COVID-19 pandemic: a review of smart cities initiatives to face new outbreaks

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Abstract: While the world still struggles against the devastating effects of the COVID-19 pandemic, governments and organisations are discussing how new technologies can be exploited to relieve its impacts and how future pandemics can be avoided or minimised. Among the envisioned solutions, the development of more efficient and widespread smart city initiatives can improve the way critical data is retrieved, processed, stored, and disseminated, potentially improving the detection and mitigation of outbreaks while reducing the execution time when taking critical actions. In fact, some first responses to this pandemic are exploiting different technological solutions that could be ultimately adopted in more integrated city-scale systems, opening many possibilities. Therefore, this study discusses potential solutions and review recent approaches that can be exploited in this complex scenario, describing feasible and promising development trends for the construction of the new expected health-centric smart cities.

1 Introduction

The dramatic events of the COVID-19 pandemic in 2020 are expected to deeply change the way health information will be managed in this century. With the rapid and almost uncontrolled propagation of the SARS-CoV-2 virus, with untraceable cases suddenly arising inside the borders of countries even far from known outbreak epicentres, the need for more efficient management of critical information has become apparent [1]. The lessons left from this outbreak are pointing to more coordinated actions from governments and public organisations, requiring new levels of urban digital integration [2]. In fact, for this complex envisioned scenario, the smart cities can be leveraged as one of the best resources to face this and next pandemics [3].

Nowadays, most people live in cities. Since this trend is not expected to change in this century, large cities will be the home of most part of mankind. Besides, the expected problems originated from this urbanisation process, such as pollution, energy efficiency, mobility, and security [4], new highly-contagious diseases may emerge in densely populated areas, rapidly propagating. In addition, international traffic among large cities can strongly increase the potential of world propagation of new flu-like diseases [5]. Actually, the negative potential of this urban pattern has been seen in the COVID-19 pandemic, which rapidly spread to all continents in just a few weeks. As new highly contagious diseases may emerge anywhere and anytime, the question to make is what we must do now to better face a pandemic.

To avoid or even reduce the impacts of this and the next pandemics, information management is essential. While specialists argue that fast diagnosis and good sanitation are strong requirements to face epidemics, the new actors of the digital era can also play important roles in this fight. Therefore, cities must be prepared to rapidly detect potential outbreaks of new or already known diseases, processing sensitive information in a way that fast decisions can be done. In essence, information can be as vital as any other element of the healthcare systems, and data provided by cities are crucial in this aspect.

In general, cities can be perceived as living organisms [6]. Terabytes of data can be daily provided from different sources, such as lamp posts, buses, climatic stations, police vehicles, traffic lights, security cameras, automated hospitals, universities, museums, and any other ‘element’ that can be connected to a digital city’s macrocosm [7]. This integration of different sources of data can be one of the greatest transformations in our way of living in this century, along with the processing possibilities provided by data science and deep learning algorithms. However, this potential can be enlarged even more when cities and their inhabitants are considered as a symbiotic organism: for any city in the world, its inhabitants spontaneously provide many relevant data that can tell a lot about what is happening in an urban area. This full massive integration of a city’s cyberspace with social media and people’s smartphones and gadgets can not only pave the way for the anticipated digital society [8], but it can also be a source for prevention and mitigation of virus outbreaks.

In 2003, the severe acute respiratory syndrome (SARS) disease affected many countries with thousands of cases. In that year, the SARS-CoV virus outbreak was an important alert about fast contagious in modern urban times, harder affecting cities such as Beijing, Hong Kong, Taipei, Toronto, and Singapore [9]. After that, in 2009, the H1N1 outbreak (H1N1pdm09 virus) hit the world very hard and very quickly, ringing the alarm bell [10]. Once again, this type of influenza virus took advantage of the modern way of living, with large globalised cities interconnected in a worldwide transportation network, infecting more than 1 billion people. Now, the COVID-19 pandemic hits the globe with a significant death toll, and the lessons eventually left from this pandemic should not be neglected. Figs. 1 and 2 show how astonishing was the initial spread of this virus, urging the world for more effective means to contain the next pandemics.

The modern way of living in highly-populated cities with globalised businesses is the perfect scenario for outbreaks of infectious diseases and the next pandemic is just a matter of time. Therefore, this study discusses recent developments that can support current cities to better prepare to face this and the next pandemics, surveying technologies, and innovative approaches related to the evolution of the smart cities paradigm. Good practices are highlighted and promising development trends are envisioned. Finally, cities that are ahead in this development process are mentioned, pointing out potential directions to be followed.
initiated anywhere and rapidly spread, with potential property in Wuhan, a large and highly populated city in China that is an urbanisation process has made such interactions a reality in some large cities such as Milan (Italy), Madrid (Spain), and New York (USA) were facing uncontrolled dissemination of the SARS-CoV-2 virus, leading countries to determine lockdown and mandatory quarantines. Actually, even though coronaviruses will originally come from human interaction with animals [11, 12], the urbanisation process has made such interactions a reality in some cities outskirts, with transportation services connecting them to downtown areas very quickly. In this complex scenario, new pandemics will be a constant threat. Any city is an emergency-prone environment. Fire can be initiated anywhere and rapidly spread, with potential property damages and deaths. Heavy rain can result in flooding, devastating low-lying areas. Chemical gas leakage is also extremely dangerous in urban areas, requiring prompt action. Whatever the case, there are many critical events that may happen in large cities, and some initiatives have been developed to manage such critical situations [13, 14]. However, can potential outbreaks of infectious diseases to be managed considering three different elements [15]:

- Detection: emergencies will be detected by the identification of some pattern that is out of the expected ‘normal’ behaviour in a city. For example, if the temperature in some area suddenly rises, it may be an indication of a fire emergency. Concerning the detection of an infectious disease outbreak, e.g. the identification of an emergency pattern may be done through the analysis of the number of requested medical assistance in an area or the processing of social media for abnormal behaviour [16, 17].
- Alerting: after an emergency is detected, some alerting procedure has to be performed. The basic alert procedure is to deliver warning messages, which could be emails, SMS messages, or even television broadcasts. Sirens or luminous signs could also be deployed in some areas for more efficient alerting, e.g. as deployed when detecting and warning about tsunamis [18]. For outbreaks prevention, more elaborated alerts could be performed, e.g. indicating critical places to avoid.
- Mitigation: detected and alerted emergencies have to be eventually mitigated [19]. However, it may be a hard task when considering infectious diseases. While an obvious response to a fire emergency will be the dispatch of fire trucks, detected infected people and potential outbreaks will typically require a series of actions such as public decontamination, prophylactic isolation, tracking of potentially infected inhabitants, public transportation reordering, and many other measures that should be efficiently coordinated.

The recent events related to the COVID-19 pandemic have raised many questions about how potential outbreaks can be detected, alerted, and mitigated. Also, as cities will be in the centre of the major contagious spread, current and future smart cities should be designed, implemented, and managed to address disease outbreaks as highly critical emergencies. Doing so, data provided by the cities will be the main ally of the governments and healthcare systems when facing pandemics.

Although alerting and mitigation are separate and independent procedures [13, 14], we believe that the characteristics of known and future pandemics will demand a more stringent perception of emergency management. Hence, we believe that alerting and mitigation should be performed simultaneously as a single unified process.

Therefore, considering the literature in this subject, we believe that disease outbreaks can be processed as urban-related emergencies. Moreover, we classify the solutions in this area according to Fig. 3, which presents the processing of potential outbreaks through three conceptual procedures. In fact, such types of emergencies have to be detected as soon as possible, providing at least location (where) and temporal (when) information. In fact, that information will be crucial when facing an outbreak in its initial stage. Afterwards, alerting and mitigation procedures are expected to be performed concomitantly, suppressing the spread of the detected pathogen.

For the conceptual model depicted in Fig. 3, the first stage is the detection. After that, assuming that a potential outbreak is an extremely relevant emergency for any smart city context, both mitigation and alerting procedures should be performed as soon as possible, and thus they are equally defined as the second stage. Doing so, while the alerting procedures will be concerned with notification of affected people and the government, mitigation actions such as isolation of the outbreak zone and tracking of potentially infected people should take place immediately. Moreover, even though alerting and mitigation are necessarily separated and independent procedures in a smart city [15], they can interchange data among themselves (dashed line in Fig. 3), dynamically updating information to the inhabitants.

Overall, it is expected that cities with a high concentration of urban poor and deep inequalities are potentially more vulnerable to new outbreaks. For those cities, the lack of proper sanitation and the presence of very crowded areas are subject to the rapid dissemination of airborne diseases. For new pandemics to come,

### 2 Cities: an emergency-prone environment

Although infectious disease outbreaks can be assumed as global events, they will spread in cities. The COVID-19 pandemic started in Wuhan, a large and highly populated city in China that is an economic and transportation hub. Just a few months later, other large cities such as Milan (Italy), Madrid (Spain), and New York (USA) were facing uncontrolled dissemination of the SARS-CoV-2 virus.
we can also add to this equation the lack of a cyber-physical data infrastructure to support quick and efficient response to potential outbreaks. As highly contagious diseases may be assumed as an intelligence (AI) algorithms, automated crime prevention solutions have shown the rapid propagation in Wuhan, China, and also the positive impact of quarantines when fighting the propagation. In a different study [21], results also presented a rapid spread of the outbreak, with mathematical models being used to predict new infection cases. Although the impacts of this pandemic will still be felt for months or even years, the initial studies and reports are advocating for the need for coordinated identification of new cases.

The adoption of new technologies for different types of monitoring has been a trend in large cities, but not in a uniform way [22]. Nowadays, intelligent cameras can be easily spotted in many cities, supporting the detection of suspicious behaviour and crowd incidents. With the development of more efficient artificial intelligence (AI) algorithms, automated crime prevention solutions have become more common and some cities are already integrating such data to other databases for stronger results when identifying criminals and even terrorism. In this context, although face recognition algorithms have raised privacy issues [23, 24], the recent COVID-19 pandemic should reignite the need for more active monitoring in large cities, especially when detecting and tracking potential individuals that may inadvertently propagate viruses. However, are smart cameras sufficient to face this type of pandemic?

The last few years have seen the surge of new data acquisition and processing paradigms. Actually, the transformations provided by the cloud computing paradigm are more than one decade ago have created a wealthy scenario for even deeper changes [25]. Soon, data became the most relevant asset, with AI and data science algorithms allowing new perceptions about virtually anything. In parallel, the hardware evolution has culminated with the development of countless independent and interconnected devices [26, 27], giving birth to the internet of things era [28]. Ultimately, new technologies and paradigms are supporting more comprehensive and efficient decisions in critical issues, affecting business, sports, science, and even how cities detect emergencies.

Therefore, the current technological arsenal can be exploited to create a new generation of smart cities, which will be able to detect viruses’ outbreaks more efficiently, potently facilitating their conten tion. Obviously, it is not straightforward and many challenges will still arise as cities become more and more interconnected. Nevertheless, the negative impacts of the COVID-19 pandemic may give the required boost for this process.

The ideal detection of potential outbreaks should exploit retrieved data from different sources. Actually, this overall problem is not only constrained to the cities, also relating to their local and global supply chains, travel networks, airports, and neighbourhoods that may be sources of contagion. In such cases, sensor stations, public agents systems, social media, and even individual gadgets should be integrated to provide comprehensive data. Fig. 4 depicts this overall idea of integrated and distributed monitoring in smart cities.

Fig. 4 Outbreak should be detected in its early stages. For that, different sources of data may be exploited.

Sensor-based monitoring stations can be used to detect patterns related to flu-like outbreaks. Also, past works have provided valuable clues of how effective those approaches can be. The work in [29] employed monitoring stations composed of multiple sensor units to detect different environmental variables in cities. Doing so, a more detailed perception of a city is achieved, complementing other databases. Multi-sensor monitoring units were also considered in [15], but that work focused on the detection and alerting of emergencies. With some modifications in sensing and communication, such types of monitoring approaches based on heterogeneous sensors can be valuable when detecting patterns related to outbreaks at early stages.

When employing sensor-based stations, an important component is the camera. Visual data can be valuable when detecting and identifying sick people, even in the crowd. For smart cities being designed, cameras will be indeed a core monitoring element, as recent works suggest. In [30], a camera-based approach was proposed to screen febrile passengers at international airports, detecting people that can potentially spread a contagious disease. That work combined visible and thermal images and some algorithms to assess the heart rate, body temperature, and respiration rate of passengers, potentially reducing the probability of false alarms. Integrating with other types of sensors for more comprehensive monitoring, as performed in [31], cameras can be an important element for the detection of disease-related emergencies in smart cities.

Still considering the detection of potential outbreaks, social media can be mined for some types of information. Actually, we can consider that people are a type of spontaneous sensor, which asynchronously provide information about their lives. For micro-blogging services such as Twitter, such a pattern is even more evident, with people describing their daily events. Since described negative events such as sickness complains, headaches, fever, coughing, or things like ‘I heard that some people in a particular neighbourhood are getting sick’ can be retrieved from social media, specialised algorithms can extract precious information, identifying some important patterns [32]. This idea was partially exploited in [33], which considered the processing of tweets for...
geo-referenced identification of critical events that could be used for prioritisation of IoT devices. Similarly, the work in [34] also processed tweets to identify critical events, but that work is directly focused on the detection of emergencies. In both works, the target mined data could be easily adapted to detect patterns related to a contagious disease outbreak, supporting the overall detection program.

A different but still promising approach is the individual monitoring of health conditions using gadgets or wearable sensors. If people are being seamlessly monitored about their body temperature, heart rate, sugar levels, or any other variable, a smart city macro-system could retrieve that information and store the historical health behaviour of their inhabitants, quickly detecting sick people. Although such an approach could raise privacy concerns, the COVID-19 pandemic has shown how some ‘invasive’ solutions can be highly effective when trying to reduce the virus spread, as could be seen in China. Then, as a promising approach, the work in [35] developed a smart shirt that was able to retrieve physiological data of any individual. Employing a group of different sensors, the sensed data is transmitted to a smartphone and then to a cloud-based system. Doing so, information about the health of all monitored people can be known. Other promising solutions for monitoring based on wearable-sensors have emerged in the last few years, giving clues of how active health monitoring can be performed [36].

All presented solutions can be exploited when composing integrated systems for active monitoring and detection of potential outbreaks. However, the reach of such detection resources could be enlarged even more, especially during initial stages of an already detected outbreak emergency. For example, in China, the Government of Wuhan employed drones to monitor people and reduce the virus spread: people not using masks were detected using drones’ cameras and immediately alerted. Moreover, drones could be used to detect if people are not respecting established quarantine curfews, supporting the action of police agents, as could be seen in some cities during the COVID-19 pandemic. In this sense, thermal cameras could also be used in drones to potentially identify people with fever, proactively detecting infected people.

When smart cities are properly designed, all potential sources of data are valuable for early and continued detection of an outbreak. The designing and management of smart cities should then consider the maximisation of the number and types of data sources, which obviously will demand a robust networking structure and massive data storage [37]. Therefore, the construction of such cyberspace should be one of the main goals for the development of cities in the next decades.

### 4 Processing massive data

With the availability of huge amounts of data, from different sources and with different characteristics, the development of computational solutions to process all retrieved data is as important as the implementation of monitoring and detection approaches [38, 39]. Actually, smart cities may provide massive amounts of data every single second, uninterruptedly, demanding highly efficient algorithms to transform such data in useful information [40]. For the smart cities that should be created or adapted to handle this and the next pandemics, recent developments are giving some clues of how these goals might be achieved.

When considering historical data about people and cities, statistical information is of paramount importance [41]. Recently, big data and data science disciplines have become hot research and development topics, being largely exploited by companies for better marketing campaigns and business intelligence [42]. In the last few years, the development of algorithms for data processing following those paradigms has also opened opportunities for the maturation of smart cities projects, with promising results in areas such as healthcare assistance and public governance [43]. In fact, the lack of efficient governance, poor planning, and decentralised healthcare assistance can undermine eventual pandemic responses, with terrible consequences. Therefore, the development of models to understand how virus outbreaks emerge and how transmissions evolve is as important as for the construction of smart cities.

AI algorithms can also be a valuable tool when predicting and mitigating a virus outbreak. In [20], a neural network was defined to predict confirmed cases of people infected by the SARS-CoV-2 virus. In that work, different variables were considered as input for the city of Wuhan, notably temperature, its population density, relative humidity, and wind speed. Then, the proposed model was used to predict infections for 30 days. Machine learning techniques may also be exploited, as proposed in [44]. In that work, potential outbreaks were predicted considering different factors, such as the number of reported cases, the type of pathogen (and how contagious it is), environment information mined from the Web (provided by the press) and social media (provided by the individuals). Then, the combined processing of all that data could give important indications of how and where new outbreaks of infectious diseases might arise. In fact, these initial results concerning the COVID-19 pandemic are some of the promising initiatives that have been employed to address this crisis, but new reports are still coming about data-centric developments around the world, continuously, indicating research and development trends for the next few years.

In general, AI will be a powerful new weapon against infectious diseases, especially when models and algorithms are defined to predict new outbreaks. New developments in machine/deep learning are already bringing promising results when tracking how diseases spread and the COVID-19 outbreak has provided valuable data to train and assess the effectiveness of neural networks. Actually, population screening and assessment of infection risks are some of the expected ‘services’ of AI algorithms, but other relevant information may be produced by such algorithms, with research in this area still gaining a lot of attention [45].

Another not so obvious potential use of AI when facing a pandemic is the detection of fake news on social media. The misinformation resulted from false messages posted accidentally or not on social media may be too dangerous for any contention and mitigation plan in a city, and thus algorithms may be used to identify and denounce such posts [46, 47]. In short, the detection, avoidance, and mitigation of fake news should be an active service of any healthcare-oriented smart city.

Finally, the effectiveness of AI-based prediction and detection approaches will depend on the ‘quality’ of the available data, and previous outbreaks (H1N1, SARS-Cov, Ebola etc.) can be valuable when training computation solutions based on AI [48]. Therefore, we believe that the development of highly-integrated smart cities, with lots of different data sources, will be the most important factor when facing a pandemic.

### 5 Alerting and mitigation

The particular characteristics of worldwide pandemics have shown how fast and dramatic they can evolve and infect people. Thus, the response to them must be equality fast [2]. After an outbreak is detected, which can be handled as an urban emergency, alerting and mitigation should be performed as soon as possible. Ideally, they should be coordinated for enhanced impact, although this can be complex and tricky sometimes. Nevertheless, there are some initiatives that can be exploited for this goal, as discussed in this section.

When an outbreak of an infectious disease is detected, different resources should be employed to mitigate its impacts. Actually, cities will need to have well-defined plans to mitigate an outbreak, as soon as possible, potentially reducing the number of deaths and also the number of newly infected people [49]. For the COVID-19 pandemic, its rapid worldwide dissemination is an important clue that the current resources may not be sufficient to face such an adverse scenario [50]. This is, in fact, a fight against the clock, demanding serious resources from the cities.

There are different alerting and mitigation approaches when responding to a detected outbreak, as can be seen in academic works and practical developments. Among such possibilities, we analysed promising solutions and selected five basic procedures that should be implemented when creating smart cities, discussed as follows:

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• Automatised hospitals and healthcare systems: this is, in fact, the most obvious approach when considering the mitigation of a pandemic. Nonetheless, it is not the easiest. When facing initial stages of an outbreak and eventually an uncontrolled pandemic, hospitals should be managed considering the diversity of data provided by a smart city [51, 52]. The number of available hospital beds, medical staff, and medicine has to be managed in advance, processing statistical data, or even employing AI algorithms. The presence of a hospital in the area of a detected outbreak should also be exploited to redirect new patients not related to that pathogen to different hospitals, avoiding new infections and overwhelming of the healthcare system, potentially reducing deaths. In fact, the absence of such measures required multiple quarantine decrees in entire cities and countries during the COVID-19 pandemic, aimed at the reduction of the number of concurrent patients at critical stages of an outbreak and eventually an uncontrolled pandemic, [57]. As discussed in recent works [54–56], intelligent healthcare systems have to be a central element of future smart cities.

• Smart transportation: the way people move in large cities is determinant to the spread of any contagious disease. Hence, smart transportation can also be an ally when preventing or mitigating the effects of an outbreak [57]. Processing data provided by the city, affected areas can be rapidly isolated, limiting the movement of people from and to that area. Public transportation can also display warning messages and instructions on how to prevent from being infected, as has been seen in many large cities during the COVID-19 outbreak [58]. When the cyber-physical integration level of the cities goes deeper, other ideas may emerge in the short time. For example, driveless autonomous cars could be used to transport infected people or health workers, reducing the probability of new contagious. Obviously, the correct positioning of such automated services requires a comprehensive perception of the entire urban space, which can only be achieved when smart cities are properly built.

• Response teams: after an outbreak is detected, the city must act very quickly. Public decontamination, prophylactic isolation, and tracking of potential infected people are some examples of required responses, which will typically involve public health workers, transit agents, police, and even special response teams that may be created to deal with this particular scenario [59]. Moreover, some new technologies and development platforms may also play an important role in this mitigation process, complementing ‘traditional’ action measures [26]. In China, the epicentre of the COVID-19 pandemic, drones were used as essential tools, guiding and alerting people about quarantine restrictions. Moreover, drones also had some other innovative uses, as the delivery of supplies and the disinfection of certain areas by releasing chemical products. In Hong Kong, robots were reported disinfecting public transports, reducing the risk of new infections when humans are designated to clean potentially infected areas. Actually, such initiatives could be provided as an automatic contention service of the smart city macrocosm, which would dynamically allocate mitigation services with very short delays.

• Research and innovation: when a new disease is discovered, the correct pathogen and its DNA/RNA information should be discovered as soon as possible, allowing clinical tests and experimentation for better treatment of infected people [12]. In this context, scientists will struggle to create new medicines and vaccines to face that pathogen, trying to save lives and potentially reduce its propagation. In fact, scientific labs and universities should receive all types of information from the city cyberspace, supporting a better perception of how the studied pathogen is spreading in different conditions: e.g. the weather, sanitation conditions, and population density information of a recently detected outbreak can give clues of how to face this new pathogen. Moreover, the information should also be provided by the scientific units towards the cities’ services, e.g. allowing the rapid alerting of people and authorities about how to prevent from contagious.

Fig. 5 presents the expected mitigation procedures that should be automatically coordinated to achieve the most efficient responses in all phases of a pandemic. The highest is the level of integration among them, higher is the effectiveness of the city when facing detected infectious diseases outbreaks.

6 Current and promising smart cities initiatives

The emergence of epidemic diseases is expected to significantly transform the way we live and interact with the world. Besides the death toll of this pandemic, which is still unknown but may be huge [61], negative impacts on the economy and the consequent social problems may be too severe. While the COVID-19 pandemic still leaves its mark creating one of the biggest economic crises of modern history, with a significant recession period ahead, the world starts to wonder how to avoid the next pandemic, which may be even worse. The answer to this question may be on the development of more robust, proactive, and integrated smart cities.

Large urban centres are naturally vulnerable to infectious diseases. In general, cities that are more collaborative and integrated are better prepared to manage pandemics than those that are not. In this sense, this section discusses what some large cities are already doing to become smarter and how such actions can be leveraged when facing the next pandemics.

6.1 Wuhan

Widely known as the source of the COVID-19 pandemic, Wuhan is a ‘Tier II’ city in China (cities having from 3 to 15 million residents) [62]. Wuhan's Smart City planning started back in 2010, in a conference held by its Science and Technology Bureau, finishing their construction blueprint in July 2011. According to the authors in [63], this is the most ‘perfect’ system in China, paying high attention to smart health.

The Wuhan's Smart Health approach is intended to connect various healthcare systems and databases to enhance communication among patients, doctors, and other healthcare professionals. Automated systems are capable of exchanging the world.
patients’ health records to ensure that correct information reaches proper healthcare professionals, reducing mistakes (e.g. nurses getting wrong data).

Besides Wuhan’s Smart Health, the Chinese government has been using technologies to tell who must get into quarantine. In a partnership with Alipay, they are providing a colour QR code to citizens that install Alipay app on their smartphone. The QR code may have three colours: green, meaning the user can move around; yellow, meaning the user must have a 7-day quarantine; and red, meaning the user must have a 14-day quarantine [64]. The app gets users’ information provided by the healthcare system and it also tracks their pharmacy purchases and movements to verify if they have had contact with infected people. Although this approach can help determine who must self-isolate, some people are reporting that the app sends personal data, as user localisation to police enforcement, which may raise some privacy concerns.

6.2 Singapore

Since 2003, Singapore has learned a lot from the SARS outbreak. After that, they created a task force to fight new outbreaks and minimise their effects. Largely considered as the smartest city in the world [65], Singapore has created a programme called Smart Nation that makes extensive use of smart city technologies to improve the perceived life quality in the city. One of the products of Smart Nation is the Contact Tracing App [66]. A person can install it in a smartphone to detect nearby people who are also using this app and store information about people at user’s proximity. This information can then be shared with the Ministry of Health and help to identify citizens who were in contact with infected individuals, potentially enhancing the mitigation actions (who to test, interviews etc.).

Another initiative of Singapore was to create a national level WhatsApp one-way messaging group to feed people with COVID-19 information and fight the outbreak. Also, web sites to find masks and healthcare facilities, as well as gaming apps to educate against panic buying, have favoured Singapore’s response to the COVID-19 pandemic [67].

6.3 London

London is doing well when it comes to smart city initiatives. The Mayor’s Office promotes digital healthcare through London’s Smart City technologies, linking data in the National Health Service through its DigitalHealth.London program [68]. Additionally, London is making use of data provided by wearable devices, data analytics, and AI to better understand its citizens’ conditions.

DigitalHealth.London is aimed at bringing digital innovation to its healthcare system. Some of its initiatives are digital outpatient services, digital therapeutics, and an innovation hub, among others [69]. With this programme, London is making use of technology and smart city concepts to enhance its health system.

Regarding tourism, a businesswoman in London who owns a tour company has found a way to continue working despite the lockdown. She is making use of Google Maps and her own photos to create virtual tours for those who want to visit London sites, but cannot go out [70]. Although it is not properly a London smart city initiative, it is something that could be considered as a tool to relieve stress during quarantine.

6.4 Seoul

Seoul is another good example of a smart city. Actually, South Korea is an early adopter of the smart city concept at a national level [71]. In Seoul, the programmes address various issues such as mobility and energy efficiency (commonly supported in initial smart cities implementations), as well as e-governance and public spaces reorganisation.

Seoul and South Korea as a whole have also implemented a Digital Health programme. The South Korea Digital Health key sectors include big data, AI, block chain, telemedicine, and consumer health electronics [72]. All this digital health implementation has helped South Korea fight the COVID-19 outbreak. The Ministry of the Interior and Safety has developed a self-quarantine app that keeps track of its users’ location to make sure they are not breaking the quarantine. Also, another app called ‘Corona 100m’ alerts when the user comes within 100 m of an area visited by an infected person. The Corona map website keeps a history of confirmed patients’ movements so its users can know where infected people were [73].

6.5 New York

New York has been in the first place in IESE Cities in Motion Index for three consecutive years until 2019 when the first place was taken by London. However, according to IESE Business School, New York is still leading in the economy dimension [74]. In the health dimension, the city is favoured by the New York eHealth Collaborative (NYeC) approach, a non-profit organisation that works in partnership with the New York State Department of Health, creating a special network called State-wide Health Information Network for New York (SHIN-NY) [75].

The SHIN-NY network is aimed at connecting state’s regional networks to exchange data quickly. Participants can make use of this network to retrieve patients’ records, receive alerts about their patients, and share clinical data, among other services [75]. This initiative is making use of technology to connect the whole State of New York and bring digital health to its citizens. In outbreaks times or when any epidemics threaten a region’s health, fast access to records can be of great importance to fight the disease spreading [76].

6.6 Initiatives and future developments

It is noticeable that many cities are using smart city concepts and digital technology to embrace healthcare, even before the COVID-19 pandemic [54, 77]. From simple websites providing useful information to its citizens to complex data exchange networks aiding health professionals in their daily work, cities are undergoing a silent but important transformation. Although the results are promising, however, cities still have a lot to do when concerning pandemics.

In general, we can say that Asia seems to be ahead in the COVID-19 fighting, deploying smartphone applications specifically for this purpose, while cities in other continents rely on their current digital health initiative to defeat the disease. Nevertheless, the challenges are still great and new developments are still required.

Table 1 lists ten cities that have implemented promising smart city initiatives, summarising some of their adopted procedures and solutions. Their results and lessons should be considered when

| City      | Continent | Population | Initiatives                                                                 |
|-----------|-----------|------------|-----------------------------------------------------------------------------|
| Berlin    | Europe    | 3.7M       | ambient-assisted living; web-based services [78]                            |
| Helsinki  | Europe    | 0.6M       | Helsinki smart region [79]                                                  |
| London    | Europe    | 8.9M       | DigitalHealth.London programme (digital health services)                    |
| New York  | North America | 8.6M | NYeC; SHIN-NY [75]                                                          |
| Seoul     | Asia      | 9.7M       | big data, AI, blockchain; self-quarantine app; corona 100 m app; Coronamap |
| Shanghai  | Asia      | 24.2M      | 5G-powered robots [80]                                                       |
| Singapore | Asia      | 5.6M       | contact tracing app [66]; WhatsApp group; websites; educational games       |
| Sydney    | Oceania   | 5.2M       | my health record [81]; secure messaging [82]                                |
| Wuhan     | Asia      | 11M        | records exchange; Alipay QR code for quarantine [64]; smartphone tracking   |
implementing the expected transformations in urban life to face the next pandemics.

The COVID-19 has brought new challenges that have demanded fast responses to mitigate the dramatic effects of this pandemic. In this context, there is no 'silver bullet' and each city has applied technological solutions that better fit to the encountered challenges [83]. Nevertheless, studying employed solutions can be crucial when preparing to face the next pandemics.

Actually, although the public initiative is mostly responsible for digital health and smart city programmes, private companies can also join the battle and help cities to defeat COVID-19 and the next pandemics. In Belgium, e.g. telecom operators are combining their datasets to determine high-risk areas, offering real-time monitoring for proactive authorities response [84]. In China, big companies such as Alibaba are also playing an important role in fighting the pandemic, managing large amounts of data. Also, other initiatives supported by private companies are expected to be implemented in many countries.

Finally, digital health programmes are very important in smart cities to get prepared for infectious disease outbreaks. Actually, cities that had previously implemented digital health solutions are doing better fighting COVID-19. The cities listed in Table 1 are making use of their digital health solutions to cease the outbreak and give their citizens access to good information about the disease. However, the negative impacts of the COVID-19 pandemic should push additional pressure on them, demanding new technologies and solutions in the near future.

7 Brazilian case when facing the COVID-19

Brazil is the largest country in South America with over 210 million people, having an important political and economic influence in that region. Although it is natural to associate this importance with the surge of new cases of COVID-19, mostly due to many international daily flights and the existence of economic hubs such as São Paulo, the rapid spread of the SARS-CoV-2 virus through many Brazilian cities drew the attention of the world, with serious concerns about the death toll after this pandemic. Actually, the lack of unified actions from the Brazilian governments, in both national and regional levels, has been pointed out as one of the main reasons for the high-infection rate, but other factors such as poor sanitation and high population density also contribute to the achieved numbers.

The dramatic situation of Brazil, which had its first confirmed case on 26 February, has been aggravated by the absence of coordinated actions for the tracking of the infection and the definition of measures to avoid its spread. This combination of factors could be seen in the first months of this pandemic. Fig. 6 presents the increasing number of infected people per million inhabitants, compared to other countries with early cases of COVID-19.

Regarding South America, COVID-19 cases in Brazil are also rapidly increasing, as can be seen in Fig. 7.

In both graphics, Brazil is presenting an ascending trend for the COVID-19, but the real situation can be even worse [85]. Owing to under-reporting resulted from the low number of performed tests, as can be seen in Fig. 8, the actual number of cases in Brazil may be seven times higher [86]. As an example of this concern, although Chile and Peru are having more cases than Brazil per million inhabitants, they make many more tests for COVID-19.

Actually, cases of the new COVID-19 disease dramatically grew in a short period of time and many more cases are expected in 2020. However, although this scenario is terrible, many initiatives are being developed by universities and research centres in Brazil, trying to reduce the spread of the virus. Such initiatives are already having some good results and they can help Brazil to better face this and next pandemics. Some of those developments are presented in this section.

Some cities in Brazil are making use of smart cities initiatives to fight COVID-19. One of them, Curitiba, was the first large Brazilian city to use remote medical appointments through online video calls to aid COVID-19 suspected people [87]. Their robust infrastructure was essential in this task, avoiding unnecessary crowds in hospitals and the complementary healthcare system, potentially reducing the risk of new transmissions. This infrastructure is then considered as a positive case for other large cities in Brazil.

Considering the largest city in Brazil, São Paulo, many initiatives are being developed exploiting different strategies. In that city, some smartphone-based and web solutions were developed, mostly focused on the management of health information, the reduction of agglomerations, and the tracking of quarantine restrictions. As examples of those initiatives, Meu Corujão [88] and Busca Saúde [89] are some of the early solutions designed to face the COVID-19 pandemic. People can use the web-based Busca Saúde to search for health centres and hospitals, while Meu Corujão gives citizens exam results online, without the need of going to a health centre or hospital, reducing crowding. Following this trend to better manage health information, we can also cite Aqui Tem Remédio [90] as a positive initiative. Additionally, the São Paulo State government developed the mobile phone tracking SIM (Sistema de Monitoramento Inteligente – Smart Monitoring System), a dynamic monitoring
system to check how many people are obeying the quarantine restrictions, using for that cellphone networks data [91].

The under-reporting of COVID-19 cases is one of the biggest challenges that Brazil is facing in the initial months of the pandemic. Since this is a known fact, some initiatives have leveraged big data techniques as an alternative to better understand the real situation over the country. In São Paulo, a statistical tool called ‘Newcasting’ was created to mitigate the delay of the notification systems [92]. In other cities of the State, live maps dynamically show the detected COVID-19 cases [93], allowing people to check where the virus is spreading with higher rates and also supporting the authorities to better implement an isolation agenda. In fact, the lack of coordinated governmental actions in many cities in Brazil has fostered the development of maps and open databases, creating parallel solutions [94]. Also, such actions are being strongly supported by universities and research centres.

In a combined effort of the State University of Feira de Santana and other universities in Bahia, a Northeast state in Brazil, the ‘Portal GeoCovid-19’ combines data of all the country’s confirmed cases and deaths, generating charts and projections [95]. That open web-based portal can then support public authorities to have a better understanding of the disease situation across the country. Another effort was designed by the Federal University of Rio Grande do Norte, also in the Northeast region. The designed system performs sociodemographic analysis about COVID-19 effects on people's lives, associating data related to violence, unemployment, poverty, education, among others [96].

Actually, Brazil is struggling to face this pandemic and it is still too early to say what its impacts will be. By the end of May, Brazil was already the second country worldwide with the greatest number of confirmed cases, even with under-reporting. Nevertheless, many promising initiatives are emerging, mostly exploiting big data analyses for better understanding of the contagious rates and quarantine monitoring. Owing to the economic and political importance of Brazil, as well as its challenges as an under-developed country, its success and failure cases may give important clues to how the world may prepare for the next pandemics, and what mistakes should be avoided.

8 Conclusions

The COVID-19 pandemic that was declared on 11 March 2020 has affected countries on all continents, dramatically impacting our lives. Although the final death toll and economic impacts are not yet known, with bad news still coming from this pandemic, it is certain that the mankind will have to deal with new outbreaks. Therefore, we should be prepared to face the next pandemic in a better possible way.

A crucial element to predict, detect, and mitigate a pandemic is ‘data’. As discussed in this study, data can be retrieved from different sources and the increase of data sources should be pursued by the cities. Actually, the required actions to create smart cities can come from different areas, but governments should play the leading role in this process, particularly with the definition of laws and budgets for it. Hence, when the effects of the COVID-19 pandemic are relieved, the world should start to prepare for the next pandemic.

The surveyed works indicated promising solutions to be adopted by cities, but there is no golden rule. In fact, each city has to consider its particularities when implementing the most appropriate technologies and systems. The discussed cities provided some clues on how to do that, but each urban area will pose particular challenges that must be properly addressed. Nevertheless, the reward may be considerable.

As our last comments, pandemics are real and scientists around the globe expect that they will be more frequent and potentially more deadly. The preparedness for them is urgent and governments must take it seriously. Nevertheless, the construction of more efficient smart cities can significantly support better responses to outbreaks, which may be crucial when saving lives.

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71
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