Not everything is as it seems: digital technology affordance, pandemic control, and the mediating role of sociomaterial arrangements

Luca Mora[a,b]*, Rama Krishna Reddy Kummitha[c], Giovanni Esposito[d]

[a] The Business School, Edinburgh Napier University, Edinburgh, UK

[b] Academy of Architecture and Urban Studies, Tallinn University of Technology, Tallinn, Estonia

[c] Newcastle Business School, Northumbria University, Newcastle, UK

[d] Smart City Institute, HEC Liège Management School, University of Liège, Liège, Belgium

* Corresponding author: L.Mora@napier.ac.uk

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An overly favorable narrative has developed around the role played by digital technologies in containing Covid-19, which oversimplifies the complexity of technology adoption. This narrative takes sociomaterial arrangements for granted and conceptualizes technology affordance - the problem-solving capability of a technology - as a standard built-in feature that automatically activates during technology deployment, leading to undiversified and predetermined collective benefits. This paper demonstrates that not everything is as it seems; implementing a technology is a necessary but insufficient condition for triggering its potential problem-solving capability. The potential affordance and effects of a technology are mediated by the sociomaterial arrangements that users assemble to connect their goals to the materiality of technological artifacts and socio-organizational context in which technology deployment takes place. To substantiate this argument and illustrate the mediating role of sociomaterial arrangements, we build on sociomateriality and technology affordance theory, and we present the results of a systematic review of Covid-19 literature in which 2,187 documents are examined. The review combines text data mining, co-occurrence pattern recognition, and inductive coding, and it focuses on four digital technologies that public authorities have deployed as virus containment measures: infrared temperature-sensing devices; ICT-based surveillance and contact-tracing systems; bioinformatic tools and applications for laboratory testing; and electronic mass communications media. Reporting on our findings, we add nuances to the academic debate on sociomateriality, technology affordance, and the governance of technology in public health crises. In addition, we provide public authorities with practical recommendations on how to strengthen their approach to digital technology deployment for pandemic control.

Keywords: digital technology; technology affordance; sociomaterial arrangements; government; pandemic control; Covid-19

1. Introduction

During the fight against the novel coronavirus (Covid-19), digital technologies have proven effective in helping to limit the spread of the infection and enhance resilience (Brem, Viardot, & Nylund, 2021; Kumar, Gupta, & Srivastava, 2020; Steen & Brandsen, 2020; Ting, Carin, Dzau, & Wong, 2020). Covid-19 literature shows that public authorities[1] have heavily relied upon digital technologies to intensify their virus containment efforts, in particular where national infection curves have been flattened and mortality rates have been minimized (Whitelaw, Mamas, Topol, & Van Spall, 2020). For example, in applauding South Korea for its success in rapidly slowing down the infections, Sonn & Lee (2020) explain that public authorities have achieved this result by combining different smart technologies - especially digital solutions for surveillance, contact tracing, and testing purposes. Similar stories are also shared in other studies, which examine the impact of Covid-19 containment measures in different countries across the world - Australia, China, the United Kingdom (UK) and United States of America (US), Italy, Brazil, and India, just to name a few (Guo, Ren, Yang et al., 2020; Kummitha, 2020; Moloney & Moloney, 2020).

But embedded in this literature, we found an overly favorable narrative around the effectiveness of digital solutions in the pandemic setting, which oversimplifies the complexity of technology adoption. This narrative suggests that public authorities have contained Covid-19 by easily benefitting from the problem-solving capability of digital technologies - which we refer as *technology affordance*. The potential affordance of a technological object, according to this reasoning, is a standard built-in feature, which activates by default during the technology adoption process, leading to undiversified and predetermined collective benefits. However, not everything is as it seems; as sociomateriality and technology affordance studies highlight, the problem-solving capability of a technological device is not a static feature and is rooted in the way users adopt it (Orlikowski, 2010; Parchoma, 2014). When a technology is brought into action, users determine an *actual affordance*, which results from the connection between their specific goals and the social and organizational context surrounding usage. The actual affordance can deviate from the *potential affordance*, which is instead established by technology designers during the ideation process (Conole & Dyke, 2004). Therefore, the relationship between a technology, its users, and their approach to operationalization is pivotal to achieve technology affordance, and it should not be considered as a predetermined condition. Rather, this interrelation shapes during the interaction (Cecez-Kecmanovic, Galliers, Henfridsson, Newell, & Vidgen, 2014; Leonardi, 2013). When identical technological solutions are used in different contexts, different levels of affordance can materialize and the

[1] In the framework of this study, the term 'public authorities' refers to governmental organizations that carry out tasks in the public interest. For example, government departments and agencies, legislative bodies, publicly funded healthcare systems, and the armed forces.

extent of the benefits can vary (Barley, 1986). Potential technology affordance and effects are both mediated by the "sociomaterial arrangements" (Schraube & Sørensen, 2013, p. 7) that users assemble to connect the social and material dimensions of technology deployment (Strong, Volkoff, Johnson et al., 2014).

When discussing how public authorities use digital technologies in the context of the pandemic, the current Covid-19 literature overlooks the importance of sociomaterial arrangements and does not distinguish potential affordances, which are expected to materialize because established by design, from actual affordances, which result from real-world applications. Accordingly, by focusing on government-led digital technology deployment, this paper illustrates how sociomaterial arrangements mediate the potential affordances and effects of ICT-based virus containment measures. Understanding how public authorities can maximize (or undermine) the potential affordance of technological solutions is critical to improve future pandemic responses and can inform national and intergovernmental pandemic preparedness and response plans.

To achieve our objective, we present the results of a systematic review of the Covid-19 literature that offers written accounts on how digital technology has been deployed for pandemic control. This body of literature - gray and academic publications released between January and April 2020 – is reviewed by combining techniques for data mining, co-occurrence pattern recognition, and inductive coding. We begin with text data mining to extract the most relevant words and phrases embedded in our selection of Covid-19 literature and to determine their strength of association by using co-occurrence data. These textual components are then organized in thematic clusters, in order for ICT-related expressions to light up and emerge from the huge mass of unstructured qualitative data. We use these expressions to establish which digital solutions have been deployed to contain the spread of Covid-19 during the four months under investigation. By using inductive coding, we examine the textual data and uncover 39 technologies. Finally, we systematically analyze the Covid-19 literature that is associated to each digital technology. The analysis makes it possible to extract qualitative data that illustrate how sociomaterial arrangements mediate the potential affordances and effects of the digital solutions that public authorities have introduced in their virus containment strategies. More specifically, the available data point us in the direction of four technologies: infrared temperature-sensing devices; ICT-based surveillance and contact-tracing systems; bioinformatic tools and applications for laboratory testing; and electronic mass communications media.

Building on the findings of our review, we provide public authorities with practical recommendations on how to strengthen their approach to digital technology deployment for pandemic control. In addition, we add nuances to the academic debate on sociomateriality, technology affordance, and the governance of technology in outbreaks of infectious diseases. Our findings contribute to strengthening "the view that there is an inherent inseparability between the technical and the social" (Orlikowski & Scott, 2008, p. 434). Introducing digital technologies in pandemic response strategies require creating the necessary balance between socio-organizational factors and the materiality of technological artifacts (López Peláez & Kyriakou, 2008; Mora, Deakin, & Reid, 2019). Otherwise, technology adoption may result in unmet expectations, which are likely to be rooted in the socio-organizational dimension of the adoption process, rather than technical failure (Kane, Phillips, Copulsky, & Andrus, 2019; Mora, Deakin, Zhang et al., 2021). For example, we uncover the undermining role of the following factors: nonadherence to public health agencies' recommendations, lack of training and transparency, poor leadership, overcomplicated bureaucracy which hinders cross-sector collaboration, logistical barriers, bureaucratic authoritarianism, unresolved privacy issues, and inappropriate public sector values.

The paper is structured into four main sections. Initially, we provide a concise overview of relevant literature on sociomateriality and technology affordance. This first section is instrumental in setting the theoretical foundations of our study. We then report on the methodology used to conduct the systematic review and offer a comprehensive account of the results. Finally, in the last section of the paper, we describe the theoretical and practical contributions of our findings. In addition, we detail the limitations of the study and advance suggestions on future research directions.

2. Theoretical background

We define affordance as the problem-solving capability of a technology - a feature which is determined by the "goal-oriented behavior" of its user (Bobsin, Petrini, & Pozzebon, 2019, p. 15). This conceptualization builds on Gibson's (1977) attempt to illustrate the complementarity between human beings and the environment. In his research, Gibson focuses on environmental cues - such as substances, surfaces, and places - and notes that human beings utilize identical cues in multiple ways, generating different types of environmental affordances. According to Gibson, these multiple approaches to usage result from the individual interpretations of environmental cues that human beings develop, by pooling distinctive combinations of knowledge, skills, experiences, and expectations. Personal interpretations influence how individuals engage with environmental cues and make them functional; subjectivity and distinguishing attributes trigger different possibilities for action and interaction.

Building on this argument, Norman (1988) connects the environmental affordances perspective to material objects and introduces the twofold origins of their affordances. According to Norman, physical objects possess a potential affordance, which is defined by design, and actual affordances, which users assemble during the practice in alignment with their goals (Conole & Dyke, 2004). Through their actions, users can autonomously reinterpret the intentions of a designer and actualize affordances that were not considered (Parchoma, 2014). Therefore, each technology has a *design mode* and a *user mode*, where the latter does not always comply with the former, producing different technology affordances (Orlikowski, 1992).

By following this logic, the sociomateriality perspective has shifted the focus of technological affordance from technological determinism to volunteerism. From the standpoint of technological determinism, the problem-solving capability of a technological device represents a static feature, which is predetermined by its creator, whereas volunteerism proposes a different frame of reference. It suggests that technology affordance is enabled by human-technology interactions (Suchman, 2007) - and hence rooted in the way users deploy a technology (Orlikowski, 2010). Technology and users symbolize "an ontology of separate things that need to be joined together" (p. 257) in order for technology affordances to manifest.

In the study of technology affordance, sociomaterial research interprets human-technology interactions by means of two different philosophical approaches: agential realism and critical realism. Agential realism rejects subject-object dualism; it considers social and material as inextricably related, to the point that "there is no social that is not also material, and no material that is not also social" (Orlikowski, 2007, p. 1473). According to the agential realism view, social and material do not hold any inherent properties and do not maintain their "ontological separation" (Barad, 2003, p. 816). There is neither social nor material, but only the sociomaterial, whose existence manifests during the enactment. However, without considering social and material as independent entities, it remains unclear where the social ends and material starts vis-à-vis (Leonardi, 2013). Therefore, as Orlikowski (2007) herself emphasizes, when scholars adopt the agential realism approach, they experience severe difficulties in operationalizing their research and in understanding the intertwining of humans and technology in the practice. Conversely, critical realism considers social and material as inseparable but independent entities, which are brought together by human activity. This interpretation allows to more easily pinpoint the elements that both users and technology introduce into the practice and to determine what affordance is achieved via technology adoption (Mutch, 2013).

Reflecting upon this duality of approaches, Leonardi (2013) concludes that critical realism is more suitable for studying technology affordance, because distinguishing material from social is indispensable to examine how technologies, people, and their boundaries are enacted in the practice (Cecez-Kecmanovic et al., 2014) and to analyze the social and organizational context in which this interplay occurs. Technological objects and humans are not confined in a set of "inherently determined boundaries and properties" (p. 811). Rather, they forge their relationship by interacting with each other in real-world settings. The affordance of a technological artifact is located in the boundaries that this interaction creates (Cecez-Kecmanovic et al., 2014). The act of using a technological object triggers an ongoing double dance of human and technology agency, in which the use and application context determine technology affordance and technological effects (Rose & Jones, 2005).

This understanding advances a key point of sociomateriality theory: social dynamism shapes technology affordance. When users belonging to different social contexts engage with identical technological solutions, recognizably different approaches to utilization emerge, which can result in varying technology affordances and technological effects (Taipale, 2019). For example, Barley (1986) examined the use of computed tomography technology (CTT) in the radiology departments of two community hospitals in Massachusetts. Although an identical technological apparatus has been deployed in both hospitals to achieve the very same goal (to perform standard radiological procedures), the comparative analysis shows that the radiologists of each department have used CTT in different ways. This variation has generated diversified results, which include unexpected effects, such as the alteration of power relations and institutional interactions.

This example demonstrates that identical technologies and their potential affordances are linked to multiple actual affordances (Leonardi & Barley, 2010). Enabling the potential affordance of a technology during the practice and fully benefiting from its adoption require users to take sociomaterial arrangements into account; their goals need to be correctly coupled with the materiality of technological artifacts and socio-organizational factors influencing technology adoption (Strong, Volkoff, Johnson et al., 2014). Given the neutrality of technology and flexibility in usage, actual affordances cannot be established in advance, because they are affected by the user during the interaction. The training, experience, skills, and knowledge of users, for example, are well-known social aspects which modulate the affordance of a technology (Goh, Gao, & Agarwal, 2011).

"No matter what features are designed into a system, users mediate technological effects, adapting systems to their needs, resisting them, or refusing to use them at all. The operative technology is determined by patterns of appropriation and use by human beings" (Poole & DeSanctis, 1990, pp. 176–177). Once technological devices are out in the market, social groups develop and reinforce their understanding on how their goals can be achieved by deploying such technologies (Leonardi, 2013). People use their agency to put technology into use and fulfill specific goals. Based on their interests, groups of users can use the same technology, but to reach different purposes and with different outcomes (Orlikowski & Scott, 2008). Based on this rationale, identifying a standard outcome for a given technology tends to be inherently problematic and leads to an oversimplistic view of technology deployment.

This issue is particularly evident in the overly positive perspective that we found in the Covid-19 literature commenting on technology deployment for pandemic control. During the fight against the novel coronavirus, we have witnessed a massive utilization of digital technologies to limit the spread of the infection, with public authorities among the most-keen adopters. The Covid-19 literature champions this digitally enhanced approach to containment, which has produced undoubtable collective benefits (see Brem, Viardot, & Nylund, 2021; Guo, Ren, Yang et al., 2020; Kumar et al., 2020; Sonn & Lee, 2020; Ting, Carin, Dzau, & Wong, 2020). But this enthusiastic approval overlooks a relevant factor: the existence of a potential affordance does not "guarantee its achievement or the accomplishment of the objective that guides the relationship between action and technology" (Bobsin, Petrini, & Pozzebon, 2019, p. 19). This literature tends to take the potential affordance of technological solutions for granted. As sociomateriality and affordance studies highlight, implementing a technology is a necessary but insufficient condition for triggering its potential affordance and producing the benefits which are associated to such affordance. The problem-solving capability of a technology is not a built-in feature; it is mediated by sociomaterial arrangements. As a consequence, the very same technology can have different levels of effectiveness and technology adoption can produce different results, which cannot be predicted. And despite the expectations, technological effects can even be negative. This line of thought functions as the theoretical framework for our study (see Figure 1), which illustrates how sociomaterial arrangements mediate the potential affordances and effects of ICT-based virus containment measures.

Figure 1 here

3. Methodology

Our argument is substantiated with the results of a systematic review of academic and grey publications that report on how digital technologies have been deployed in the fight against Covid-19. This literature was examined by combining text data mining, co-occurrence pattern recognition, and inductive coding, and it was identified by aggregating and filtering the results of a series of keyword searches conducted in a number of online repositories. The peer-reviewed literature on Covid-19 (letters, commentaries, journal articles, notes, and editorials) was extracted from Scopus and Web of Science, whereas the grey literature was sourced from the United Nations' central archive of Covid-19 documents (reports, policy briefs, and communications) and 97 repositories of newspapers, magazines, and news-based television channels (articles and news). All keyword searches were performed in mid-April 2020 and covered a 16-week timespan, going back to the beginning of January 2020. Prior to January, no knowledge items on Covid-19 were found. By considering this period of time, the search phase concluded with the identification of 2,187 records containing the following combination of keywords: (tech* OR smart* OR digital* OR automation OR machiner* OR computer* OR robotic* OR telecommunication* OR "applied science" OR "scientific knowledge" OR "technical knowledge") AND (coronavirus OR Covid OR SARS-CoV-2 OR pandemic).

After being organized in a single dataset, all the records were manually checked to determine whether the selected combination of keywords was embedded in the body text. All documents that failed to comply with this requirement were eliminated, because irrelevant to the analysis. This verification process has proven very effective; a significant number of newspaper articles, magazine articles, and news were removed because the keywords were located in the credit sections - which provide details about the digital sources - or headlines and titles redirecting to other online material. After completing this filtering process, we retained 515 documents for text data mining, which has been instrumental in extracting the co-occurrence data required to determine the most relevant textual elements and to measure their strength of association.

For the text data mining, we used the content analysis software WordStat (Version 8.0.21). But before starting the analysis, all the source documents were converted to Rich Text Format (RTF) files to facilitate automatic text recognition (see Mora, Xinyi, & Panori, 2020). WordStat transformed the source documents into high-dimensional sets of unstructured textual data. This transformation made it possible to semi-automatize data cleaning and data processing operations. Through data cleaning, the dimensionality of the dataset was reduced while preserving quality information. This process consisted in the removal of unimportant textual information. In the case of academic literature, for example, we filtered out the footers, headers, and details about the authors and their institutions. Given their little semantic value, we also removed stop words by relying on WordStat dictionaries. In addition, misspellings were corrected, and variant forms of identical words were lemmatized. Following the data cleaning phase, we extracted 13,894 textual items: 5,917 words and 7,977 phrases. Phrases are conceptual units composed of minimum two and maximum four words.

After completing the extraction process, WordStat was tasked with measuring the strength of association between each couple of words and phrases, by calculating their co-occurrence - an indicator of semantic proximity (Lu, Liu, & Qian, 2016). Words, phrases, and their co-occurrence data were then uploaded on the network analysis software Gephi, where textual elements and their strength of association have been respectively represented as nodes and edges of a co-occurrence network. In this network, the couples of words and phrases that occur together in one or more source documents are connected by an edge, and each edge possess a specific weight. This numerical value indicates the degree of semantic proximity between two nodes. The more two items co-occur in the source documents, the higher their level of thematic association. Given that the co-occurrence data were normalized, the weight ranges from 0 to 1, where the former indicates a complete lack of similarity (the two textual items never occur together in a source document). In alignment with research by Eck & Waltman (2009), to normalize the data, the probabilistic affinity index Association Strength was preferred to set-theoretic measures.

To group words and phrases in clusters of thematically related textual components, we used the Louvain community detection algorithm (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). The clustering process was conducted in Gephi (Panori, Mora, & Reid, 2019) by adopting a trial-and-error approach (Sun & Sun, 2006). An initial attempt was made to join all available expressions, which formed a 13,894x13,894 co-occurrence matrix. But this first step did not produce significant results, because the co-occurrence data contained too much noise; irrelevant network components generated defective clustering dynamics, which impacted negatively on the accuracy of the results (Glenisson, Glänzel, Janssens, & De Moor, 2005). When attempting to cluster the textual elements, the noise caused an excessive level of fragmentation, which prevented us from obtained an organized representation of the data. The ineffectiveness of the clustering process required reducing the extent of the co-occurrence network by removing non-salient edges and nodes. To find an optimal partitioning scheme, with compact and well-separated clusters, it is common practice to introduce a fixed cut-off value (see Chi & Young, 2013; Ding, Chowdhury, & Foo, 2001; Liu, 2005; Shiau & Dwivedi, 2013). Following this approach, we progressively reduced the dimensionality of the matrix. Three different settings were tested, with the threshold level of the strength of association between couple of nodes at 0.1, 0.2, and 0.3, respectively. We obtained unambiguous results only in the last two occasions. Therefore, to avoid excluding a higher number of network elements, we pragmatically decided to only eliminate the edges with a co-occurrence measure lower than 0.2 – and the nodes that this cut-off value left detached from others. Based on this decision, the initial group of keywords was reduced to 4,733 expressions.

To uncover the technological solutions embedded in each thematic cluster, inductive coding (Saldana, 2009) was deployed to tag all ICT-related expressions emerging from the huge mass of unstructured qualitative data. These expressions represent the "seed keywords" (Sousa, De Mello, Cedrim et al., 2018, p. 36) of this exploratory phase. They allowed to easily uncover the technological solutions which have been deployed to contain the spread of Covid-19 during the period under investigation, whereas the remaining textual data in the clusters helped understand the context in which such solutions have been deployed. The thematic clusters with no ICT-related words and phrases were excluded from the analysis because considered irrelevant in the framework of this study.

In the final step of the review process, we systematically analyzed the Covid-19 literature associated to each digital technology. The analysis aimed to source all the qualitative data which could help illustrate how sociomaterial arrangements have mediated the potential affordances and effects of the digital solutions that public authorities have introduced in their Covid-19 containment strategies. The software Atlas.ti was used to support the extraction process and to facilitate the organization of the qualitative data in concise written accounts (Jack & Raturi, 2006), which are presented in the next section of the paper.

4. Findings

The analysis of the co-occurrence data has uncovered 50 thematic clusters. Eleven of these clusters are non-technology-related, because no seed keywords can be found among their textual components; on the contrary, the other 39 thematic clusters introduce a digital solution each. These technologies are catalogued in Table 1, where they are accompanied by the list of seed keywords extracted during the text mining process. For example, medical workers in China have deployed remote-controlled robots equipped with ultraviolet light systems to sanitize hospital rooms. Drones have assisted South Korean public authorities in disinfecting outdoor spaces. Advanced computational tools for epidemiological modelling have been used extensively across the world to model Covid-19 scenarios and inform decision-making via predictive analytics. Using telepresence robots, medical staff and care workers in Asia, Europe, and North America have been able to interact with Covid-vulnerable individuals without endangering their health. Frontline workers in the UK have used online crowdfunding technology to help overcome the shortage of medical devices and personal protective equipment in healthcare facilities.

Table 1 here

The data sourced during the systematic review led us to consider the following technologies (see Figure 2): (1) infrared temperature-sensing devices; (2) ICT-based surveillance and contact-tracing systems - which include counterterrorism tracking systems using geolocation data, facial recognition technology, unmanned aerial vehicles, and wearable GPS tracking devices; (3) bioinformatic tools and applications for laboratory testing; and (4) electronic mass communications media. Deployed by public authorities to contain the spread of Covid-19, these digital solutions are best placed to showcase the mediating role of sociomaterial arrangements on potential technology affordances and technological effects. This decision is based on data availability reasons.

Figure 2 here

4.1. Infrared temperature-sensing devices

Because fever is among the most common symptoms of coronavirus infection (Tian, Hu, Lou et al., 2020), many public authorities have introduced temperature checkpoints in public spaces, where officials have started relying upon non-contact infrared thermometers (NCITs) and infrared thermal image scanners to detect and isolate infected individuals during mass screening operations. For example, NCITs have been introduced in a number of Chinese cities and subway entrances (Dou, 2020; McFall-Johnsen, 2020; Normile, 2020a; Pietsch, 2020). Military personnel in Kiev, the capital city of Ukraine, has been instructed to conduct temperature checks with NCITs at the entrance of presidential office buildings (Rauhala, 2020). The Civil Aviation Administration of China (CAAC) - the aviation authority of the People's Republic of China - has required security personnel working at high-risk airports to check the body temperature of all arriving and departing passengers with NCITs (CAAC, 2020b). In addition, since the beginning of March 2020, CAAC (2020a) guidelines for airlines have also required cabin crews to take temperature measurements during flights. Between January and February 2020, temperature checkpoints with NCITs or infrared thermal image scanners for pre-boarding and after-landing testing were also introduced in several international airports outside China (Baragona, 2020; Cripps, 2020; Gilbert, Pullano, Pinotti et al., 2020; WHO, 2020b). Examples include airports in the Philippines, United States of America (USA), United Kingdom (UK), United Arab Emirates, Thailand, Japan, and South Korea (Drewett, 2020; Kim & Talmazan, 2020; Ripley, 2020; The Guardian, 2020).

However, on several occasions, public authorities have acted against WHO recommendations, by deploying infrared temperature-sensing devices as the sole testing measure for mass screening operations. At the beginning of the Covid-19 outbreak, WHO (2020a, 2020d) has urged public authorities to use temperature screening technologies only in combination with other screening methods. These recommendations take into account that fever is but one symptom of Covid-19 infection; although fever-free, individuals can still carry the virus. For this reason, WHO has advised public authorities to always accompany temperature checks with the dissemination of health communications - to properly inform individuals about the relevant signs and symptoms that should be reported during mass screening – and to collect data on symptoms by administering questionnaires.

In line with this advice, the Medicines and Healthcare products Regulatory Agency (MHRA) of the UK Government urged caution in interpreting the results of temperature screening, explaining that infrared temperature-sensing devices are not suitable for mass screening operations when “used as the main method of testing. Infected individuals who do not develop a fever […] would not be detected by a temperature reading and could be more likely to unknowingly spread the virus” (MHRA, 2020, p. 8).

Infrared temperature-sensing devices are commonly used in healthcare facilities, where they allow health professionals to obtain non-invasive and contact-free temperature readings of patients. When deployed in healthcare settings, these digital devices have proven to be reliable medical instruments. Conversely, when this technology has been positioned in the Covid-19 setting, many public authorities expected to achieve a technology affordance that did not fully materialize in practice (Normile, 2020b). Against their expectations, infrared temperature-sensing devices have a limited capability for virus spread reduction when deployed in isolation from other testing measures; they struggle to detect infected individuals and offer false assurance. Scientific evidence sourced during the review process confirms this assertion.

During the evacuation of citizens from Wuhan to Frankfurt, two passengers with no fever have been found positive for coronavirus with a throat culture test. However, the discovery was made after the flight landed in Germany. The infected passengers were not detected during the pre-boarding testing phase (Hoehl, Rabenau, Berger et al., 2020). In addition, at the end of February 2020, a group of passengers travelling from Italy to Shanghai were tested for fever at their arrival in China and passed undetected despite being infected (Normile, 2020b). On both occasions, infrared temperature-sensing devices were deployed as the only screening measure. These application cases cast doubt upon the use of infrared temperature-sensing devices as the only measure for mass screening operations, and the modelling work presented by London School of Hygiene and Tropical Medicine introduces additional skepticism. Their mathematical model estimates that, during pre-flight screening, thermal scanning is likely to miss up to 50% of coronavirus-infected individuals (Quilty, Clifford, Flasche, & Eggo, 2020). In addition, when examining how NCITs have been deployed during the Covid-19 pandemic, technology experts have raised concerns in relation to the overall impact that an improper use may have generated. On some occasions, NCITs were used in environments with extreme temperatures, where they "tend to be unreliable" (Yaffe-Bellany, 2020). In these circumstances, infrared thermometer measures are likely to identify false positive or false negative cases. For example, misleading temperature readings have been reported in China by a Financial Times journalist who was requested to undertake a temperature check in an outdoor space - with freezing temperatures. The NCIT device provided an abnormal reading, which turned out to be to a false positive. In addition, experts have reported of cases in which the devices were managed by officials without the necessary medical training (Yaffe-Bellany, 2020; Yang, 2020). As a result, NCITs were hold inappropriately – for example, too far from or too close to the subject - and incorrect usage is a well-known cause of wrong temperature measurements (McFall-Johnsen, 2020).

4.2. ICT-based surveillance and contact-tracing systems

Tracking systems using geolocation data, facial recognition technology, unmanned aerial vehicles, and GPS tracking devices are largely deployed in the fight against terrorism. But a number of public authorities have decided to use these ICT-based surveillance and contact-tracing systems to ensure that citizens adhere to social distancing restrictions, such as lockdowns and home quarantine (Thompson, 2020). These drastic control measures have been taken by appealing to the state of emergency that countries have declared to contain Covid-19, and they have helped government officials to seize their power, suspend some conventional constitutional rights, and control citizen behavior (Chandler, 2020).

For example, the Polish government has forced citizens undergoing a compulsory quarantine to regularly share their location. Citizens have been requested to constantly provide police officers with their real-time location data by using a purpose-built smartphone application that combines facial recognition with geolocation (Bartoszko, 2020; Hamilton, 2020). Police forces in the UK have used drones to keep citizens under surveillance, and this action stirred up a debate on power abuse; the Derbyshire police posted uncensored drone footage on Twitter to shame two individuals who were walking in an isolated outdoor environment - although lockdown measures were in place - while being stealthily recorded (Castle, 2020). Drones have also been extensively deployed as a spy tool for surveillance purposes in other European countries, including Spain, Italy, Hungary, France, and Germany (Ball, 2020; Roth, Kirchgaessner, Boffey, Holmes, & Davidson, 2020; Wood, 2020). Inspired by legislations launched in South Korea and Taiwan, the Slovak parliament has authorized the national government to use private-owned mobile phone data to track the movements of people who have tested positive for Covid-19 and to ensure that they adhere to social distancing rules (Fildes & Espinoza, 2020; Shotter, 2020). Similarly, the Israeli government has tasked its counterterrorism unit with tracing the location history of coronavirus-infected individuals and monitor their self-isolation by maintaining regular surveillance over their mobile phones. The mobility patterns have been used to determine whether citizens have met up with infected individuals and should therefore be forced to quarantine (Calvo, Deterding, & Ryan, 2020; Gregory, 2020; Servick, 2020). Similar contact-tracing techniques have also been used in Taiwan, China, and South Korea to enforce quarantine measures (Cho, Ippolito, & Yu, 2020). Contact tracing in South Korea has been based on a combination of GPS, CCTV, and credit card data (Jo, 2020; Kim, 2020), whereas China has used mobile phone apps - such as AliPay and WeChat - as data sources to trace interactions (Ienca & Vayena, 2020). The Government of South Korea has also collected GPS tracking information of a group of individuals who contracted the virus and has shared detailed personal data via multiple smartphones apps – including their recent movements - with users living in the vicinity (Servick, 2020; Zastrow, 2020). Since the data were not fully anonymized, this approach has been accused of “unmasking and stigmatizing infected people and the businesses they frequent” (Zastrow, 2020, p. 10).

In all these cases, ICT systems for massive surveillance and contact-tracing may have helped limit the spread of the infection during the Covid-19 crisis (Cho, Ippolito, & Yu, 2020; Ting, Carin, Dzau, & Wong, 2020; Wheeler, 2019). But the approach to deployment has also severely undermined privacy and public trust, by not taking ethical implications into account. Although these authoritarian surveillance measures have been imposed to protect the public, they have been enforced without robust and transparent accountability measures, leaving citizens and their rights unprotected (Santow, 2020). As a result, insecurity and anxiety have increased among local communities (Calvo, Deterding, & Ryan, 2020), leaving governments in dispute with data privacy experts and human rights activists, who have called for a more responsible use of digital surveillance tools and large-scale collection methods of location data (Ienca & Vayena, 2020).

Concerns have been raised about the vast amounts of location data being used to track individuals, which have triggered a growing lack of trust in the authorities who handle such information (Beattie, 2020; Cho, Ippolito, & Yu, 2020; Ienca & Vayena, 2020; Santow, 2020; Stein, 2020). Questions have surfaced in relation to how the data have been used, who has been granted access to such data, and "how the data will be used once the crisis is over and whether such datasets are ever truly anonymous" (Fildes & Espinoza, 2020, p. 7). These concerns demonstrate that extreme monitoring tools can easily become a mean for generating unrest in the society. In addition, governments may take advantage of this temporary control mechanisms to abuse the system, by increasing mass surveillance through hype, criminalizing citizens unnecessarily, interfering with their privacy, and jeopardizing personal freedoms, especially in authoritarian governments (Kavanagh, 2020).

In response to these concerns, in March 2020, the UN Special Rapporteur on the right to privacy has recommended countries to select more privacy-friendly alternatives and voluntary data collection tools rather than authoritarian surveillance systems (Rossman, Keshet, Shilo et al., 2020). The UN has also urged countries to set up independent monitoring agencies to oversee such measures and ensure that responses are proportionate, absolutely necessary when used, written in law, and strictly limited in time (Gregory, 2020). These recommendations are also highlighted in the civil society statement released by Human Rights Watch (2020, p. 3), which recognizes that "an increase in state digital surveillance powers […] threatens privacy, freedom of expression, and freedom of association, in ways that could violate rights and degrade trust in public authorities, undermining the effectiveness of any public health response. Such measures also pose a risk of discrimination and may disproportionately harm already marginalized communities".

4.3. Bioinformatic tools and applications for laboratory testing

The use of computer-based approaches to the analysis of biological data has accelerated biotechnological research. As a result of these technological advancements, the Covid-19 virus genome was sequenced in only two weeks. During the 2002 Severe Acute Respiratory Syndrome (SARS) pandemic, the genome sequencing process required two months (Callaway, Cyranoski, Mallapaty, Stoye, & Tollefson, 2020). On 31 December 2019, the Chinese national authorities informed WHO that a number of patients in Wuhan were diagnosed a pneumonia of unknown cause. On 12 January 2020, Chinese researchers had already isolated the pathogen causing the disease, discovered that it was a new type of coronavirus, determined its DNA sequence, and shared their findings (WHO, 2020c). Accelerated by next-generation technology platforms (Le, Andreadakis, Kumar et al., 2020), this knowledge production process allowed the worldwide research community to start working on vaccines and to develop diagnostic tests and computer-implementable instructions for laboratory testing at unprecedent speed (Callaway et al., 2020). WHO-vetted diagnostic tests and testing protocols have been made available at the beginning of February 2020, allowing governments across the globe for rapidly collecting and testing appropriate clinical specimens from potentially infected patients (Cohen, 2020a; Sheridan, 2020).

Finding and isolating infected individuals is key to stop the spreading of highly contagious viruses. Therefore, in January 2020, WHO recommended governments to prepare for Covid-19 mass testing and started distributing a diagnostic test. In the meantime, China had already marketed five additional tests, which made it possible for the country to massively increase its coronavirus testing capacity. At the end of February, the Chinese government was already processing 1.6 million tests a week (Cohen, 2020a; Maxmen, 2020).

Widescale testing efforts have become crucial to relax the social distancing measures that have been imposed. This explains why a well-organized and fast-implemented nationwide testing strategy has turned out to be one of the core components of the successful coronavirus response that South Korea has adopted (Cohen, 2020b; Fleming, 2020). In collaboration with all regional and city governments, the central government has designed a joined-up strategy which has included the construction of an extensive network of drive-through testing stations. This network made it possible for patients and medical staff to avoid risky contacts and process 5,200 tests per million inhabitants by 16 March. Meanwhile, the US was severely lagging behind, with only 74 people tested per million inhabitants since the beginning of the outbreak (Cohen & Kupferschmidt, 2020).

The enormous advantage generated by advancements in bioinformatics notwithstanding, USA and UK have exposed serious difficulties in developing effective national testing programs (Cohen & Kupferschmidt, 2020; Servick, 2020). The UK approach to massive infection tracing, for example, has proved ineffective. Comparing government-declared testing capacities in March 2020, we can report that the UK government was processing some 90,000 people a week, whereas Germany was performing almost 500,000 tests a week (Iacobucci, 2020; Pollock, Roderick, Cheng, & Pankhania, 2020). Data from the Department of Health and Social Care show that only 218,577 UK citizens had been tested by 7 April (Schraer, 2020) and the UK government opened its first mass coronavirus-testing facility very late, at the beginning of April[2].

The findings of an investigation conducted by the scientific journal *Nature* demonstrate that the key factors contributing to the failure of the mass testing phase in the USA are the lack of leadership at the federal government level, heavy bureaucratic environment, lack of control over supply, and inaccurate decision-making. Everything started with the unclear decision of the US Centers for Disease Control and Prevention (CDC) to replace the ready-to-use test and computer-based protocol already vetted and distributed by the WHO (Dyer, 2020). Until the end of February, no other tests than the one designed by CDC were permitted for testing Covid-19 infections in the US. But health labs in the country started receiving the CDC test very late. The kits were in short supply and, in addition, they were not fit to be used, because distributed with a faulty reagent (Cohen, 2020a; Maxmen, 2020).

The issues that caused low testing supply availability have also forced US university labs to work at limited capacity. Additionally, despite being certified and equipped with the technology needed for increasing the national testing capacity, universities have been significantly slowed down by the impossibility to work independently. Processing the tests required to activating a collaboration with the healthcare system. But developing this relationship has proved very challenging due to overcomplicated administrative procedures and software interoperability issues (Cohen, 2020a; Maxmen, 2020).

[2] See the coronavirus coverage webpage of the scientific journal Nature: https://www.nature.com

4.4. Electronic mass communications media

During the Covid-19 emergency, electronic mass communications media, such as social media platforms, instant messaging apps, online video-sharing services, digital media, and websites of governmental organizations have played a twofold role. On the one hand, they allowed public authorities to provide citizens with a one-stop shop for sourcing up-to-date and reliable information about the outbreak. On the other hand, these digital communication channels have become the main supporting tool for online users interested to fuel one of the largest *infodemic* of misinformation in the human history (Zarocostas, 2020).

Fake online news tends to spread faster than information from trusted sources (Vosoughi, Roy, & Aral, 2018) and can put public health at risk, in particular when the use of unproven medical products for curing the infection is suggested or evidence-based medical advice is falsely contradicted (Ioannidis, 2020; Tasnim, Hossain, & Mazumder, 2020). Recognizing the gravity of the situation, governmental authorities, intergovernmental organizations, and tech and media companies have reacted with a coordinate response, by proposing multiple ICT-based countermeasures (Cellan-Jones, 2020; Holmes, 2020). For example, factchecking systems have been deployed to scrub off the fast-growing number of false claims hosted on the web (Brennen, Simon, Howard, & Nielsen, 2020). Facebook have sent alerts to users who have engaged with posts containing harmful coronavirus-related misinformation (Wong, 2020). WHO and BBC have opened myth-buster webpages, which have been used to crack down some of the most common false beliefs that Internet users have disseminated[3].

But despite joining the front-line fight against fake news, even government officials have sometimes become the carrier of misleading coronavirus information. For example, social media misconduct is visible in Brazil and the US. A video circulating on Facebook and Twitter shows the Brazilian President Bolsonaro who publicly endorses the anti-viral drug hydroxychloroquine as a Covid-19 therapy (Ricard & Medeiros, 2020). The same message was also backed by US President Donald Trump. However, the CDC immediately confirmed that these claims were made only by considering anecdotal evidence rather than the findings of empirical studies (Mahase, 2020; Milman, 2020). In addition, during the live streaming of a daily briefing of the coronavirus task force - whose recording has circulated across several digital communication platforms - the US President has also suggested administering

[3] The myth-buster webpages of BBC and WHO can be found at https://www.bbc.co.uk and https://www.who.int.

disinfectant products into the human body as a possible treatment (Cookson & Sevastopulo, 2020; Yamey & Gonsalves, 2020).

Additional criticisms against the approach of government institutions to social media communication can also be raised in relation to the restrictions that the Chinese state censorship has imposed to cover up the Covid-19 outbreak. Evidence presented by Fu & Zhu (2020, p. 4) demonstrates that "Chinese authorities censored online discussion on the coronavirus and restricted the public access to early warning on social media". A report released by Citizen Lab – a Canada-based Internet censorship research organization - confirms these findings. The report shows that, in December 2019, the Chinese government introduced an initial list of keywords to filter information in online discussions reporting on the novel coronavirus infection. According to the report, to control the narrative surrounding the pandemic, the scope of censorship was also broadened in February 2020, when the government selected 516 coronavirus-related keyword combinations and blocked them on the instant messaging and social media app WeChat. The research notes that, at the initial stage of the outbreak, this censorship curbed alerts to the public on the threat of the then-unknown virus. Later, the censored contents were broadened to include any reference to Li Wenliang (Ruan, Knockel, & Crete-Nishihata, 2020). In late December 2019, Wenliang was among the first Chinese doctors who warned medical officials and the public about the outbreak in Wuhan (Fu & Zhu, 2020). But after sharing this early warning in a number of WeChat groups, Chinese police forces accused him of spreading false statements which were endangering the public (Green, 2020).

Although we cannot estimate the overall economic and social impact that the Internet censorship has generated, this lack of transparency has certainly prevented citizens from becoming aware of the outbreak in its early stages (Zhu, Fu, Grépin, Liang, & Fung, 2020). Communication on the outbreak on Chinese social media platforms was almost inexistent before the Chinese Government publicly revealed the existence of human-to-human transmissions of a novel coronavirus in Wuhan. But this only happened the 20th of January.

5. Discussion and conclusion

One out of five WHO Member States faces a public health crisis every year[4]. Most of these crises remain confined within national borders and impact upon a small and localized group of individuals. But when a disease spread to larger populations within a short period of time, what

[4] Data from WHO: https://www.who.int/hac/about/threeyearplan_focus/en/.

started as a local health emergency can escalate into devastating epidemics or pandemics. For example, after reaching Europe in 1347, the Black Death - a multi-century pandemic of bubonic plague – killed an estimated one third of the continent's population in a few years (Ziegler, 1969). During a 1576 epidemic caused by a malignant form of hemorrhagic fever, almost half of the population of Mexico was killed. Hemorrhagic fevers started in 1545 and have remained in the Mexican territory for three centuries (Acuna-Soto, Romero, & Maguire, 2000). The 1889 influenza pandemic – also known as Russian flu - started with some earliest cases in Russia, but it only took six weeks for the virus to spread throughout Europe and four months to circulate around the globe. Unfortunately, we know little about the mortality impact (Ramiro, Garcia, Casado, Cilek, & Chowell, 2018). Other three influenza pandemics followed in 1918, 1957, and 1968, which are known as Spanish Flu, Asian Flu, and Hong Kong Flu, respectively. The Spanish Flu caused an estimated number of deaths which ranges between 20 and more than 50 million (Trilla, Trilla, & Daer, 2008), whereas the Asian Flu and Hong Kong Flu ended about one million lives (Mylius, Hagenaars, Lugnér, & Wallinga, 2008). A few years later, Acquired Immune Deficiency Syndrome (AIDS) made its first appearance. Due to this life-threatening condition, millions have died over the last fifty years and a cure is yet to be discovered (Gallo & Montagnier, 2003; UNAIDS, 2020). The number of influenza pandemics grew again in 2009, when a novel strain of swine influenza hit the world (Butler, 2009); during the first year, the Swine Flu pandemic claimed between 152,700 and 575,400 lives worldwide. The 2014 West African Ebola epidemic - the largest in history - severely damaged Guinea, Liberia, and Sierra Leone, with a total number of 29,616 cases and 11,310 deaths in two years[5]. Finally, previously unknown coronaviruses associated with SARS - a highly contagious respiratory disease - have triggered the first two large-scale outbreaks of the twenty-first century: the SARS and Covid-19 pandemics. With 8,422 cases and 916 fatalities between 2002 and 2004, the SARS pandemic was the less severe (Cherry & Krogstad, 2004). As of April 2021, WHO data show that Covid-19 has reached all continents, infected 135,000,000 individuals and caused 3,000,000 deaths in approximately 18 months[6].

[5] The data on the 2009 Swine Flu pandemic (https://www.cdc.gov/flu/pandemic-resources/2009-h1n1-pandemic.html) and 2014 West African Ebola epidemic (https://www.cdc.gov/vhf/ebola/history/2014-2016-outbreak/index.html) are provided by CDC.

[6] Data sourced from the WHO Coronavirus (COVID-19) Dashboard: https://covid19.who.int.

The ravages of infectious diseases have loomed large over the years, challenging the existence of humanity. In response to this threat, governments and health organizations have been investing considerable resources in contingency planning, while academic and industrial research has been releasing improved vaccines, faster production methods, and new technological developments for minimizing health risks and socio-economic effects. Digital technologies are among these advancements, which have been extensively deployed during the fight against Covid-19. The impact of the pandemic has pushed public authorities towards experimenting with ICT-based virus containment measures in an attempt to more quickly identify, isolate, and monitor infected individuals and to prevent infection rates from rising (Islam, Marinakis, Majadillas, Fink, & Walsh, 2020).

Evidence from recent studies confirm that digital technologies have proven effective in helping public authorities to limit the spread of the infection and enhance resilience. But when reporting on how these technologies have been deployed, the current Covid-19 literature tends to oversimplify the complexity of technology adoption; it conceptualizes technology affordance as a standard built-in feature that automatically activates during technology deployment. Based on this rationale, no matter who is using a technology, how, and in what circumstances, the affordance that such technology is attributed by design will always materialize in full, leading to undiversified and predetermined benefits. Potential and actual affordances are not examined in detail, and the mediating role of sociomaterial arrangements is not taken into account.

Against this backdrop of overstated optimism, we show that potential technology affordances and collective benefits are mediated by the sociomaterial arrangements that users assemble to connect their goals to the materiality of technological artifacts and the socio-organizational context in which technology deployment is embedded. To substantiate this argument, we present the results of a systematic review of Covid-19 literature that reports on how digital technologies have been deployed to fight the pandemic. The review illustrates the mediating role of sociomaterial arrangements by focusing on the virus containment efforts in which public authorities have introduced the following digital technologies: infrared temperature-sensing devices; ICT-based surveillance and contact-tracing systems; bioinformatic tools and applications for laboratory testing; and electronic mass communications media. Table 2 presents a summary of the findings; for each technology, we provide a concise description of how sociomaterial arrangements can mediate potential affordances by using the data collected during the review process and lessons learned from the application cases that such data relate to.

Table 2 here

5.1. Theoretical contribution

Our findings offer a three-fold contribution to the current academic debate on sociomateriality, technology affordance, and the governance of technology in public health crises.

First, the review confirms that the problem-solving potential of digital technologies is determined by the way in which actors position their use in a given context. This evidence reinforces the assertion that affordance is a context-specific feature. Therefore, we argue that a clearer distinction should be made between potential and actual affordances when the impact of digital technology deployment in pandemic settings is examined (Conole & Dyke, 2004). Our findings align with theorizing in sociomateriality and technology affordance literature (Iden, Methlie, & Christensen, 2017; Salancik & Pfeffer, 1978; Tyre & Orlikowski, 1994); when adopting a technological artifact, the potential affordance can be undermined by sociomaterial factors. Statements on the effectiveness of digital technology adoptions in pandemic settings, therefore, need to take technology usage into account. Technology affordances in a given application context depend upon the interaction between technological features and socio-organizational arrangements (Picazo-Vela, Fernandez-Haddad, & Luna-Reyes, 2016). Looking beyond technological built-in affordance is pivotal when facing a large-scale outbreak, and more efforts should be oriented towards understanding the role that actors and institutional setups play in technology adoption – and their diversified effects. As Orlikowski (Orlikowski, 2000) notes, despite technologies have a preferable operationalization mode (which is more likely to materialize potential affordances), users may be unaware, and they also “have the option, at any moment and within existing conditions and materials, to choose to do otherwise” (p. 412). But “in such possibilities [lie] the potential for innovation, learning, and change” (p. 412) that comparative studies on the effects of different technology adoption processes can help trigger.

Second, introducing digital technologies in the response to the pandemic represents an effort of public authorities to enhance public sector performance and resilience in times of crisis. This decision is in line with recent developments in the field of public administration, which suggests governance can be more efficient and objective when public authorities rely on digital technologies (Nograšek & Vintar, 2014; Weerakkody, Janssen, & Dwivedi, 2011). But the results of our study show that, although deploying digital solutions can uplift the capacity to protect the public from infections like Covid-19, technology deployment may not result in objective governance (Kummitha, 2020); once again, the outcome depends upon the approach to usage. We argue that technologies offer "a vector of options for decision-makers to choose, based on their own judgment" (Kummitha, 2020, p. 8). Public authorities can use digital solutions to reinforce their power, manipulate public information, and act against collective interests, by screening and controlling information flows based on their own interests. For example, our study shows that the role of human agency in attempts to enhance objective governance via social media should not be underplayed (Mohajerani, Baptista, & Nandhakumar, 2015), and technologies used for surveillance purposes are neither autonomous nor capable to objectively shape society (Bierwisch, Kayser, & Shala, 2015).

Third, the notion of sociomateriality builds on the practice-based perspective of science and technology studies (Moura & Bispo, 2020) and suggests examining affordances by "exploring technology at work" (Orlikowski, 2007, p. 1435). But the practical utility of sociomateriality theory has been criticized, because research in this knowledge area is more oriented towards theorizing rather than empirical applications. This explains why the concept of sociomateriality remains "extremely theoretical" (Leonardi, 2013, p. 59). As Moura & Bispo (2020) have noted, limited efforts have been made to determine how the sociomateriality concept can be operationalized and what methodological possibilities should be considered for conducting empirical research that captures an understanding guided by the observation of the practice. In addition, methodological issues are still to be clarified. Due to these critical gaps, researchers continue to experience difficulties when attempting to operationalize a sociomaterial perspective, which represents a complex and resource intensive task (Mutch, 2013).

Our research supports the dialogue on the practical contribution of sociomateriality and brings new insights into the discussion on methodological possibilities and constraints. Although limited in scope, this study contributes to demonstrating the theoretical and - most important - analytical support that sociomateriality can offer to the study of technology affordances. In addition, it showcases how content analysis of academic literature and media-generated contents can be used as a method to acquire and organize empirical evidence for sociomaterial enquiries. These data sources function similarly to archives (see Johri, 2011): they can help capture "events that occurred in the past and can uncover a diversity of heterogeneous interactions" (Moura & Bispo, 2020, p. 360).

5.2. Practical contribution

Reflecting on the moderating factors captured during the review process, we have formulated a set of practical recommendations that can help public authorities to strengthen their approach to digital technology deployment for pandemic control.

First, we encourage public authorities to take notice of pre-existing knowledge and recommendations of public health agencies on digital technology adoption and to ensure that technology users receive the necessary training. Public authorities have operated infrared temperature-sensing devices during mass screening operations, to detect and isolate Covid-19 infected individuals in public spaces. But our review shows that the potential technology affordance has been reduced in situations where infrared temperature-sensing devices were deployed as the only screening measure - acting against WHO's Covid-19 technical guidance - and by officials without the necessary training. The WHO Interim Guidance for Ebola Virus Disease (EVD) released during the 2014 West African epidemic had already exposed the limitations of mass screening operations in which temperature checks were used as the only screening method. As a result of these limitations - exactly as it happened during the Covid-19 pandemic - WHO recommended public authorities to screen large groups only by combining, "at a minimum, a questionnaire, a temperature measurement and, if there [was] a fever, an assessment of the risk that the fever [was] caused by EVD" (WHO, 2014, p. 3). Similar concerns on the usability of infrared temperature-sensing devices as mass screening tools for Ebola were also expressed by the European Centre for Disease Prevention and Control (ECDC), which decided to assess the performance of NCITs. Their study concludes that NCITs can perform relatively well in pandemic settings, because they are sufficiently accurate and low cost. But to reach an appropriate level of performance, infrared temperature-sensing devices should be complemented with visual reviews and health questionnaires. In addition, to ensure that accurate temperature readings are collected, the ECDC has highlighted that infrared temperature-sensing devices should be handled by trained staff only (ECDC, 2014).

Second, the right to privacy of citizens should be protected as part of any attempt to use ICT-based contact tracing and surveillance systems. In addition, alternative measures should be considered to replace authoritarian monitoring tools, whose usage – if unavoidable – requires cautious planning, a clear rationale, and independent monitoring systems. A key aspect in this process is the design of appropriate strategies that define – in a transparent manner – who oversee such measures, how the data are collected and stored, who can access such data, and how the data will be erased after the crisis ends. For example, in response to the call for solutions that mediate between privacy concerns, data protection requirements, and the need to increased surveillance, the Singapore Government and Australian Government have respectively launched TraceTogether and Covidsafe. These privacy-preserving mobile applications for instant contact-tracing have helped break the chain of transmission by combining community-based voluntary action and Bluetooth technology, while ensuring privacy protection for their users. They record when users are in close proximity and, if one of them is found positive to Covid-19, the applications automatically alert all users who have been in direct contact with the infected person, suggesting self-quarantine measures and immediate testing (Cho, Ippolito, & Yu, 2020; Greenleaf & Kemp, 2020). Similar mobile applications have also been developed by a number of European countries - such as Italy and the United Kingdom – and introduced in the post-lockdown phases. But despite the potential affordance of privacy-preserving mobile applications for instant contact-tracing, it is important to note that some under-investigated challenges remain, which may constrain the implementation of this technology. For example, more research is required to assess the willingness of citizens to use bottom-up contact tracing functionalities and clarify what strategic approaches are more likely to stimulate public participation (Gerli, Arakpogun, Elsahn, Olan, & Prime, 2021).

Third, public authorities should also ensure that strategic preparedness and response plans are ready to implement, strong leadership is available in time of emergency, and stringent bureaucratic protocols can become more agile and flexible when subject to the intense pressure of public health crises. The pandemic has undoubtably posed public leaders in front of very unusual challenges, and they may have struggled to handle the emergency due to a lack of experience (Ahern & Loh, 2020). Although the cause is not clear, the limited capability of some leaders to stand at times of uncertainty, to build and sustain trust, and to boost efficiency and resiliency, has contributed to undermining potential technology affordances – for example, in the cases of electronic mass communications media, bioinformatic tools, and laboratory testing applications. More preparatory and planning work for emergencies is needed in the light of the leadership gap that the current pandemic has exposed, which includes a review of those response plans where key activities - such as national mass testing operations - have proven to be inefficient. Flexibility is also required to ensure that stringent bureaucratic arrangements can be loosen up when technological advancements need to be adopted quickly in line with local needs, as in the case of US university labs, which have been prevented from working at full capacity during mass testing operations.

Finally, more consistent collaborative efforts are required to improve the public response to large scale infections. A pandemic generates complex challenges that public authorities may struggle to tackle without tapping into the know-how and resources of other stakeholders (Budd, Miller, Manning et al., 2020). For example, complementary measures linking quadruple-helix actors – government organizations, industry, academia, and civil society – are needed to accelerate the large-scale rollout of privacy-preserving mobile applications for instant contact-tracing and to improve their functionality. In addition, cross-sector collaboration is also indispensable to ensure that misinformation and unjustified censorship do not prevent the public from receiving reliable data on public health crises. Factchecking systems and myth-buster webpages can be deployed to fight fake news, but these counter measures are insufficient; as we witnessed during the Covid-19 pandemic, false claims can reach the public before being invalidated. Teaching the public to recognize misinformation is a complementary action that can generate additional resilience, and the education sector is already moving in this direction. For example, some secondary and primary schools in Finland have recently introduced multi-platform information literacy in their national curriculum (Charlton, 2019); the objective is to teach children understand how to spot fake news. Similarly, universities have started offering courses which aim to increase public awareness of false information and to improve media literacy skills[7]. These examples support the OECD's (2021) call for stronger national and international collaborative efforts between public sector organizations and science and technology actors, whose cooperation is indispensable to address grand challenges, such as pandemics.

5.3. Limitations and future research directions

Despite its rigor, we recognize that there are limitations in our study, which open up future research opportunities.

Our review focuses on the digital solutions that have been introduced during the first four months after Covid-19 was discovered. Considering that the pandemic was still unfolding while we were completing our analysis, additional technologies may have emerged in the fight against the newly discovered virus. Therefore, the list of digital solutions presented in Table 1 is extensive but should not be considered as exhaustive. Future research is required to understand whether additional technologies have been adopted.

In addition, data availability has represented a limiting condition, which we faced by examining only four digital technologies out of the initial 39 that we mapped. We assembled a

[7] For example, the University of Michigan has launched the short online course "Fake News, Facts, and Alternative Facts": https://online.umich.edu/teach-outs/fake-news-facts-and-alternative-facts-teach-out/.

methodological approach whose design combines the research requirements associated to our objective with the limitations imposed by the pandemic, which has made it difficult to conduct field research based on interviews, observations, and ethnographic methods. Our analysis has captured sufficient evidence to reach our goal and demonstrate that studies commenting on digital technology affordances in a pandemic scenario should more clearly distinguish potential from actual. But we overlooked how users have perceived technological affordances and what decision-making processes have framed the sociotechnical arrangements that we discovered. Although positioned beyond the scope of our analysis, these lines of enquiry can offer additional insight into the relationship between public health crises and the governance of digital technologies. In addition, further moderating factors related to the technologies that we have analyzed - or others that were not included in our study - may surface as more data become available. For these reasons, we encourage future research to build on our results and expand the investigation, in particular through fieldwork.

Future research is also encouraged to bring a focus on a broader range of actors. During the pandemic, public actors have become but one user group of digital technologies; it would be interesting to compare how different users implement digital technologies in time of crises by using quadruple-helix innovation as a theoretical lens.

Finally, new research questions related to digital technology adoption have surfaced from our analysis. For example, what are the consequences that the misuse of electronic mass communications media has generated? The societal impact of misinformation in a global public health crisis is worthy of future study, so is a more in-depth understanding of the real benefits that authoritarian surveillance measures have produced and how governments in different geographic regions have coped with personal data collection processes. Comparative studies should also be encouraged in order to identify best practices.

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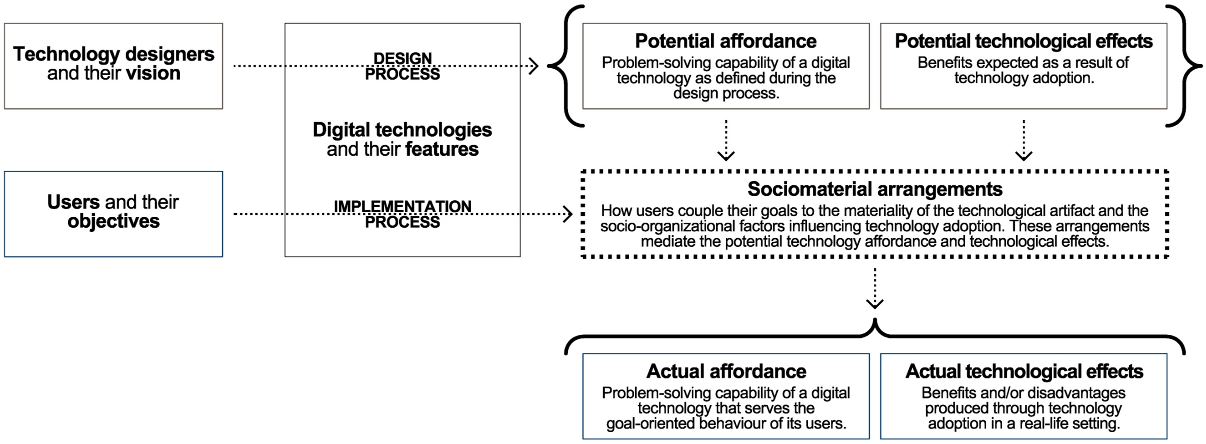

Figure 1. Theoretical framework: technology affordances, technological effects, and the mediating role of sociomaterial arrangements

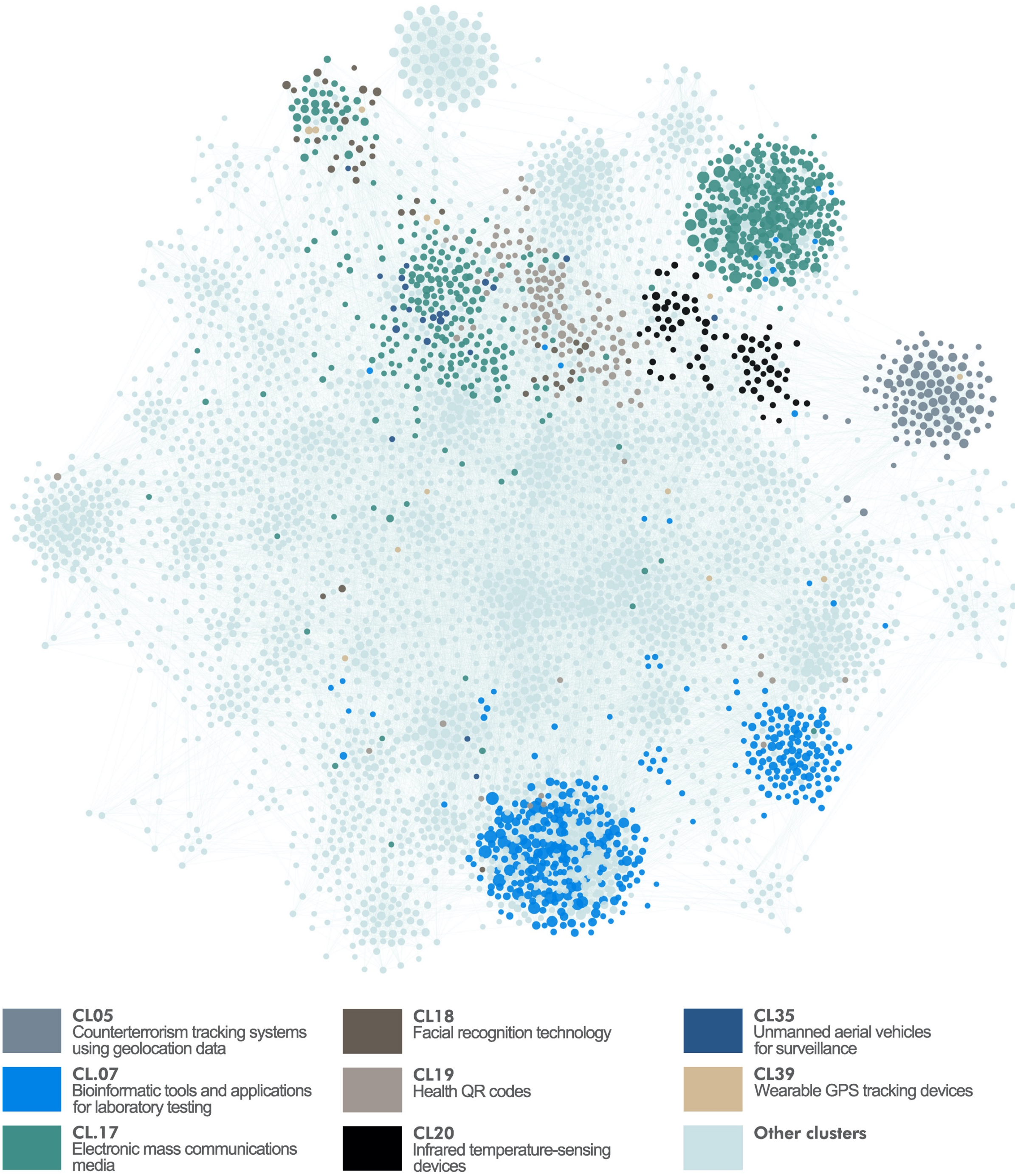

Figure 2. Co-occurrence network. Textual elements (words and phrases) are presented as nodes. The edges represent the strength of connection between couples of nodes, which was measured by means of co-occurrence data. The diameter of each node is directly proportional to its co-occurrence frequency.

CLUSTER	DIGITAL TECHNOLOGY	KEYWORDS
CL01	AI-based predictive critical care systems	Biofourmis; Data Include; Remotely Monitor; Sensor
CL02	AI-enabled early warning systems for infectious disease outbreak	AI Algorithm; AI Enable; AI Model; AI Power; AI Technology; Bluedot; Data Analytics; Data Science; Deep Learning; Diagnostic Tool; Early Warning; HealthMap; Metabiota; Natural Language Processing; Online News; Social Media Data
CL03	AI-powered diagnosis algorithms	AI System; AI Driven; Algorithm; Alibaba; Artificial Intelligence; Baidu; Big Data; Develop an Algorithm; Huawei; Scan; Tencent
CL04	AI-powered online platforms for risk-assessment and triage	Access to Data; CloudMedx; Computational; Conspiracy Video; Data Collected; Data Collection; Data Sharing; Digital Technology; Early Detection; Learning Platform; Posted Online; Predictive Model; Screening Tool; Telemedicine Support; Bright.md; Buoy Health; Digital Platform; Internet Giant
CL05	Counterterrorism tracking systems using geolocation data	Cellphone; Digital Tool; Geolocation; Radar; Satellite; Surveillance Technology; Text Message; Tracking Technology; User Data; Counter Terrorism Technology; Tracking Patients
CL06	Automated fact-checking	Banner; Circulate Online; Facebook and Youtube; Facebook Post; Facebook User; Fact Checker; Google and Twitter; Hashtag; Instagram; Photo and Video; Private Facebook Group; Quickly Remove Video; Social Network Site; Source of Information; Spread Online; Third-Party Fact Checker; Twitter and Google; Twitter Hashtag; User Search; Video Feature; Youtube Video; Automate System; Blog; Blog Post; Include Posts; Including Google; Information Flow; LinkedIn; Social Media Giant; Technology Firm; Amazon; Apple; Facebook; Facebook and Twitter; Fact Checking; Google; Social Media; Social Media Company; Social Media Platform; Tech Company; Tweet; Twitter; WhatsApp; Youtube; Audio Message; Facebook and Google; Infodemic; International Fact-Checking Network; Smartphone Location Data; Twitter and Youtube; Google Search; Tackle Misinformation; Tweeted; Twitter Account; Twitter and Facebook; Work with Google; Work with Twitter
CL07	Bioinformatic tools and applications for laboratory testing	Biotech; Biotech Company; Biotechnology; Kaiser Permanente; Moderna; Clinical Lab; Commercial Lab; Develop Tests; Diagnostic Test; Mammoth Bioscience; PCR Test; PCT Technology; RNA Extraction Kit; Test Kit; Testing Kit; Bioinformatics; Computer Program
CL08	Blockchain-based anti-censorship systems	App WeChat; Apple and Google; Blockchain; Browser; Facebook and Instagram; Firewall; Internet Platform; Online Misinformation; Podcast; Quality Video; WeChat Account; WeiBlocked; Wikimedia
CL09	Cloud computing technology	Cloud Computing; Computing; Computing Resource; Supercomputer
CL10	Cloud robots	CloudMinds; Online Health Platform
CL11	Computed tomography scanning	Chest Radiograph; Computed Tomography; CT Change; CT Finding; CT Scan; Radiology; Tomography
CL12	Contactless technology	App and Website; Cashierless; Cashless; Digital Payment
CL13	Counter-cybercrime technology	Chinese Hacker; Computer System; Cyber; Cyberattack; Cyberattack Response; Cybercriminal; Cybercriminal Activity; Cybercriminal Prevention; Cybersecurity; Cyberthreat; Dark Web; Digital Shadow; DomainTools; Email; Email Address; Email Attachment; Email Fraud; Email Phishing; Email Scam; Emotet; Fake Email; Falsely Claimed; Fearware; Hack; Hack Group; Hacker; Hackers Exploit; Interactive Map; Internet User; Kaspersky; Malicious Software; Malware; Message Platform; Mimecast; Password; Phishing; Phishing Email; Phishing Scam; Ransomware; Remote Access; Scammer; Send Emails; Service Provider; Spam; Virtual Private Network; VPN Server; VPN User; Web App; Website; Collect Information; Connectivity; Cybersecurity System; Information System; Sequencing Data; Teleconference
CL14	Disease situation dashboard	Collect Data; Dashboard; Real Time Update; Tracker; Visualization
CL15	Driverless vehicles	Apollo; Autonomous Vehicle; Driverless; Driverless Delivery; Driving Technology; Neolix; Food Delivery Platform
CL16	Ecommerce platforms	Airpods; Ebay; InstaCart; Meituan; Ocado; Online Marketplace; Online Shopping; Ecommerce

CL17	Electronic mass communications media	Artificial Intelligence Powered; Broadcast; Broadcaster; Broadcaster CCTV; ByteDance; Camera; CCTV; Chinese Internet; Chinese Internet User; Chinese Social Media; Computerized; Cyberspace; Digital Health; Facebook Group; Hand Over Data; Internet Police; Mobile Phone; Online Platform; Phone Call; Retweet; Short Video; Smartphone App; Social Media Account; Social Media Site; Social Media User; Surveillance Camera; Tencent And Alibaba; Tencent WeChat; TikTok; TikTok User; Tracking App; WeChat; WeChat Group; Weibo; App; Data; Digital; Internet; Online; Platform; Post; Real Time; Technological; Technology; Video; Website User; File Photo; Group Chat; Whatsapp Group
CL18	Facial recognition technology	Facial Recognition Company; Facial Recognition System; Facial Recognition Technology; Mass Surveillance System; Mobile Network; Mobile Payment; Sensetime; Software Company; Surveillance Tech; Surveillance Tool
CL19	Health QR codes	Alibaba and Tencent; Alipay; Alipay Health Code; Alphabet; Bluetooth; Close Contact Detector; Computing Power; Data Security; Google Account; Id Number; Meituan Dianping; Messaging App WeChat; Pin; QR Code; Scan QR Code; Server; Share Information; Social Media Post; Travel Data; Webpage
CL20	Infrared temperature-sensing devices	AI Champion; Data Tracking; Deploying Drone; Fever Detection System; Infrared Camera; Infrared Sensor; Infrared Thermometer; Robotic; Screening System; Technology to Track; Temperature Gun; Temperature Screening System; Thermometer; Thermometer Gun
CL21	Live streaming and online event management technology	Google and Facebook; Move Online; Online Event; Online Format; Online Tool; Livestream; Livestream Event; Livestreaming; Post Video; Programming; Video Platform; Webcam
CL22	Advanced computational tools for mathematical modelling of infectious diseases	Mathematical Modelling; Real Time Information; Surveillance System; Epidemiological Model; Historical Data; Online Activity; Google Map; Location Information; Location Tracking; Modeller; Modelling; Palantir
CL23	Privacy-preserving mobile applications for instant contact-tracing	Aggregate Data; Amount of Data; Anonymized Data; Anonymized Mobile Data; Anonymizing Personal Data; Automatic; Carrier; Contact Tracing; Customer Data; Data Driven; Data Privacy; Data Protection; Data Protection Law; Deutsche Telekom; Digital Strategy; Facial Recognition; General Data Protection Regulation; Gmail; Health App; Health Data; Identify Information; Location Data; Mobile Advertising; Mobile Carrier; Mobile Company; Mobile Data; Mobile Operator; Mobile Phone Data; Mobile Technology; Personal Data; Phone App; Provide Data; Share Data; Share Location Data; Telecom Data; Telecoms; Telecoms Company; Telecoms Operator; Track Case; Track Individual; Track Infectious Disease; Track the Movement; Vodafone; Wireless
CL24	Online crowdfunding technology	Online Crowdfunding
CL25	Online crowdsourcing technology	AI Tool; BioRxiv; Data Analysis; Data Mining; Data Scientist; Dataset; Free Online; IBM; Information Technology; Kaggle; Machine Learning; Machine Readable; Major Online Platform; Open Dataset; Open Research Dataset; Repository; Database
CL26	Online education tools	Bandwidth; Broadband; China Mobile; Class Online; Cloud Learning Platform; Digital Divide; Distance Education; Distance Learning; Douyin; Edtech; Education Platform; Home Computer; Home Learning; iPad; Laptop; Learn from Home; Offer Online; Online Class; Online Education; Online Education Market; Online Learning; Online Teaching; Remote Instruction; Remote Learning; Teaching Remotely; Video App; Virtual Classroom; Virtual Reality; Virtual Reality Training; Work Online; Zoom Meeting; Augmented Reality; Coursera; Digital Trend; Google Classroom; Internet Access; Kaltura; Mobile Application; Stream Video; Videoconferencing Software; Virtual Reality Technology
CL27	Online health care platform for consultation	Good Doctor; Online Consultation; Online Health Care; Ping An Good Doctor; Qihoo; Taobao; Video Consultation
CL28	Online web-based systems for interviewing	Online Interview; Virtual Open House; WhatsApp Message
CL29	Remote controlled disinfection robots	Deploying Robot; Disinfection Robot; Robot; Robotics
CL30	Rule-based chatbots	Babylon; Chatbot; Medical Chatbot; Recording their Response
CL31	Teleconferencing and telework technology	Chat App; Cisco; Conference Call; Desktop; DocClocker; Facebook Messenger; Facetime; Gaming; Google and Microsoft; Google Cloud; Google Drive; Google Hangout; Internet Connection; Live Streaming; LogMeIn; Making Video; Microphone; Online Service; Platforms like Facebook; Record Meetings; Remote Meeting; Screen Share; Skype; Snapchat; Social Platform; Technological Development; Teleconferencing; Telework; Video Call; Video Chat; Video Conferencing; Video Conferencing Feature; Video Conferencing Service; Video Meeting; Videogame; Virtual Meeting; Webex; WIFI; WIFI Connection; App Store; Business App; Digital Room; DingTalk; Google Hangout Meeting; Interact with Digitized; Make Remote Work; Microsoft Team; Rumii; Teleconference

		App; Video Conferencing App; WeChat Work; Zoom Video Communication; Group Video Call; Microsoft; Remote Work; Trello; Virtual; Work from Home; Work Remotely; Zoom; Antivirus; Daily Download; Emailed; iPhone; Lark; Remote Employee; Remote Work Software; Remote Worker; Remote Workforce; Telecommuter; Telecommuting; Microsoft and Facebook; Online Post; Remote Work Policy; Tech Leader; Transition to Online
CL32	Telepresence robots	Digital Health Tool; Humanoid; Intouch; Medicaid; Medicaid Service; Robot Design; Robotic Arm; Tech Platform; Telehealth; Telehealth Company; Telehealth Service; Telehealth Visit; Telemedical; Telemedicine; Telemedicine Service; Telemedicine Visit; Virtual Visit; Virtually
CL33	Thermal-imaging cameras	Big data analytics; Contact information; Data processing; Facial Recognition Camera; Megvii; Online Report; Scanner; Short Message Service; Thermal Camera; Thermal Scanner
CL34	Unmanned aerial vehicles for disinfection	Agricultural Drone; Drone and Robot; High Tech; Internet of Things; Unmanned Vehicle; Xag
CL35	Unmanned aerial vehicles for surveillance	Drone; Phone Track
CL36	UVD robots	Suning; Ultraviolet Light; UVD Robot; Xenex; Disinfecting Robot
CL37	Virtual town hall technology	Online Chat; Virtual Campaign; Virtual Event
CL38	Voice-activated intelligent virtual assistants	Alexa; Chatbot System; Google Assistant; Search Query; Siri; Voice App; Voice Assistant; Wikipedia
CL39	Wearable GPS tracking devices	Mobile Device; People-tracking wristband

Table 1. Digital Technologies deployed during the Covid-19 pandemic.

DIGITAL TECHNOLOGY	AFFORDANCE AND EFFECTS Potential	SOCIOMATERIAL ARRANGEMENTS Description	 Moderating factors	AFFORDANCE AND EFFECTS Actual
Infrared temperature-sensing devices	Infrared temperature-sensing devices can be introduced in mass screening operations when they are complemented with other testing measures that contribute in detecting and isolating infected individuals.	Infrared temperature-sensing devices are deployed as the only screening measure and managed by officials without the necessary medical training.	• Nonadherence to WHO's technical guidance on Covid-19 mass screening operations • Lack of training	Infrared temperature-sensing devices have a limited capability to identify infected individuals when deployed in isolation from other testing measures. Therefore, they offer false assurance. Infected individuals who do not develop a fever are not detected by temperature readings and help the virus to spread, because no additional screening tools searching for alternative symptoms are deployed. In addition, the lack of training can lead to improper usage and is more likely to generate misleading temperature measurements (false positive or false negative cases).
ICT-based contact-tracing and surveillance systems	Tracking systems using geolocation data, facial recognition technology, unmanned aerial vehicles, and GPS tracking devices can be used to ensure that citizens adhere to social distancing restrictions - such as lockdowns and home quarantine.	ICT-based contact-tracing and surveillance systems are enforced as authoritarian surveillance measures; they are imposed without robust and transparent accountability mechanisms and without taking into account privacy and ethical implications.	• Bureaucratic authoritarianism	ICT systems for massive surveillance and contact-tracing may help limit the spread of the infection. But this approach to deployment increases insecurity and anxiety among local communities, leaving governments in dispute with data privacy experts and human rights activists, who call for a more responsible use of this technology. In these circumstances, public authorities may take advantage of this temporary control mechanisms to abuse the system by increasing mass surveillance through hype, criminalizing citizens unnecessarily, interfering with their privacy, and jeopardizing personal freedoms.
Bioinformatic tools and applications for laboratory testing	Bioinformatic tools and applications for laboratory testing can help to quickly sequence the genome of the novel coronavirus, use the sequence data to produce diagnostic kits and computer-implementable instructions for laboratory testing, and accelerate large-scale testing operations.	National governments fail to develop effective testing programmes.	• Poor leadership • Overcomplicated bureaucracy • Logistical barriers	Accelerated by next-generation technology platforms, diagnostic kits and computer-implementable instructions for laboratory can be made available at unprecedent speed. But despite the advantage generated by the technological advancements, the national testing capacity remains low. As a result, mass testing is significantly delayed, so is the relaxation of social-distancing measures.

Electronic mass communications media	Electronic mass communications media - such as social media platforms, instant messaging apps, online video-sharing services, digital media, and websites of governmental organizations - can provide the public with a one-stop shop for sourcing up-to-date and reliable information about the outbreak.	Restrictions are imposed to cover up the existence of the outbreak in electronic mass communications media and government officials use this technology to spread misleading information on unverified treatments for curing the infection.	• Lack of transparency • Inappropriate public sector values	The censorship prevents the public from receiving relevant alerts on the outbreak, while inaccurate information on unproven medical products reaches a large number of electronic mass communications media users. Both actions significantly put public health at risk.

Table 2. Summary of findings: lessons on digital technology deployment for large-scale virus containment purposes and the moderating role of sociomaterial arrangements.