shocks. Recovery was determined through time and scale of the disturbance. Lastly, adaptation was based on memory, learning from, and management of functions that could not be recovered.

Like resilience, there was also no common definition for smart cities. Primarily, the goal of a smart city is to improve the quality of life of its population and improve operational efficiency. Initially, the concept of smart cities was focused on technology and infrastructure. This concept evolved as numerous studies on smart cities were conducted. The current idea is that although smart cities are heavily influenced by the advancement and utilization of technology, as demonstrated by the ICTs, IoTs, big data, etc., there is a growing recognition of the importance of the people and effective governance in smart solutions. The bottom-up approach and participatory measures are now deemed essential in the application of smart solutions to urban issues.

Additionally, a framework about the concepts of resilience and smart city was developed. This illustrated the essential components of smart city and its solutions. Also, it showed the role of these solutions to urban resiliency and how it related to planning and preparation, absorption, recovery, and adaptation.

Moreover, the contributions of smart city solutions to urban resilience were explored through its different phases, and in the context and real-world cases of

COVID-19 pandemic control. First, its contributions to planning and preparation have enhanced the resilience characteristics of connectivity, innovation, and resourcefulness. The utilization of big data and ICTs by different countries for functions such as contact tracing, tracking, and testing proved effective in early infection detection and management of the spread. However, concerns on data privacy, security, lack of regulation, and costs were also observed from the case studies.

Second, smart city solutions strengthened resilience characteristics such as connectivity, robustness, flexibility, and resourcefulness, when contributions to absorption were analyzed. The strict lockdown and physical distancing approaches brought about online learning and remote work. These initiatives were focused on maintaining critical functions in economy and education as much as possible. Smart solutions such as telemedicine, virtual meetings, work collaboration tools, social media, and other communication services were necessary to absorb the shock from the sudden distance and isolation. Additionally, government initiatives were not the only ones that applied smart solutions. Resilience was identified when bottom-up approaches by the people were initiated as they saw a gap in the situation. For instance, the case of Brazil in which smart technology was utilized by academic and scientific institutions to provide accurate, real-time updates on the COVID-19 pandemic to local communities.

Third, smart city solutions contributions to recovery have enhanced the resilience characteristics of connectivity, creativity, agility, flexibility, and inclusion. The cases in which the extensive use of artificial intelligence (AI) have brought about the essential application of drones and robots in certain situations. These smart technologies were used in contactless deliveries, provide alerts during lockdowns, and sanitize public areas; functions that prevented further spread of the disease. Another case was crucial role that AI played in the rapid development of COVID-19 vaccine. An endeavor that would usually take years to complete.

Lastly, contributions to adaptation had fostered connectivity, learning capacity, and flexibility in resilience. The response and behavioral change of the population in terms of information management, data privacy, and economic and business models were observed. The case of the establishment of Integrated Command and Control Center (ICCC) in Pimpri-Chinchwad Smart City, which was essential in fighting the COVID-19 pandemic, brought about 45 more ICCCs across India. This has also resulted in the government's investment on maintaining and establishing more ICCCs in planning for future disaster risks. Also, in the case of the public transport sector, due to the initiative to keep air pollution levels down after COVID, some cities in the UK are investing in smart buses. Furthermore, the widespread use of smart technology was observed to have changed how government bodies and citizens interact. The increasing interest in participatory approaches, encouraged by smart city solutions, has positioned citizens as direct or indirect contributors to decision-making for their city's development.

This article discussed the contributions of smart city solutions to urban resilience broadly. Further study is recommended to explore the specific resilience characteristics and how it was enhanced by smart city solutions. It is also suggested that the contributions of smart city solutions that were not heavily dependent on smart technologies, in the context of urban resilience and pandemics, be examined for future research.

7.5 Conclusions

Undoubtedly, the increasing importance of urban resilience requires a more comprehensive approach in addressing existing urban issues and the increasing number of disaster risks. The experience of the global population in the COVID-19 pandemic has reinforced the necessity for resilience characteristics such as, but not limited to, connectivity, innovation, resourcefulness, inclusion, and flexibility; so that communities would be able to plan and prepare, absorb, recover, and adapt from future disruptions. Additionally, as much as smart technologies and other smart solutions develop, it is imperative that the roles of the people and good governance do not fall behind. Also, it is essential that the advantages and disadvantages of smart city solutions be analyzed to prevent exacerbating existing socioeconomic urban issues such as inequality and poverty. Furthermore, the COVID-19 pandemic is far from over. As much as recent studies have tried to explore its impacts on the global population, there is still much to be observed and analyzed on its real long-lasting impacts and implications for urban resilience.

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