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# Contributions of Smart City Solutions and Technologies to Resilience against the COVID-19 Pandemic: A Literature Review

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**Abstract:** Since its emergence in late 2019, the COVID-19 pandemic has swept through many cities around the world, claiming millions of lives and causing major socio-economic impacts. The pandemic occurred at an important historical juncture when smart solutions and technologies have become ubiquitous in many cities. Against this background, in this review, we examine how smart city solutions and technologies have contributed to resilience by enhancing planning, absorption, recovery, and adaptation abilities. For this purpose, we reviewed 147 studies that have discussed issues related to the use of smart solutions and technologies during the pandemic. The results were synthesized under four themes, namely, planning and preparation, absorption, recovery, and adaptation. This review shows that investment in smart city initiatives can enhance the planning and preparation ability. In addition, the adoption of smart solutions and technologies can, among other things, enhance the capacity of cities to predict pandemic patterns, facilitate an integrated and timely response, minimize or postpone transmission of the virus, provide support to overstretched sectors, minimize supply chain disruption, ensure continuity of basic services, and offer solutions for optimizing city operations. These are promising results that demonstrate the utility of smart solutions for enhancing resilience. However, it should be noted that realizing this potential hinges on careful attention to important issues and challenges related to privacy and security, access to open-source data, technological affordance, legal barriers, technological feasibility, and citizen engagement. Despite this, this review shows that further development of smart city initiatives can provide unprecedented opportunities for enhancing resilience to the pandemic and similar future events.

**Keywords:** COVID-19; pandemic; smart cities; resilience; urban resilience; innovation



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## 1. Introduction

As of 6 July 2021, according to the COVID-19 Dashboard of Johns Hopkins University, there were over 184 million confirmed cases of the COVID-19 disease globally, resulting in more than 3.9 million deaths. Indeed, more than one year since its emergence in Wuhan, China, trends associated with the pandemic are still precarious. While initiation of vaccination programs has increased hopes of returning to normal conditions, the pandemic is on an upswing in some countries, as evidenced by the third and fourth waves of the infections and lockdowns. This is not the first time in human history that pandemics have hit cities. In fact, human communities have experienced deadlier pandemics such as the Spanish flu of 1918 [1,2]. A distinct feature that makes the COVID-19 pandemic unique is its occurrence in an era of increased connectivity driven by, among other things, globalization and technological advances in different domains such as information and communication technologies (ICTs). On the one hand, increased physical mobility and connectivity is argued to be one of the main factors contributing to the spread of the virus (Sharifi and Khavarian-Garmsir, 2020). On the other hand, technological advances have reduced reliance on physical connectivity, offering alternative methods to maintain urban functionality during times of crisis, when physical connectivity becomes limited. Such technological advances are increasingly discussed in the context of smart cities. In fact, in the past two decades or so, smart city solutions, enabled by technologies such as ICTs, the internet of things (IoT), artificial intelligence (AI), deep learning, and cloud computing have been emphasized for their potential to address societal challenges, and the recent pandemic has offered an unprecedented opportunity to test their effectiveness [3–6]. Accordingly, since the early days of the pandemic many communities have relied on smart solutions to contain the spread of the virus and enhance their response capacities [3,7]. Furthermore, the role of such solutions has also been recognized by the World Health Organization (WHO) and the US Center for Disease Control (CDC) [2].

Although the smart city is a relatively new field of research and practice, its literature is already vast and increasingly expanding [6,8]. As expected, the COVID-19 pandemic has provided additional momentum to smart city research given the potential utility of smart city solutions for dealing with the crisis. Accordingly, a large body of research has been published in this area over the past year or so [9]. This provides a good opportunity for reviewing the growing body of literature to examine if and how smart city solutions and technologies have contributed to dealing with the pandemic and helped build resilience. This line of research is important because reviewing existing social scientific and innovation research that focused on responses to COVID-19 can significantly contribute to understanding effective approaches to build resilience during a pandemic [10,11]. Despite this, there are only a few review articles on this topic, which mainly focus on a few types of smart technologies. Existing reviews provide valuable information on how some smart solutions and technologies such as AI, blockchain, IoT, and machine learning can be used to minimize the impacts of the pandemic. Marbouh et al. [12] reviewed different applications of blockchain-based technologies and showed their potential for dealing with pandemic challenges. They also proposed a tracking system based on blockchain that can contribute to controlling the spread of misinformation by validating data collected from different sources. Similar functionalities have also been discussed in a review by Chamola, Hassija, Gupta, and Guizani [2]. The latter also discusses how other technologies such as AI, IoT, and unmanned aerial vehicles (UAVs) can facilitate better management of the pandemic through improving, among other things, diagnosis, surveillance, and treatment capacities [2]. Focusing on the applications in the health sector, Naseem et al. [13] also found that AI-enabled solutions are effective in timely and accurate identification and monitoring and tracing of COVID-19 cases. While these reviews have been successful in highlighting the utilities of smart solutions, they are mainly sector-based (i.e., the health sector). Additionally, they do not provide a holistic analysis of contributions during different stages of the pandemic. To fill this gap, this study aimed to review contributions of smart city solutions to resilience, with a particular focus on cities. Focusing on resilience is desirable as it allows exploring contributions during different stages of crisis management. Accordingly, the major question guiding this review was: what are the contributions of smart solutions to combat (plan for, absorb, recover from, and adapt to) the pandemic and enhance resilience?

## 2. Definitions of Resilience and Smart City Solutions

Resilience is a polysemic concept that can have different definitions from one discipline to another [14]. In some disciplines, such as engineering, features such as robustness, resistance to shock, and minimal disruption are emphasized. In other words, it is expected that resilient systems are well prepared to undergo shocks without major functionality loss, and they are capable of rapidly returning to equilibrium points [14,15]. Therefore, such systems entail planning and preparation (pre-disaster), absorption (during disaster), and recovery (post-disaster) capacities. Other fields such as those related to social and ecological aspects and processes have a more dynamic approach to resilience (as opposed to the static approach of engineering resilience), and they pay more attention to the capacity to "adapt." Therefore, they recognize the possibility of multiple equilibrium or non-equilibrium (i.e., living with risk) states following disruptions [14,15].

For this study, we adopted a definition that entails a combination of all these different approaches. The definition was provided by the National Academies of Sciences, Engineering, and Medicine and has been frequently used in different disciplines. It defines resilience as the "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to actual or potential adverse events" [16]. This definition suited the purpose of this study as we aimed to discuss contributions during different stages of the crisis management.

In this context, planning and preparation refers to measures that are taken before the pandemic and that can facilitate better response. These could also include measures that are taken following the initial wave of the pandemic to ensure better preparation for the subsequent waves. Absorption is mainly related to measures that are taken at the immediate aftermath of the event to minimize functionality loss. Such measures also contribute to recovery to normal (pre-disaster) conditions [14,15]. Compared to absorption, however, recovery often takes a longer time. Finally, adaptation refers to the ability to seize the adverse event as an opportunity to enhance the overall performance in the short and long term. Therefore, it involves learning from the event and making necessary transformations (e.g., in operation, management, behavior, etc.) to ensure better planning and preparation for future events [14,15].

However, it is worth noting that resilience building should not be considered as a linear process, as it follows an evolving cycle that, ideally, leads to enhanced planning, absorption, recovery, and adaptation capacities over time. In addition, these four stages are not mutually exclusive, and measures taken during one stage may also contribute to the others. This is, particularly, the case for the recent pandemic. A unique characteristic of this pandemic that makes it distinguished from other adverse events such as earthquake or flooding is its continuous and evolving nature, as characterized by multiple waves of infection for instance. Accordingly, for example, there could be overlaps between measures aimed at absorption and recovery. Despite this, these four stages are discussed separately in the paper for simplicity.

Similar to "resilience," there is still no universal definition for smartness [17]. While smart initiatives were initially driven by ICT-enabled technologies and their integration with physical infrastructure, it is now recognized that non-physical dimensions and components (e.g., people, institutions, knowledge economy, etc.) are also important and inextricably linked to physical infrastructure [18–20]. Accordingly, efforts have been made to consider interlinkages between different dimensions as much as possible, particularly when discussing connections with the resilience stages and abilities. However, as data and technology are the cornerstones of smart solutions [17], and since more attention has been paid to technological dimensions in the literature, the technological dimensions of the smart city received more focus in this study. Smart solutions and technologies are diverse and can include AI, machine learning, blockchain, IoT, UAVs, autonomous vehicles, next-generation communication networks such as 5G, virtual reality (VR), augmented reality (AR), 3D printing, cloud computing, and big data analytics, among others [21,22].

## 3. Materials and Methods

This review was based on the content analysis of literature that has discussed actual and/or potential applications of smart technologies to combat the COVID-19 pandemic in cities. The procedures taken for the literature search and selection are shown in Figure 1. To identify relevant literature for inclusion in the study, we designed a broad-based search string that is a combination of terms related to smart solutions and technologies, the pandemic, and cities (see Appendix A). The initial search was performed using the Scopus database in October 2020 and returned 156 documents. Among different databases, Scopus was selected for its broad coverage of academic articles from different fields. As research related to the pandemic is rapidly expanding, we also activated the alert function of Scopus to receive weekly updates on newly published documents and add them to the database. In addition, reference sections of the retrieved articles were also checked to add potentially relevant research that was not retrieved from the initial search. Overall, 63 additional records were identified through these steps and were added to the database, resulting in a total number of 219 articles. Next, we screened the abstracts of these studies to determine their relevance to the review topic. Based on the resilience definition provided in the previous section, articles addressing issues related to planning, absorption, recovery, and adaptation abilities were considered relevant and selected for in-depth analysis. During this stage, 53 articles were excluded. Full texts of the remaining articles were downloaded for detailed content analysis. During the full text analysis, 19 other articles were excluded as we found them not relevant. Accordingly, the total number of articles reviewed for the purpose of this study was 147.

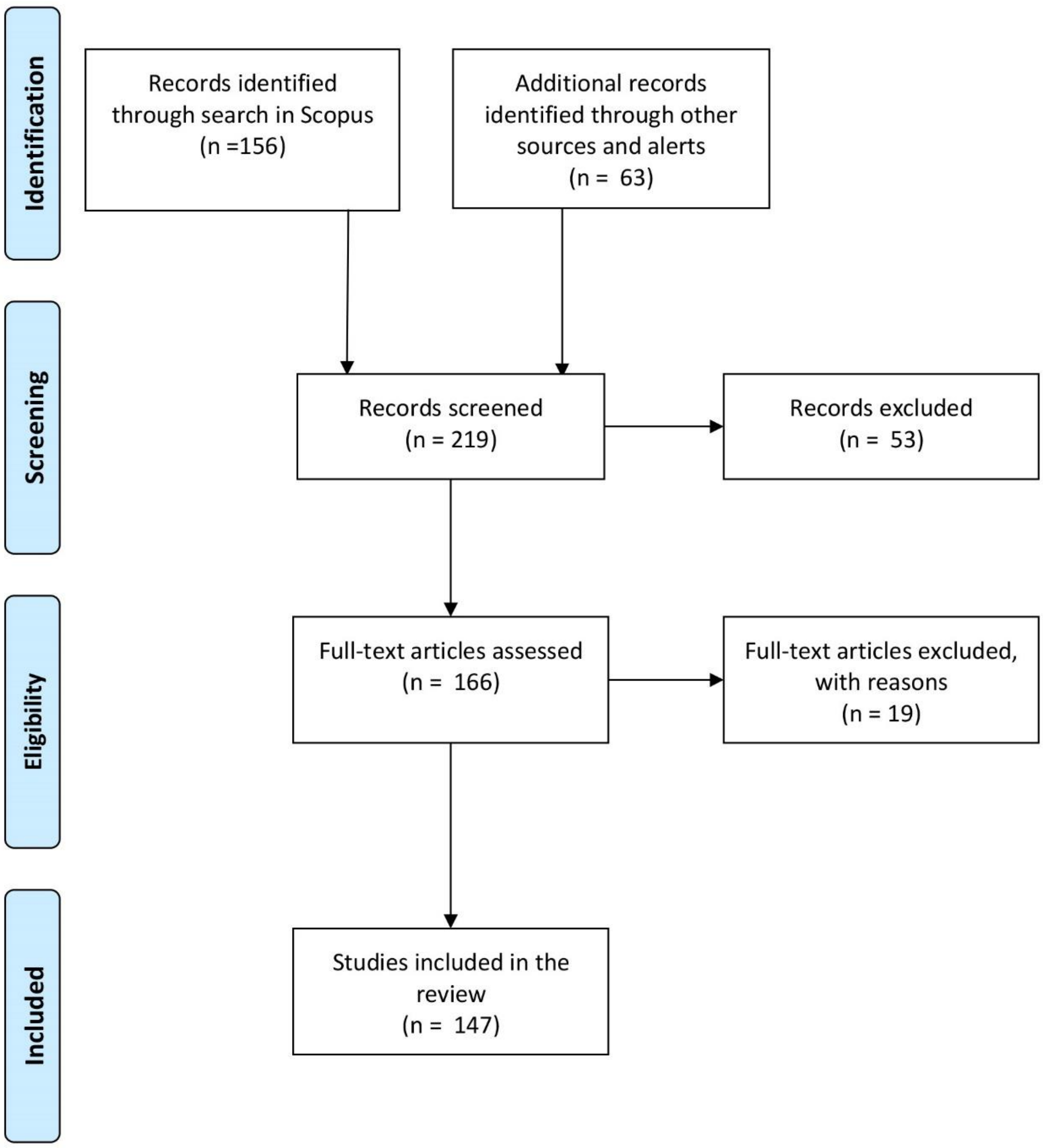


**Figure 1.** Procedures for literature search and selection. Adapted from Moher et al. [23].

For qualitative content analysis, we adopted an inductive approach. In inductive content analysis, data collection/extraction and analysis are performed simultaneously and discussions are developed incrementally [24]. The interpretive coding approach was adopted for this purpose. In other words, while reading each article, whenever information related to resilience (i.e., planning, absorption, recovery, and adaptation) was found, it was recorded in a separate Microsoft Word document. As the next article was examined, it was checked whether the discussed information (related to the four abilities) was new or could be combined with an existing record. This process was continued until all articles in the database were analyzed. It helped us to collect as much information as possible related to actual and/or potential contributions of smart technologies to resilience. At the end, we synthesized collected information related to each resilience ability, which is reported in the following section. This qualitative method can be considered as a "thematic analysis" approach that allows identifying and extracting themes from existing literature and classifying them to develop overarching themes and categories. This approach allows understanding major issues related to the research/review questions and may also provide insights on how they are interconnected by developing a hierarchical framework of themes and sub-themes [25].

It is worth noting that we also collected information related to the geographic focus of the publications and the type of smart technology they have discussed. The reviewed studies discussed applications in 32 different countries, with more cases reported from China, India, South Korea, the United States, the United Kingdom, Italy, South Africa, and Singapore (in descending order of frequency). In terms of solutions and technologies, there was more focus on artificial intelligence (AI) and its associated functions (e.g., machine learning and deep learning), smart phone apps and platforms, the internet of things (IoT), big data analytics, e-health and telemedicine, blockchain technologies, digital platforms for integrated data sharing and communication, and smart surveillance systems. In the following section we will discuss how these, and other technologies, have been used to enhance resilience abilities.

## 4. Results and Discussions

The thematic analysis identified 10 major contributions of smart solution technologies to the four resilience abilities (i.e., planning, absorption, recovery, and adaptation). These contributions are presented in Figure 2 and are discussed in detail in the following sub-sections.

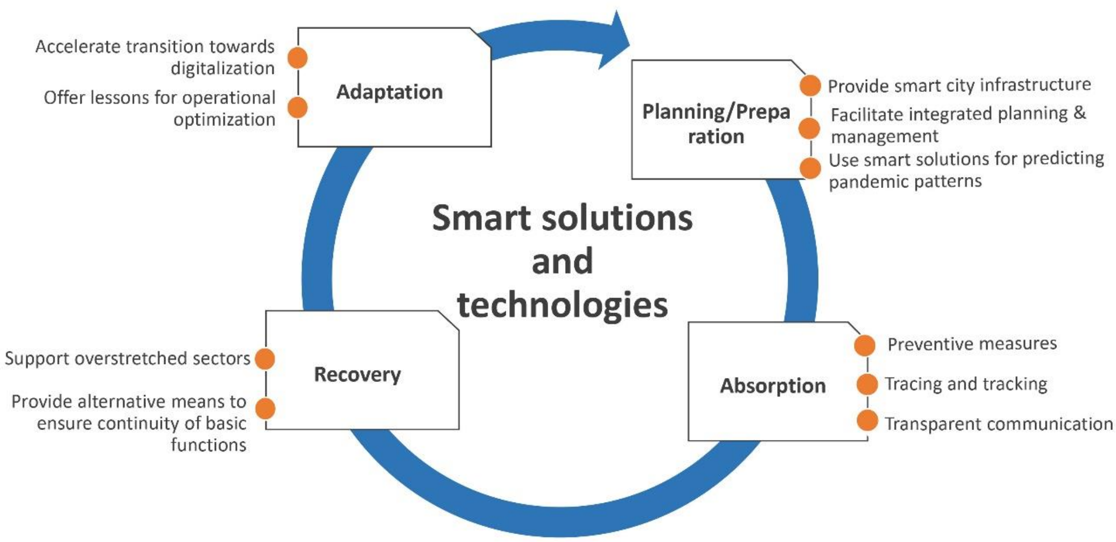


**Figure 2.** Contributions of smart solutions and technologies to different resilience abilities.

*4.1. Planning and Preparation*

Based on our synthesis of the literature, smart technologies and smart city policies have contributed or are expected to contribute to better planning and preparation by, among other things, preparing and providing smart city infrastructure, facilitating collaborative and integrated planning and management, and using smart technologies for forecasting and prediction and for identifying hotspots that can contribute to prevent or minimize disease outbreak. As can be seen in Figure 2, some of these actions should be done before the pandemic, whereas some others could have an ongoing and emergent nature and facilitate enhanced urban planning and management during different stages/waves of the pandemic. Figure 3 shows that different types of smart solutions and technologies can contribute to better planning and preparation. These contributions will be further explained in Sections 4.1.1–4.1.3.

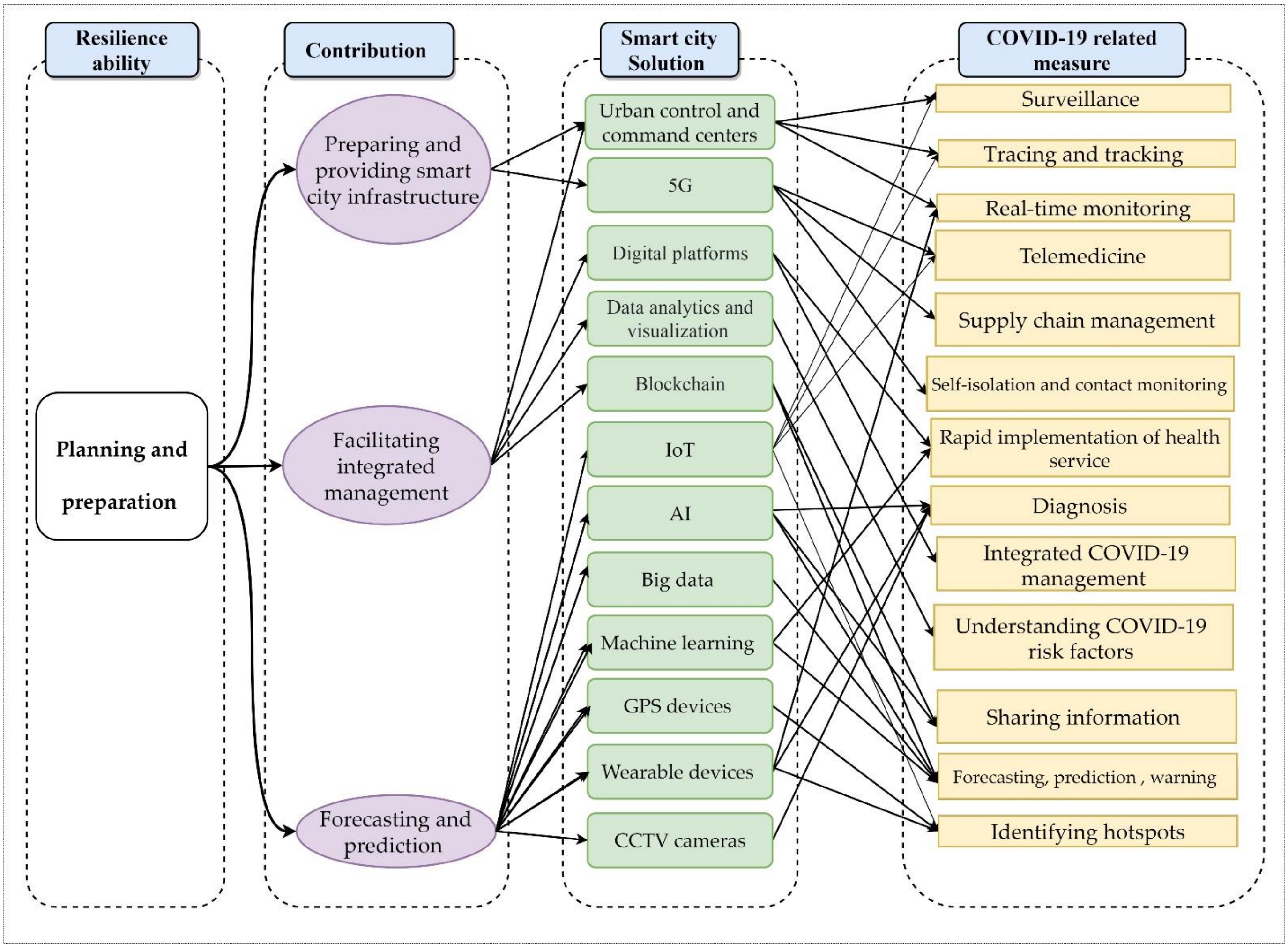


**Figure 3.** Contributions of different smart solutions and technologies to better planning and preparation. It is worth noting that these contributions are just highlighted based on evidence reported in the literature and are, therefore, not exhaustive.

4.1.1. Preparing and Providing Smart City Infrastructure

Planning and preparatory activities and measures taken before the occurrence of adverse events may affect the abilities to respond and recover. Although there have always been concerns about disease outbreaks that could become global health threats, the outbreak of COVID-19 surprised many cities around the world because of limited pre-event preparations [26]. However, there have also been some cities that have done better preparations, leading to a relatively better response. In fact, some cities that have suffered the least are those that have reacted in a timely and intelligent manner, based on lessons learned from previous disease outbreaks such as SARS [27]. Among other things, those previous experiences have led to increased investment in smart city infrastructures. In addition, investment in smart technologies could have been driven by other factors such as national smart city development policies or the hosting of major sporting or other events. During this recent pandemic, such cities have repurposed some of their existing smart city infrastructure to facilitate improved response abilities [28]. For instance, in some cases, cities have repurposed athletes' wearable devices for new purposes, such as remote health monitoring and modeling the virus's spread [29].

Hong Kong and Rio de Janeiro are examples of relatively well-prepared smart cities that have been relatively successful in controlling the pandemic. Hong Kong was one of the main cities that was hit by SARS in 2003, and its society was psychologically and practically prepared to encounter COVID-19. Cartledge [30] believes that Hong Kong's success in containing the virus can be attributed to two measures that are rooted in the city's planning and preparation efforts. First, the timely implementation of border control and the closure of land and sea borders within seven days after observing the first positive case. Second, using smart technologies to develop an effective testing system and tracing infected individuals and those that have come into contact with them. Another successful case, Rio de Janeiro, is a city that made significant investments in technological development to prepare for the 2016 Summer Olympics. Urban control and command centers developed during the Olympics for security purposes were reproposed during the pandemic to facilitate surveillance and tracing and tracking of infected individuals. It also allowed real-time monitoring of the changing urban dynamics and designing appropriate measures in response to the changing conditions to ensure a timely return to normal conditions [31]. Similarly, out of the 100 smart cities that are part of India's smart city program, 45 have repurposed their integrated command and control centers as COVID-19 war rooms [32].

One specific technology that has been highlighted for its contribution to pandemic control is 5G. Indeed, it has played a very important role in fighting the pandemic in cities that it operates in, such as Beijing, Shanghai, and Bangkok (Y Siriwardhana et al., 2020). While 5G infrastructure is more costly and complicated than 4G and 3G, it improves the efficiency, speed, and flexibility of the pandemic-related interventions such as telemedicine, supply chain management, self-isolation, and contact monitoring, and it allows rapid implementation of health services [33,34].

However, the existence of smart infrastructure may not always translate into a better response to the pandemic, and it should be coupled with other factors such as the availability of emergency plans and the agility of authorities. For instance, Hantrais et al. [35] emphasize that the data advantage that smart cities have compared to the other cities may not always help them to cope with the virus when, like other cities, they are not well prepared for a prevailing virus such as COVID-19. In contrast, cities that are not considered "smart" but that have emergency plans and know how to implement them effectively may be able to adapt quickly and show agility in delivering services in other innovative ways. These cities often have open, transparent, and accountable leadership and build partnerships with various public, private, and civil society stakeholders [35]. Despite this, smart infrastructures have shown great potential to facilitate an improved response and, as discussed below, they can also facilitate integrated approaches that further strengthen partnerships and collaboration.

#### 4.1.2. Facilitating Collaborative and Integrated Planning and Management

Cooperation between different sectors is essential for a timely response and recovery, as shown in places such as China, South Korea, and Singapore. Smart solutions can facilitate such cooperation [36,37]. For instance, the establishment of a multi-department information monitoring and sharing platform in Shanghai has facilitated cooperation between different departments, hospitals, and institutions, contributing to integrated management [37]. In contrast, evidence shows that fragmented governance and limited cooperation between different sectors and levels of governance has led to conflicts and made it difficult to combat the pandemic in some cities in the US and Australia [28].

Obviously, fragmented management is a long-standing problem and is, arguably, still dominant in many cities and across different sectors. For instance, traditionally public health emergency management systems have been centralized and relied on epidemiology and biomedical sciences only. This centralized model has proved ineffective in responding to the recent pandemic [36]. Instead, a new model wherein multidisciplinary knowledge/experience sharing can facilitate cooperative action, including urban authorities and other stakeholders, is needed. This will enable accessibility to data needed for evidence-based decision making and will allow coordinated, efficient, and more effective actions towards achieving common goals [36]. Such a new model can enhance resilience and adaptive capacity. Successful cases of using smart technologies and platforms exist that can inspire a paradigm shift towards more integrated urban planning and management.

As a case in point, around the world, urban observatories and similar platforms such as integrated command and control centers have proved very effective in facilitating evidence-based and integrated responses to the pandemic and also in enhancing trust across different stakeholders and urban sectors, which is essential for an effective response to the pandemic [17,38,39]. In Johannesburg, South Africa, the Gauteng City-Region Observatory (GCRO) used its data visualization and analytics capacities to identify social and environmental risks. It has helped understanding risk factors related to, for example, access to food, hygiene, and healthcare that may become more complicated when compounded by the pandemic effects. This integrated impact assessment allows designing and implementing suitable policy interventions [39].

In South Korea, an "Epidemic Investigation Support System" (EISS) system has been developed to facilitate integrated urban management in response to the pandemic through analysis of COVID-19 data [40]. The EISS system has facilitated integrated and seamless communication between different institutions. Conventional communication methods are based on bureaucratic processes for data acquisition and exchange, requiring excessive human resources and resulting in delays. In contrast, the EISS system facilitates real-time inter-institutional communication and information exchange with due attention to security issues. Compared to the manual method, this will reduce the time needed for processing data and, since the database is fully encrypted, the effects of potential security incidents will be minimized [40]. Moreover, the fact that an urban observatory constantly collects data related to different urban parameters allows collecting baseline databases that can help understand the level of impacts in the aftermath of crises such as COVID-19. In addition, the readily available data of the urban observatories enables taking timely data-informed decisions and mobilizing resources for effective disaster response [39].

In other contexts such as New Delhi and Newcastle, the coordination capacity of urban observatories and their utility for encouraging collaboration and facilitating paradigm shift from silo-based to integrated governance are demonstrated [28,38,39]. To further enhance the robustness of urban observatories, they can be developed based on innovative technologies such as blockchain. In fact, blockchain technology allows setting up a secure and distributed network for collecting, storing, and sharing information on COVID-19 patients, urban operations, and other variables. This way, a distributed database can be developed that makes it possible for policy makers and healthcare authorities to use this accurate and trustable data source for designing necessary response measures [2,41]. This can also facilitate developing early warning systems based on real-time data collection and analysis and can strengthen the forecasting and prediction capacities.

#### 4.1.3. Using Smart Technologies for Forecasting and Prediction and for Identifying Hotspots

Early detection of cases is essential for planning appropriate response measures to limit the spread of the disease. Various IoT- and AI-based technologies have contributed to this through, for instance, collecting travel card data, using speech-based diagnosis techniques, or using face scanners at supermarkets, airports, hospitals, and other crowded places to identify potentially infected individuals [2,22,42]. Analysis of these data using, for instance, big data analytics has facilitated developing early warning systems and models to predict the spread patterns and prevalence of COVID-19 and to inform decision makers of necessary preparatory and response actions to contain the spread of the pandemic [2,22,43,44]. For instance, machine learning techniques have been successful in accurately predicting the spread of the virus during its early stages [35].

Several promising examples have been discussed in the literature. Arguing that mainstream diagnosis systems such as polymerase chain reaction (PCR) are expensive and resource-intensive, unable to achieve large-scale diagnosis, and most likely fail to provide information on spread patterns, Sahraoui, et al. [45] propose a method based on the internet of vehicles (IoV) wherein equipping vehicles with thermal cameras, which measure the body temperature and breathing patterns of pedestrians, allows detection at a larger scale. In addition, integration of GPS devices allows obtaining real-time geo-located data of the suspected cases that can be used by authorities to take necessary response actions [45]. Similarly, using AI and machine learning, voice recognition apps have been developed that collect voice samples of many individuals (both infected and non-infected) and that estimate the possibility of infection by comparing an individual's voice pattern with that of an average person [2]. Although these methods do not substitute clinical testing for diagnosis, they can contribute to the large-scale detection of cases [2]. Similar cough-based, breath-based, and speech-based diagnosis techniques have also been mentioned in the literature [44]. Another good example is using wearable sensors as a quick way to identify cases and predict patterns [35]. Wrist-mounted wearables like the WHOOP Strap can function as early warning systems that detect deviation in health conditions of individuals (e.g., respiratory rate). This contributes to the early detection and treatment of infected individuals [2]. Chamola, Hassija, Gupta, and Guizani [2] also mention other wearables such as biosensor patches that can collect health information of individuals and report them to centralized cloud platforms so that healthcare staff can be aware of potential COVID-19 patients. They also introduce other wearable devices and sensors that collect and report real-time data (e.g., respiratory rate, temperature, etc.). Such devices have been developed in many countries like the US and China. In the latter, their widespread use has contributed to the country's success in controlling the pandemic [2].

Related to prediction capabilities, smart solutions have also been used to identify hotspots and risky public spaces that are essential for implementing targeted measures and policies [2,46]. In Tokyo, a chatbot-based health care support system named COOPERA was developed to collect large-scale information on the pandemic situation using a smart phone messenger application named LINE. About 4% of the city's population responded to the system's questions regarding their experience of related COVID-19 symptoms such as fever, a feeling of fatigue, and shortness of breath. Geographical distribution of these symptoms showed strong spatial correlation between respondents with symptoms and the cumulative number of confirmed cases, indicating that large scale monitoring using chatbot-based systems can be used as an effective method for understanding the pandemic situation and identifying infection hotspots in cites [47]. Similarly, Rezaei and Azarmi [46] developed a hybrid computer vision and deep neural network (DNN) model to automatically detect people in urban public spaces using CCTV security cameras. Using the spatio-temporal dataset of people's movement trajectories of Oxford's town center to evaluate the model, they demonstrated the utility of the model for identifying urban spaces that are not conducive to maintaining social distancing and that are likely to make it difficult to control the spread of the virus. Identification of these potentially high-risk areas helps planners and designers to redesign the structure of open and public spaces to make them more pandemic-proof [46].

Big data analytics can also help planners revise urban plans and policies in response to changing conditions. For instance, analysis of travel card data (boarding card) provides information on changes in ridership, and this can be utilized to revise transport policies.

Such IoT-based techniques can be used to design measures that enable a transition towards more effective and efficient transportation systems and can also help citizens [48].

*4.2. Absorption*

As discussed earlier, absorption refers to the ability to minimize functionality loss in the immediate aftermath of a disruptive event. Some of the planning-related capacities such as integrated management and early detection of positive cases can obviously also provide co-benefits in terms of absorptive capacity. As they have been discussed at length in the previous section, we are not repeating them here. Instead, this section focuses on other measures that are directly related to absorption, such as measures taken to prevent the spread and/or reduce the transmission speed of the virus, and measures taken to facilitate transparent communication and to prevent the spread of fake news that may make it difficult to deal with the crisis. Figure 4 shows that different types of smart solutions and technologies can contribute to enhancing absorption abilities. These contributions will be further explained in Section 4.2.1, Section 4.2.2 to Section 4.2.3.

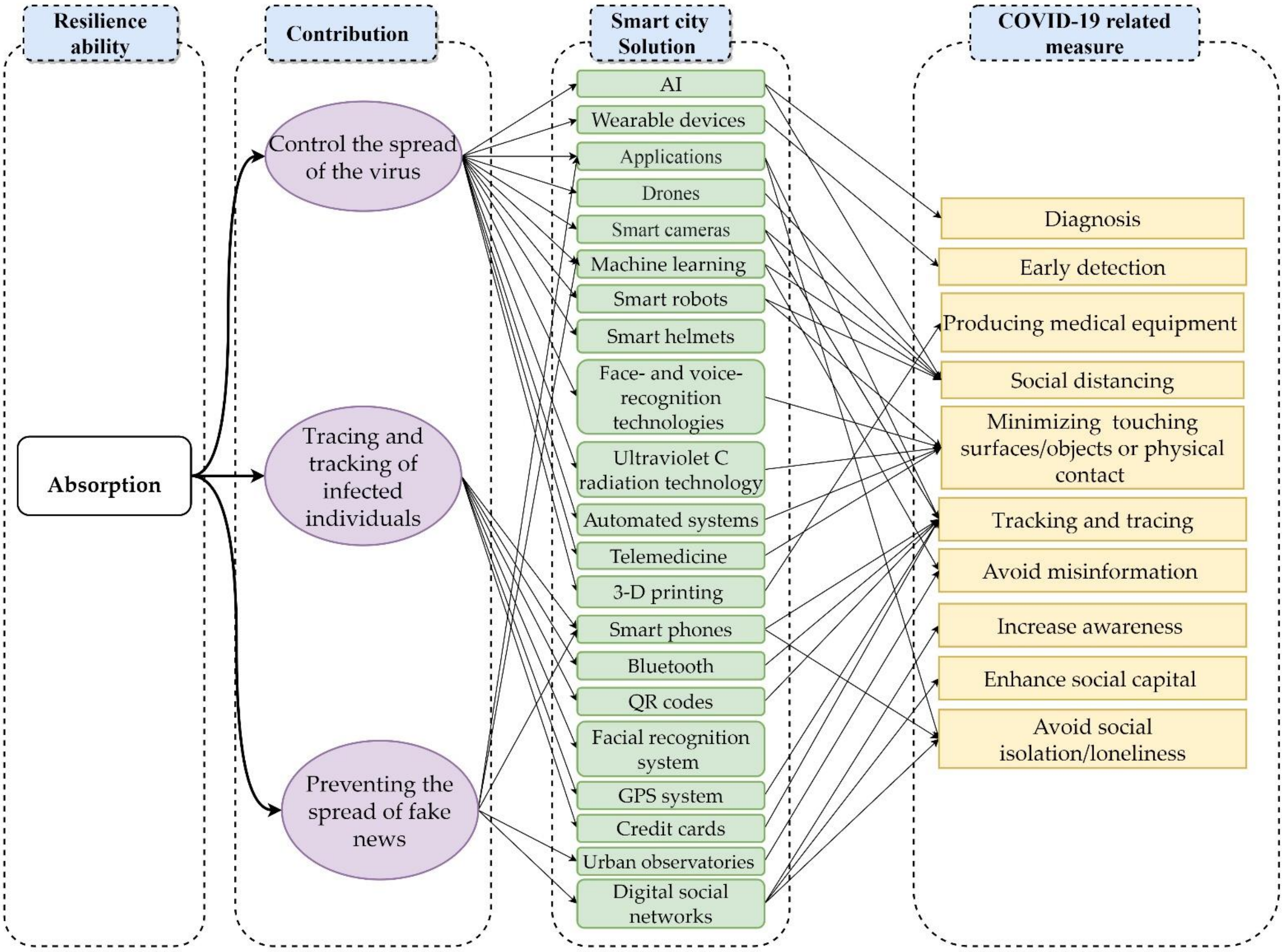


**Figure 4.** Contributions of different smart solutions and technologies to enhancing absorption abilities. It is worth noting that these contributions are just highlighted based on evidence reported in the literature and are, therefore, not exhaustive.

4.2.1. Preventive Measures to Control the Spread of the Virus

The utility of smart technologies for reducing the speed of virus transmission is highly emphasized in the literature. In fact, it is argued that cities (e.g., those in China, Singapore, and South Korea) that have used smart technologies have been able to respond in a timely manner [49]. Using such technologies has allowed them to successfully curb the spread of the virus and avoid or postpone the peak time, resulting in comparatively better performance and relatively less damage [28,49]. Two main methods to achieve this goal have been discussed. One is preventing the spread through minimizing the need for physical contact and/or ensuring social distancing. The other is using tracking and tracing techniques to ensure that infected individuals respect quarantine rules. The former is discussed here and the latter in the following subsection.

While medical and pharmaceutical solutions such as vaccination are necessary for controlling and preventing the spread of the virus, they are not sufficient as developing medical solutions takes time, there is no vaccine with a 100% efficacy rate, and mutant strains of the virus may emerge for which the vaccine may be less effective. Accordingly, the importance of non-pharmaceutical preventative measures should not be neglected [26]. The significance of using smart technologies has also been underscored by the World Health Organization [47,50]. As will be discussed under the recovery ability, such measures also help cities sustain their socio-economic activities and buy more time until medical solutions become available [34].

Extensive testing, early detection, and isolating those who have come into close contact with infected individuals is considered an effective measure for preventing the spread of the virus [36,40]. In this regard, AI-based technologies have been developed that can detect positive cases based on body temperature and common respiratory symptoms such as coughing and sneezing [2]. At the individual level, gadgets such as smartwatches and biometric wristbands allow individuals to monitor changes in vital signs, including body temperature and breathing [49,51]. This contributes to early detection. At the community level, in some cities strict monitoring was performed to prohibit individuals with fever from attending public places [52]. Smart technologies such as drones equipped with thermal cameras or smartphone apps have been used to detect individuals with symptoms and send alerts to those that do not follow emergency protocols and those who may be in their vicinity. Besides, such technologies can also inform citizens of restricted areas and infection hotspots that should be avoided [53–56].

For instance, in several places such as China, the US, the UK, and Italy data-driven, AI-enabled systems have been deployed that can contribute to achieving social distancing by facilitating mass surveillance using deep learning algorithms. Such systems monitor the conditions and send alerts to those who are in the vicinity of potentially infected individuals and also those who have symptoms, do not wear a mask, do not comply with lock-down measures, or do not respect social distancing protocols in public spaces such as streets or metro stations [2,50,57,58]. These systems feature a diverse range of technologies such as self-driving robots and drones equipped with sensors and thermal cameras and CCTV that use a combination of facial recognition systems and an infrared camera for crowd detection, distance monitoring, compliance control, and detection of potentially infected individuals [50,57–59]. Another example is smart helmets, which are used in China, India, and the United Arab Emirates for screening and identifying suspected cases. For example, police officers in Chengdu, China use smart helmets that can detect individuals with abnormal body temperatures within a 5-m radius [49,60].

In addition to measures focused on detecting individuals and ensuring compliance with social distancing protocols, smart technologies can also contribute to pandemic control by minimizing the need for touching surfaces/objects or physical contact between individuals or by contributing to the (mass) production of equipment needed for pandemic control. Face- and voice-recognition technologies are increasingly used to reduce the need for touching surfaces, and this can reduce the transmission risk [49]. To reduce the risk of human exposure to the virus, smart technologies have also been deployed to replace human workforces in risky places such as hospitals and airports. For instance, smart devices such as robots, equipped with ultraviolet C (UVC) radiation technology, have been used in India, US, and Denmark to clean and disinfect objects and places [2,49]. In countries like China, autonomous vehicles have been deployed for delivery of meals and medical supplies to hospitals. This has contributed to mitigating risks of cross-infection and has reduced the workload of healthcare staff [2,61]. Additionally, in the health sector, telemedicine is increasingly used to prevent the spread of the virus because it reduces the need for face-to-face medical visits of patients that are or are not infected. This is particularly important to reduce hospital visits of groups such as the elderly, which are more vulnerable to the pandemic [61]. As will be discussed later, telemedicine can also contribute to the recovery ability.

Finally, smart solutions may have also contributed to manufacturing devices that contribute to pandemic control. As a case in point, 3-D printing technology has been used for producing medical equipment in the innovation Co-Lab of Duke University. Similarly, the Georgia Institute of Technology and Emory University created a model that can be used to mass produce shied frames, and the Project Manus team of the Massachusetts Institute of Technology has come up with a disposable face-shield design, which produces 50,000 shields per day [62].

#### 4.2.2. Tracing and Tracking of Infected Individuals

The tracing and tracking infected individuals can contribute to absorption by containing the risk of excessive transmission of the virus in at least two different ways. First, by detecting the infection routes through following the movement patterns of infected individuals that can be used to identify people that have come into contact with them and take necessary actions [2,47,53,63]. Second, by making sure that quarantine rules are effectively implemented [47].

Contact tracing can be done either manually or by using smart solutions that rely on a variety of spatio-temporal data collected from different sources such as mobile network providers, transportation cards that allow access to origin-destination data, Bluetooth-based methods, QR codes, credit card transactions, and surveillance cameras [40,64,65]. Arguing that manual contact tracing is not sufficient for containing the pandemic because of its fast transmission rate, Rokni et al. (2020) demonstrate that large-scale uptake of a contact tracing app that stores contact proximity data and immediately alerts contacts in case they are exposed to positive cases and asks them to self-isolate can enable control of the pandemic. This also minimizes the need for a blanket quarantine and shutdown of the economy, which has major socio-economic and psychological implications, and can delay the recovery process [66]. Recognizing this, cities in different countries such as South Korea, Singapore, and China have taken actions to determine the exact location of infected cases with the help of smart solutions such as cashless transactions, CCTV footages, or positioning systems installed on smartwatches, smartphones, and biometric bracelets [49]. For instance, the facial recognition system has enabled Chinese agencies to trace and monitor the movement of people more effectively [57,67]. In Singapore, TraceTogether, a Bluetooth-enabled app that detects and stores nearby phone information, including the time of connection, has been used for contact tracing [2,57,67]. If a person is diagnosed with COVID-19, the app can identify all individuals who have encountered him/her using Bluetooth connection history. Accordingly, authorities can decide more targeted quarantine polices. Similarly, Google and Apple have suggested solutions based on Bluetooth low energy (BLE) technology for the tracing and tracking of infected individuals and understanding if they have come into contact with other people [2]. It is argued that next-generation 5G networks can enhance the efficiency of such technologies by improving battery performance and allowing direct connection to the network, instead of connection through intermediate gateways [68]. There are also some apps that are Bluetooth-based but collect GPS data that allow understanding and tracing the movement patterns of individuals. Examples of such apps are the Indian Aarogya Setu App. The use of GPS has, however, raised concerns about privacy, but governments have taken efforts to ensure that collected data will not be used for other purposes [2].

It is argued that the relative success of countries such as China and South Korea is partially attributable to their successful tracing of infected individuals using smart technologies. For instance, South Korea is one of the countries that has been lauded for its success in controlling the pandemic. In addition to extensive testing, this has been attributed to the large-scale adoption of smart technologies in Korean cities (i.e., credit and debit cards, mobile phones, and CCTV) to trace infected individuals and identify those who have had close contacts with them. This large-scale tracing has been achieved thanks to having a law that stipulates that "when the Minister of Health and Welfare declares a pandemic, the Center for Disease Control and Prevention (CDC) can request these data via the police" [65] (p. 484). The existence of similar laws that allow sharing data between different public bodies and hospitals have also contributed to pandemic control in China [37].

In some cases, tracing has also been used to ensure compliance with strict quarantine measures aimed at breaking the virus transmission chain (Chowdhury, Kabir et al. 2020). As a case in point, the "Self-Quarantine Safety Defense" app is used in South Korea to ensure effective self-quarantine, and it also allow individuals to record their symptoms and send status updates to inform authorities of their conditions [50,69]. Similarly, the "QuarantineWatch" app has been used in India to allow authorities to track compliance with self-quarantine rules. Using this app, individuals regularly send geo-tagged selfies that can be automatically verified by using facial recognition technologies [32]. Similar approaches have also been taken in cities in Poland, Russia, and Taiwan [57].

#### 4.2.3. Facilitating Transparent Communication and Preventing the Spread of Fake News

Effective communication systems are important for absorbing the initial impacts of any disruptive event. Lack of proper communication may lead to inadequate, ineffective, or delayed actions. For instance, a lack of transparency in communicating the conditions and threats posed by the virus is argued to be one of the main reasons for failure to contain it during early stages in China [2]. Although governmental policies and freedom of the media play important roles, it is argued that the increasing penetration of social media and communication apps can facilitate transparent communication. It is believed that effective and transparent communication and reporting of the conditions to the stakeholders and the public has contributed to the pandemic control in places such as South Korea and Singapore, and smart solutions have contributed to this [36].

The free flow of information and the increasing availability of online communication platforms may, however, lead to the spread of misinformation that, when coupled with the pandemic, can create additional problems [70]. Machine learning techniques can be used to avoid this risk [71]. For instance, Google and Facebook have used such techniques to detect and delete misinformation [2]. Urban observatories that collect real-time data on various urban parameters can also be effective in preventing the spread of misinformation and facilitating access to verifiable information [39].

In addition to facilitating transparent reporting of the conditions, digital social networks have also played an important role in increasing awareness about the pandemic and also helping people overcome stress caused by, among other things, social distancing. Since the early days of the pandemic, a large amount of educational content has been developed and released on social media and shared and re-shared across social networks, playing an integral part in containing the pandemic [72].

Social platforms have also allowed people to establish social networks for supporting vulnerable groups. This has contributed to enhancing social capital, which is critical for maintaining community resilience. For example, in response to the pandemic, several social groups in South Africa have developed cooperation networks to allow community assistance at the neighborhood level. Using WhatsApp and Facebook groups and pages, they organize activities such as food distribution and caring for the elderly and other vulnerable groups [73]. Similarly, in the UK, apps such as "Phone Pal" have been used to facilitate social connections between people and prevent psychological issues and physical health problems caused by social isolation [74]. This has been achieved, for instance, through offering volunteer telepsychiatry services [74]. The results of a survey conducted among Italian, Mexican, Portuguese, and Spanish older adults shows that smart technologies such as smart phones and apps have helped them cope with issues caused by the pandemic. They have used such technologies to maintain social interactions and avoid social isolation/loneliness, to get involved in rewarding activities such as doing their hobbies, to meet their spirituality needs, which are essential for overcoming challenges, through apps and websites designed for this purpose, to gain knowledge and instructions needed for checking and maintaining their health, to gain new knowledge and skills necessary for self-growth, and to use apps to improve their physical activities [75].

### *4.3. Recovery*

Any measures that enable communities to return to the pre-shock state in a timely manner can contribute to the recovery process. Some of the absorption measures discussed in the previous section (e.g., tracing and tracking that allows implementing targeted quarantine instead of blanket lockdowns) can also contribute to the recovery process. The literature synthesis shows that smart solutions can also facilitate a timelier recovery by providing support to the overstretched healthcare staff and by providing alternative means to ensure continuity of basic processes and functions. Figure 5 shows that different types of smart solutions and technologies can improve recovery abilities. These contributions will be further explained in Sections 4.3.1 and 4.3.2.

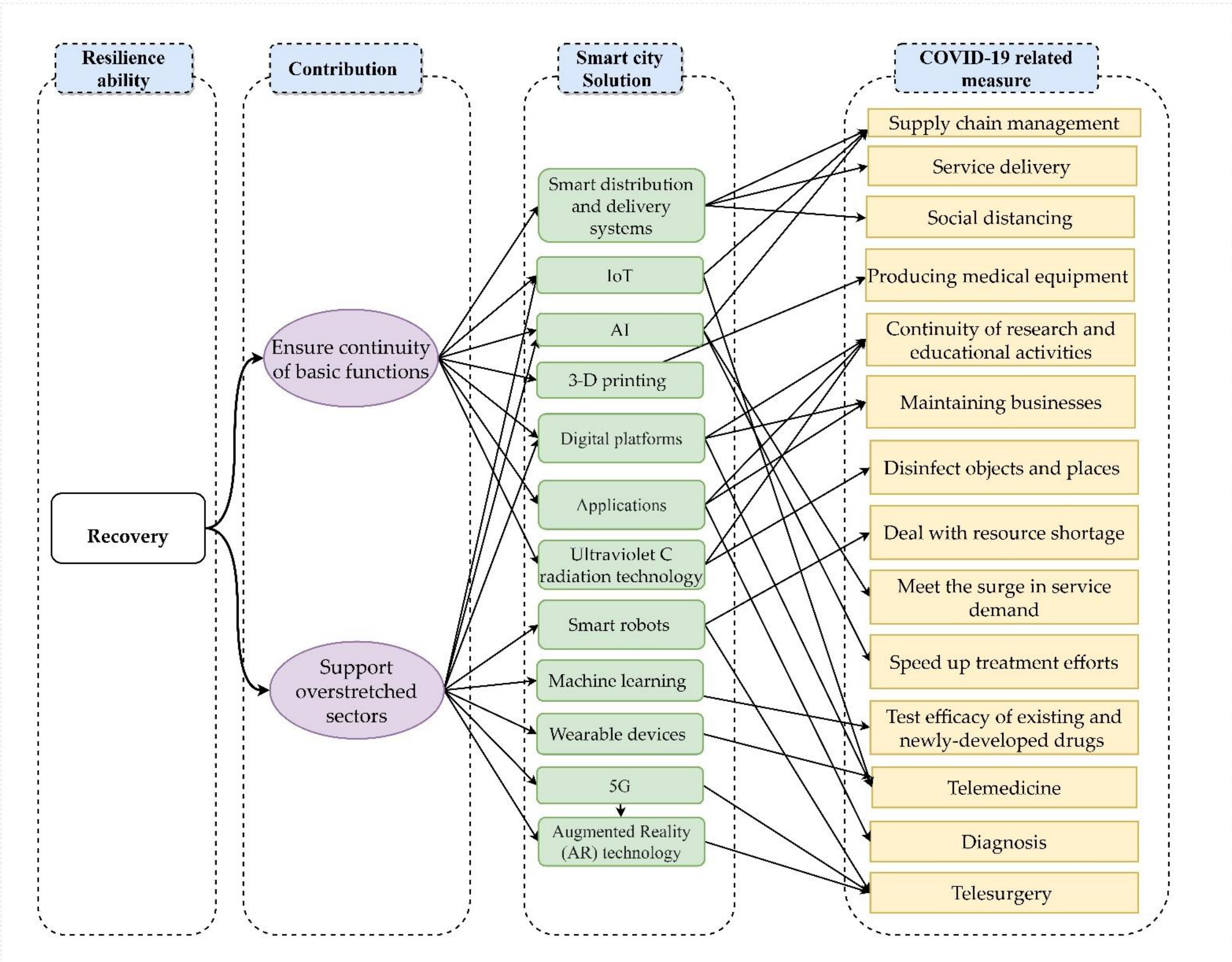


**Figure 5.** Contributions of different smart solutions and technologies to improving recovery abilities. It is worth noting that these contributions are just highlighted based on evidence reported in the literature and are, therefore, not exhaustive.

#### 4.3.1. Providing Support to the Overstretched Staff

The pandemic led to an exponential increase in the demand for services provided by some sectors, making it difficult for them to meet citizen expectations. The health sector was particularly affected, as the unprecedented increase in the number of COVID-19 patients, and the severity and urgency of their medical conditions, put limitations on the capacity of the health sector to address the needs of COVID-19 patients and other patients [68]. In fact, many hospitals around the world have reported shortages of necessary resources such as medical staff, ventilators, intensive care units, and protective equipment [2]. In this context, smart technologies have been widely used to overcome this issue and help healthcare centers recover their functionality. Smart technologies can contribute by either making some diagnosis and treatment techniques automated or by mainstreaming telemedicine, which helps reduce the frequency of hospital visits. In either case, deployment of smart technologies has been effective in addressing staff shortages, expediting service provision, preventing overcrowding in hospitals, reducing additional health costs and waiting times, and decreasing physical contacts between healthcare workers and patients [26,76,77].

Automated systems such as smart robots have been widely used to compensate for the shortage of medical staff by replacing humans [49]. While such movements have started several years ago, the pandemic has given more momentum to them and has offered a basis for expanding the roles of robots in a wide variety of sectors, including the health sector [78]. For instance, they have facilitated making better and faster triage decisions based on enhanced screening techniques [61,79]. AI-enabled computed tomography (CT) scanning is another area where smart technologies have enabled the health sector to meet the surge in service demand. As diagnosis based on polymerase chain reaction (PCR) is time- and resource-consuming, AI-enabled analysis of CT scans and X-ray images has been used to reduce the burden on radiologists and increase the response speed. This has proved to be an effective and efficient method of identifying potential COVID-19 patients [2,13]. In addition to assisting with COVID-19 diagnosis, AI-enabled technologies have been deployed to speed up treatment efforts. For instance, machine learning techniques have been used to rapidly test the efficacy of existing and newly-developed drugs [80]. Such techniques have also been used to track the capacities of different hospitals across cities and ensure a balanced load distribution as much as possible [79].

Increased adoption of telemedicine has also been essential for flattening the curve and easing the burden on healthcare centers. Telemedicine has allowed remote consultation and triage for suspected COVID-19 cases as well as other diseases [61]. In addition to reducing the burden of healthcare staff, telemedicine has contributed to containing the spread of the virus by minimizing the exposure of other patients to the COVID-19 virus, has allowed enhancing public awareness specially in remote areas, has facilitated communication and knowledge sharing between super-specialized hospitals and smaller emergency centers and ambulances to save the lives of patients in critical conditions, and has contributed to alleviating issues associated with loneliness and stress by allowing the patients to stay close to their relatives [49,61,77]. To mainstream telemedicine, in many countries, digital platforms have been developed that facilitate timely communication between doctors and patients. These smart healthcare systems function based on healthcare IoT or internet of medical things (IoMT) techniques and allow remote monitoring of patients and the tracking of their conditions using various systems such as chatbots and video conferencing systems combined with wearables that allow automated diagnosis and/or transmission of health information to medical staff for remote diagnosis or treatment [2]. For instance, chatbots, virtual assistant tools, and other systems allow communication with medical staff, as well as self-assessment. As a case in point, a coronavirus self-checker tool was designed by the US Center for Disease Control and Prevention and Microsoft to help users self-assess COVID-19 and recommend a suitable course of action [81]. In Seoul, hospitals have created an ICT-based dashboard that, combined with customized mobile apps, facilitates communication between patients and doctors. Data collected using this dashboard is stored in the hospital information system and is accessible by different medical institutions using a cloud-based system. The system also allows sharing other information such as x-ray images. The interoperability of the dashboard has been vital in flattening the curve in Korea [82].

Overall, telemedicine platforms have proved effective, particularly when coupled with other smart technologies such as robots, next generation 5G networks, and drones [2]. Such combinations can even enable complicated medical operations. For instance, Augmented Reality (AR) technology can be used to facilitate telesurgery using robotic systems by allowing experienced surgeons to provide remote guidance. As a novel technology, 5G can enhance the efficiency of this process by, among other things, enabling a better connection and enhancing battery performance [68].

#### 4.3.2. Providing Alternative Means to Ensure Continuity of Basic Functions

In addition to the health sector, ensuring the continuous operation of basic functions related to other sectors such as work and education is essential for rapid recovery to normal conditions. Since the early days of the pandemic, smart technologies have been adopted to design alternative solutions to reduce interruptions in various urban activities and functions and to ensure minimizing supply chain disruptions.

Disruptions in supply chains due to travel restrictions and a lack of key workers is one of the major impacts of the pandemic [49,79]. To minimize supply chain disruptions and to facilitate better service delivery, there has been an increasing reliance on smart distribution and delivery systems to ensure fair access to vital goods and services, including food and medicine, and this has also contributed to reducing high-risk face-to-face encounters [49]. In addition to an increase in online shopping, IoT- and AI-enabled technologies have been used to mitigate supply chain disruptions [44].

Supply chain disruptions can be minimized by, for instance, monitoring buying behavior to prevent panic buying, implementing targeted travel restrictions that allow/prioritize access to delivery vehicles, and using IoT systems that allow effective distribution and tracking of goods [68,79]. In fact, a combination of AI- and IoT-based systems and UAVs has made it possible to achieve smart logistics and completely automated supply chains in countries such as China [83]. Such systems have not only decreased the transmission risk by allowing contactless provision of services but have also facilitated delivery of goods and medical supplies to inaccessible locations in countries such as China and India [2,83]. It is argued that technologies such as blockchain can be utilized to support the functionality of AI- and IoT-enabled systems and to provide additional security and cost-saving benefits [68].

Computer-aided design coupled with 3-D printing is another smart solution that has been particularly effective in overcoming supply shortages that critical facilities such as hospitals have faced following the virus outbreak [84]. In fact, many hospitals reported a shortage of key logistical equipment such as masks and face shields, gloves, protective clothing, and testing kits soon after the outbreak [79]. In this regard, Nazir, Azhar, Nazir, Liu, Qureshi, Chen, and Alanazi [84] discuss how smart computer-aided design, in combination with 3-D printing, is effective for manufacturing lifesaving equipment and essential supplies that may become limited during pandemics or other similar disasters. The 3-D printing technology has even been used for the rapid manufacturing of portable isolation units that can facilitate better achievement of quarantine objectives or for production of drones used for monitoring compliance with social distancing measures or for detecting potentially infected individuals. Overall, integrating smart computer-aided design and 3-D printing through a cloud-based open access platform is an innovative solution that helps overcome issues faced by traditional supply chain systems and allows the rapid supply of equipment required for timely response and recovery from pandemics and other similar disasters [84].

In addition to contributing to supply chain recovery, smart solutions have also contributed to the recovery of other sectors. Online platforms and digital applications such as Microsoft Teams and Zoom have allowed the continuity of research and educational activities. They have also made it possible to organize official meetings and classes online [49,85]. Further, some technological initiatives have been deployed to facilitate returning to normal education. For example, to develop hand hygiene practices and make educational spaces safe, Herbert et al. [86] proposed and implemented a smart hand washing station based on the combination of UV light, a digital camera, and processing electronics in a school in Brisbane, Australia. No cases of COVID-19 were observed in the school during the test period. However, the duration of the research period was only ten days, and more time is needed to assess the efficiency and effectiveness of such hand-washing stations. Similarly, in the business sector, an increasing number of companies allow employees to work remotely in response to the pandemic. It is estimated that around 30% of North American and Western European employees are now working remotely, whereas this was estimated at 10% to 15% before the pandemic [81].

### *4.4. Adaptation*

As mentioned earlier, adaptation refers to the ability to learn from an adverse event in order to enhance the operation of the system and its capacity to deal with similar or more severe events in the future. In this regard, the adoption of smart technologies to deal with the pandemic has provided opportunities to accelerate the transition towards digitalization of different sectors and has also offered lessons that can be used to optimize city operations. Figure 6 shows that different types of smart solutions and technologies can strengthen adaptation abilities. These contributions will be further explained in Sections 4.4.1 and 4.4.2.

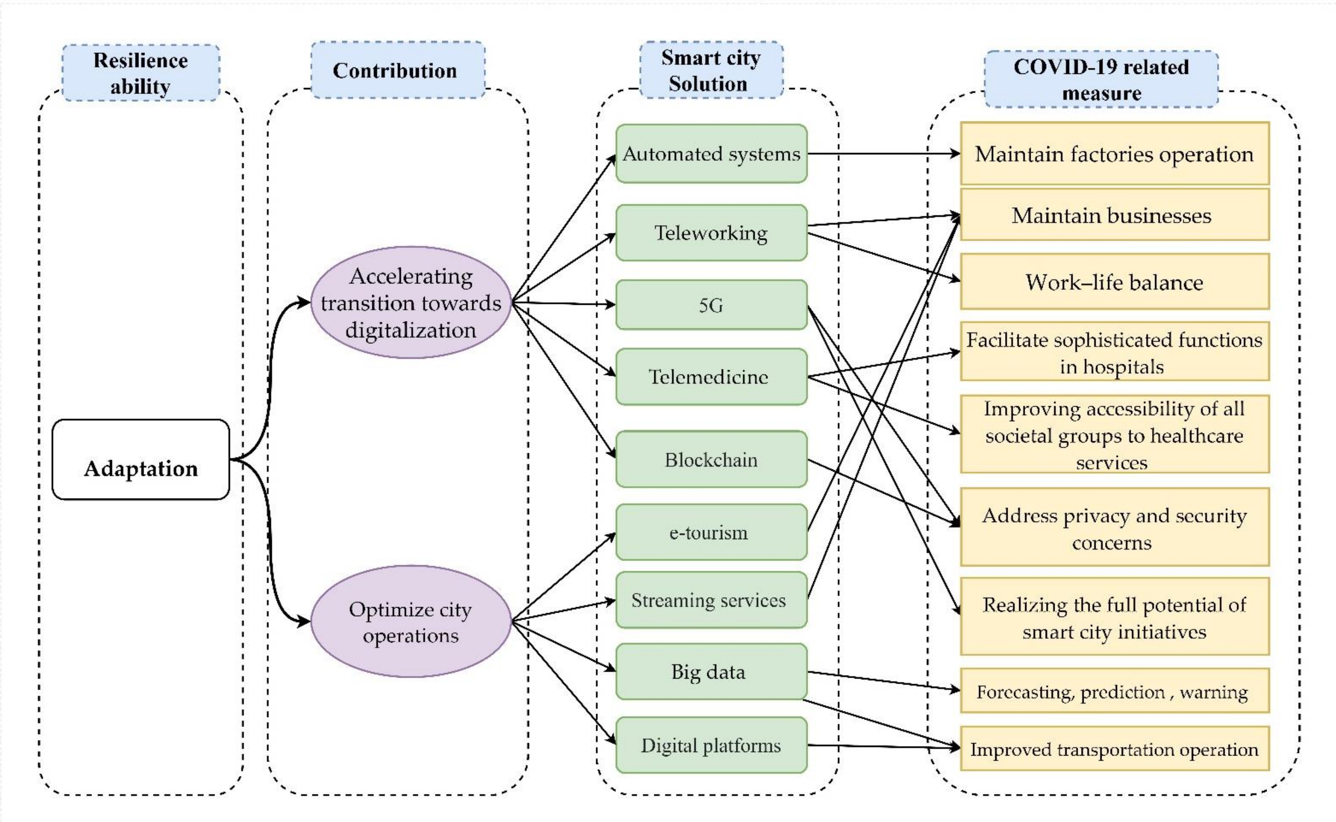


**Figure 6.** Contributions of different smart solutions and technologies to strengthening adaptation abilities. It is worth noting that these contributions are just highlighted based on evidence reported in the literature and are, therefore, not exhaustive.

#### 4.4.1. Accelerating Transition towards Digitalization

Long before the pandemic, smart city movements were gaining increasing interest in many parts of the world [4]. Given the potential contributions discussed in the previous sections, it is no surprise that the pandemic has provided additional momentum to smart city movements. In fact, it is argued that some activities and practices such as teleworking and telemedicine, which became prevalent during the pandemic to minimize human exposure to the virus, may become the new normal that will prevail in the post-COVID era [81,87]. This way, they not only provide innovative solutions to combat the pandemic but also enhance the capacity of cities to deal with future needs and threats [68,88].

The pandemic appears to have accelerated the digitalization trend faster than previous predictions [28,81]. It has brought to the fore some of the hidden or less known advantages of technical initiatives and has provided opportunities for real-world implementation of transformative smart city initiatives. These transformative initiatives have mainly been explored in the context of increased automation, which has facilitated innovative solutions such as teleworking and telemedicine.

Chen and Lin [89] believe that the closure of factories worldwide to control the transmission of the virus has posed an unprecedented challenge in sustaining the long-term functionality of factories. In this context, automation is considered as a critical solution. In fact, automation acceleration can be interpreted as an adaptation strategy adopted by many businesses around the world, which has allowed them to deal with the crisis. Based on this, it is expected that, in the coming years, there will be more investment on automation than previously estimated. While conventional automated systems are currently mainly used for low-level tasks, post-COVID automation may shift towards addressing the needs of high-level, complicated, and labor-intensive industrial activities [89].

The prevalence of teleworking is another expected new normal in the post-COVID era. Before the pandemic teleworking was considered as an option to enhance work–life balance. However, it has become the dominant work style and business strategy to survive during the pandemic [88]. Accordingly, employers have provided the necessary infrastructure, and employees have developed the skills required to work in the new work environment. This has allowed businesses to maintain their position in the market [81]. It can be assumed that remote working may become a more viable work style in the post-COVID period, and both workers and employers will continue to practice teleworking [90].

Florida et al. (2020), however, point out that some career groups are excluded from teleworking even during the pandemic. They argue that it was possible to work from home only for highly trained and experienced employees, whereas other groups that require face-to-face interaction did not have the luxury to operate remotely. Since most employees belonging to the former group are concentrated in large cities and metropolitan areas, it is expected that, in the post-COVID era, teleworking will prevail as a major working style in large cities. This may contribute to the better resilience of large cities to future pandemics. Teleworking may, however, not become a prevalent form of working in smaller cities, towns, and rural areas, which are less crowded, making it easier for residents to keep social distancing when needed [88,91].

Telemedicine is another smart city initiative whose potential and necessity became evident during the COVID-19 pandemic [92]. In the past, communication technologies were only used for low-level hospital tasks such as emailing test results or making appointments. However, they have facilitated other functions such as consultation, diagnosis, health monitoring, and even remote surgeries during the pandemic [93].

The emergency has inspired researchers to suggest novel solutions to some of the previous problems in telemedicine, which have improved its performance and can lead to better responses to similar health crises in the future. For example, some researchers have introduced novel methods to improve patients' privacy and safety [94]. As a result, patients can share their medical information securely with hospitals in the post-COVID era [95]. Rizzi, Polachek, Dulas, Strelzow, and Hynes [96] argue that while telemedicine does not appear to become a substitute for all in-person clinic visits, it can lead to favorable outcomes when it is used properly. For instance, it can increase the efficiency of the healthcare system and eliminate space and time barriers in the post-COVID era. This way, it is hoped that, as a new normal for cities, telemedicine will contribute to improving the accessibility of all societal groups to healthcare services [97]. This is particularly important in aging communities, which are expected to face a significant increase in the demand for healthcare services, leading to additional pressure on already strained healthcare systems [77]. To ensure the successful progress of the telemedicine initiative, new technologies such as 5G and blockchain could be used to not only reduce processing time but also better address privacy and security concerns [41,68,77].

#### 4.4.2. Offering Lessons to Optimize City Operations

Despite its adverse effects, the pandemic offers a window of opportunity to understand the weaknesses and shortcomings of different systems and to optimize their operations based on lessons learned [34]. In this regard, COVID-19 can be considered a turning point for the evolution of smart city movements, as it offers an unprecedented opportunity to understand what (and how) smart solutions can enable cities to better deal with adverse events. In addition, implementation of smart solutions can reveal issues that need to be addressed to enhance resilience.

One major lesson learned from the relatively successful cases such as South Korea and Singapore is that infrastructure development and high internet connectivity facilitate better responses to shocks. In general, realizing the full potential of smart city initiatives, such as telemedicine and teleworking hinges on the quality of the internet connection [34]. Evidence shows that cities equipped with 5G technology have been more successful in combatting the pandemic through innovative solutions such as telemedicine, teleworking, and smart surveillance [33]. These insights and experiences offer a strong reason for cities to increase their ICT infrastructure investment in the post-COVID period. More smart cities are expected to shift towards 5G and even 6G deployment since more effective adoption of smart city technologies requires new generations of wireless technology. It is argued that such technologies can enable better responses to future pandemics through facilitating the adoption of new initiatives and technologies such as telesurgery, hospital-to-home (H2H) services, digital twins, and intelligent wearable devices (IWD) [98]. Based on this, cities are expected to speed up their efforts to overcome the obstacles to the development and deployment of new generations of wireless technology [33,98].

The pandemic showed that adoption of smart solutions is an effective way to understand emergent societal demands and adapt to changing conditions. For instance, in sectors such as tourism and leisure that were hit hard by the pandemic, smart solutions like e-tourism and streaming services were deployed to mitigate the negative impacts [68].

Smart solutions such as big data analytics can also be utilized to understand the impact patterns and develop transformative future plans that integrate tourism with other sectors such as mobility and health/well-being and that contribute to the sustainability and resilience of tourism [99]. Insights gained from big data analytics can also inform the transformation of other sectors. For instance, analysis of travel card data (boarding card) provides information on changes in ridership and its implications. This can be used to revise transport policies. For instance, a study conducted in Qingdao, China shows that the pandemic has reduced bus ridership. This study demonstrates that when bus ridership is reduced by more than 30%, passenger cars are greener options than buses as their per-capita emission (GHG) is lower [42].

Panel analysis of mobility data (comparing data from the lockdown period with baseline data) can also offer insights on other issues such as emerging mobility needs, socio-economic and environmental impacts of different travel modes, and potential links between mobility patterns and death/infection rates. Some companies such as Apple and Google have already made efforts in this regard [44]. Based on information obtained from such analysis of mobility data, it would be possible to, for instance, optimize transportation services during different times of the day and consider different situations. This can contribute to enhancing the overall performance of the city in the post-COVID era [79]. Obviously, optimal fulfillment of these functions depends on the availability of smart platforms (e.g., the EISS system in Korea or other observatories around the world) that integrate various technologies such as IoT, AI, mobile technology, etc. [40,99].

Last but not least, smart solutions contribute to long-term adaptation by providing other co-benefits. Improving efficiency is a major expected co-benefit that is expected to be achieved by implementing smart solutions. For instance, teleworking and telemedicine provide co-benefits in terms of improving air quality and reducing resource use such as energy consumption and associated emissions [61]. Teleworking may also improve labor productivity through saving travel times [61]. As evidence shows, smart solutions such as telemedicine and teleworking may also improve citizen satisfaction, which is essential for enhancing social resilience. The latter can also be further improved by promoting the use of inclusive smart solutions that raise awareness and create innovative platforms for engagement of all citizens in social activities [61,97,100].

## 5. Conclusions

### *5.1. Summary of Major Contributions*

In this study, we reviewed literature published on the use of smart solutions and technologies during the pandemic to find out if they have contributed to enhancing resilience. The main findings of the review are summarized in Tables 1 and 2, indicating that smart solutions have the potential to enhance all abilities. The availability of smart city infrastructure was found to be a critical factor that strengthens the ability to plan and prepare for the pandemic through facilitating integrated management and offering opportunities to predict patterns related to the pandemic. As for the absorption ability, smart solutions facilitate better implementation of preventive measures through advanced surveillance methods and/or by allowing contactless provision of services. Absorption ability can also be enhanced by deploying tracing and tracking systems that help authorities enforce quarantine and social distancing measures and/or through transparent communication of information about the state of the pandemic that raises citizen risk awareness and avoids problems that can be caused by the spread of misinformation.

**Table 1.** Summary of major contributions of smart solutions and technologies to resilience.

| Resilience Ability | Issues Related to Contributions of Smart Solutions and Technologies |
|---|---|
| Planning | Preparing and providing smart city infrastructure<br>• Previous investment in smart infrastructure that can be repurposed for fighting pandemics<br>• Infrastructure availability coupled with integrated disaster management plans and committed leadership enhance preparation capacity<br>Facilitating collaborative and integrated planning and management<br>• Platforms for exchanging data and information can facilitate cooperation<br>• Urban observatories and integrated command and control centers contribute to integrated management and facilitate interoperability<br>Using smart technologies for forecasting and prediction and for identifying hotspots<br>• Contributes to early detection of the virus that can lead to timely action<br>• Prediction models can help identify potential hotspots and design targeted measures and policies |

**Table 1.** *Cont.*

| Resilience Ability | Issues Related to Contributions of Smart Solutions and Technologies |
|---|---|
| Absorption | Preventive measures to control the spread of the virus<br>• Surveillance and extensive testing using smart technologies contributes to preventing or postponing the spread of the disease by providing methods for efficient and accurate detection<br>• Monitoring and surveillance systems can be used to ensure compliance with social distancing rules<br>• Contributes to pandemic control by minimizing the need for touching surfaces/objects or physical contact between individuals<br>Tracing and tracking of infected individuals<br>• Detecting the infection routes through following the movement patterns of infected individuals<br>• Ensuring that quarantine rules are effectively implemented<br>Facilitating transparent communication and preventing the spread of fake news<br>• Facilitating transparent communication<br>• Contributes to controlling the spread of misinformation<br>• Raising awareness and facilitating social interactions |
| Recovery | Providing support to the overstretched staff<br>• Partial automation of diagnosis, treatment, and other techniques<br>• Reducing hospital visits by mainstreaming telemedicine<br>• Reducing waiting times and additional health costs<br>Providing alternative means to ensure continuity of basic functions<br>• Minimizing supply chain disruptions<br>• Contributing to recovery of different sectors through teleworking, e-learning, etc. |
| Adaptation | Accelerating transition towards digitalization<br>• Providing additional momentum and strengthening the case for smart city development movements<br>• Offering opportunities for real-world implementation of transformative smart city initiatives<br>• Mainstreaming practices such as teleworking and telemedicine that can decrease vulnerability to similar future events<br>Offering lessons to optimize city operations<br>• Offering lessons on how to deal with emergent societal demands<br>• Stimulating transformative solutions<br>• Providing co-benefits such as efficiency improvement and air pollution mitigation that contribute to long-term resilience |

The utility of smart solutions for enabling recovery to normal conditions has also been demonstrated in the literature. Because of the pandemic, healthcare facilities in many countries were overloaded. Smart solutions can mitigate this problem through partial automation of healthcare services, increasing penetration of online services that reduce the need to visit hospitals, and also saving time and costs. In addition, the deployment of innovative smart solutions can enable other sectors to have a timely return to business as usual by minimizing supply chain disruptions and/or offering alternative options to their conventional modes of operation. Finally, it is argued that the pandemic has strengthened the case for smart city development by highlighting its potentials and offering unprecedented chances for implementing innovative smart solutions. This is expected to contribute to the long-term adaptation of communities by instigating transformative solutions that also offer multiple socio-economic and environmental co-benefits.

**Table 2.** Multiple resilience-building benefits of smart solutions and potential concerns to be addressed.

| Resilience Ability | Benefits of Smart Solutions and Technologies | Examples | Concerns/Cautions |
| --- | --- | --- | --- |
| Planning | • Existing smart city infrastructure can be repurposed to contribute to pandemic control<br>• Smart infrastructure allows real-time understanding of changing urban dynamics and designing appropriate response measures<br>• Smart platforms can facilitate cooperation between different city departments and prevent fragmented governance and conflicts<br>• Smart platforms facilitate decentralization of crisis response and management, thereby facilitating a timelier response, enhancing efficiency<br>• Smart solutions enable better data accessibility for evidence-based disaster management<br>• IoT- and AI-based technologies allow early detection through big data analytic capacities<br>• Ability to complement existing diagnosis systems such as PCR that are resource-intensive and fail at large-scale diagnosis<br>• Smart solutions facilitate identifying hotspots for designing targeted actions and policies | • Repurposing of command-and-control centers in Rio de Janeiro and India<br>• Multi-department information monitoring and sharing platform in Shanghai<br>• Urban observatories in, among other places, South Africa, India, South Korea, and the UK<br>• Internet of vehicles integrated with GPS for large-scale detection and tracing<br>• Voice-based, cough-based, breath-based, and speech-based diagnosis techniques<br>• App-based approaches for identifying hotspots | • In the absence of holistic disaster risk management plans, available smart infrastructure may not be used effectively<br>• Data security could be an issue that can be solved using new technologies such as blockchain<br>• Planning and implementation of smart solutions is resource intensive (budget, skilled personnel, etc.), and some cities may not have adequate capacity |
| Absorption | • Smart solutions can contribute to reducing the speed of virus transmission by facilitating social distancing and using tracing and tracking techniques to detect infection routes and ensure compliance with quarantine rules<br>• Smart tracing and tracking minimize the need for blanket lockdowns, thereby minimizing economic impacts<br>• Increased advances in face and voice recognition reduce the need to touch surfaces, thereby reducing transmission risk<br>• Advances in automation allow replacing human workforces in risky places such as hospitals and airports<br>• The free flow of information facilitated by smart solutions enhances transparency that is critical for pandemic control<br>• Social network platforms allow raising awareness about the pandemic, establishing mechanisms to support vulnerable groups, and maintaining social interactions | • Use of AI-based technologies, gadgets, drones equipped with thermal cameras, etc. for early detection<br>• Use of transportation cards that allow access to origin–destination data, Bluetooth-based methods, QR codes, and credit card transactions for tracing and tracking<br>• Promotion of telemedicine to reduce the need for face-to-face hospital visits<br>• Use of robots, equipped with ultraviolet C (UVC) radiation technology for disinfection<br>• WhatsApp and Facebook groups have been used to organize activities such as food distribution to vulnerable groups | • Concerns about privacy<br>• Concerns about government misuse of collected information<br>• Need for (updating) regulations to govern data sharing and control<br>• Free flow of information may lead to the spread of misinformation |

**Table 2.** *Cont.*

| Resilience Ability | Benefits of Smart Solutions and Technologies | Examples | Concerns/Cautions |
|---|---|---|---|
| Recovery | • Smart technologies help overstretched sectors such as the health sector recover functionality<br>• Telemedicine has contributed to flattening the curve in many countries<br>• Smart technologies have contributed to ensuring the continuous operation of different sectors (e.g., business, education, etc.)<br>• Smart technologies help minimize supply chain disruptions | • Automation of diagnosis and treatment<br>• AI-enabled computed tomography scan<br>• Use of IoT systems for effective distribution and tracking of goods<br>• Monitoring purchase behavior to prevent panic buying<br>• Computer-aided design combined with 3-D printing | • Inequitable access to smart devices<br>• Limited penetration of smart solutions such as telemedicine |
| Adaptation | • Smart technologies have enabled cities to adapt to the new normal conditions through solutions such as teleworking<br>• Further adoption of new modes of operation (e.g., telemedicine and teleworking) may lead to more sustainable lifestyles in the long run<br>• Smart solutions enhance the efficiency of urban operations<br>• Adoption of smart solutions is an effective way to understand emergent societal demands and adapt to changing conditions | • Teleworking has become the new normal in many countries<br>• E-tourism and streaming services have been adopted to minimize negative impacts on the tourism and leisure sectors<br>• Transport policies have been revised based on changes in transit ridership | • Not all people and organizations have the necessary skills to adapt to the new conditions, and this may lead to their exclusion |

### *5.2. Key Implications for Policy and Practice*

Based on what was discussed in the previous section, the following major implications for policy and practice can be highlighted:

- Investment in smart city technologies can enhance the capacity to respond to and recover from adverse events like pandemics that require timely and integrated actions across different sectors. The availability and proper application of such technologies could contribute to early detection and effective tracing and tracking and, thereby, the successful control of pandemics;
- Maximizing benefits of smart city infrastructures, however, depends on the availability and proper implementation of emergency plans and medium- and long-term vision for disaster risk management;
- Smart technologies based on IoT and blockchain provide opportunities for developing platforms such as urban observatories and integrated command and control centers that facilitate cooperation and a timely response and that contribute to avoiding fragmented management;
- While transparent communication and free flow of information are essential for controlling pandemics (and similar adverse events), appropriate measures should be taken to prevent the spread of misinformation that may cause additional problems;
- Finally, based on the multiple contributions discussed in the study, the pandemic is expected to accelerate investment in smart cities across the world. This is likely to enhance the ability of cities to plan and prepare for, absorb, recover from, and adapt to future adverse events. To achieve this goal, however, it is essential to ensure equitable access to smart city services. Furthermore, to contribute to solving other

societal challenges, it is important to increase the environmental co-benefits of smart city development and minimize potential trade-offs.

### *5.3. Limitations and Recommendations for Future Research*

Overall, this review improved our understanding of the contributions of smart solutions to resilience. However, there are limitations that need to be acknowledged. Although it was demonstrated that smart solutions and technologies have great resilience building potentials, realizing these potentials may depend on various socio-economic and institutional factors that are not discussed in this article. These include, but are not limited to, overcoming issues related to privacy and data security, the availability of open source data that is necessary for applying some initiatives such as tracing and tracking, technological affordance to ensure just access to services, legal barriers that may make implementation of smart initiatives challenging, people's support and engagement in smart solutions, and technological limitations that may make scalability challenging. These are major issues that need to be explored in future research. Future research should also better explore if and how some smart solutions can have linkages to multiple resilience abilities. For instance, it was discussed that some planning-related measures can also enhance the absorption and/or recovery abilities. However, these warrant a more comprehensive examination. Finally, this review only focused on contributions of smart solutions to resilience. While contributions may be dominant, it is also worth examining if deployment of some smart solutions may detract from the resilience abilities. Similarly, it should be examined if implementation of smart solutions contributes to or detracts from sustainability. Despite these limitations, we hope that this review will inform researchers and policy makers of the potentials of smart solutions, thereby providing opportunities for better responses to pandemics and other similar events in the future.

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## Appendix A

TITLE-ABS-KEY ((“ict” OR “iot” OR “internet of things” OR “machine learning” OR “blockchain” OR “data analytic*” OR “smart” OR “Information and communication technolog*” OR “information technolog*” OR “artificial intelligence” OR “unmanned aerial vehicle*” OR “UAV*” OR “cloud computing”) AND (“covid*” OR “coronavirus” OR “pandemic”) AND (“city” OR “cities”)).

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