Global Landscape for Technological Innovations for COVID-19:
Lessons for Africa

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REGIONAL OFFICE FOR Africa

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Executive Summary

Background and objectives of the study: Coronavirus disease (COVID-19) has resulted in unprecedented number of infections leading to morbidity and mortality of millions of people. In a bid to control further lose to human lives; several technological innovations were developed all over the world that contributed significantly in responding to this pandemic. This paper presents an analysis of one thousand key technological innovations that have been developed worldwide targeting different areas of the COVID-19 intervention areas, which include prevention, detection, treatment & management. The study was undertaken with the view to provide African countries including other key stakeholders with information relating to technologies that can be adapted in their different context as they strengthen their response strategies. This approach is meant to catalyze leap frogging Africa's traditional approaches in responding to the pandemic and to adopt a proactive position in leveraging and mainstreaming emerging technologies in COVID-19 response.

Study design and settings: The study developed a global database of 1000 technological innovations that have been deployed for COVID-19 response across the world. These innovations were electronically retrieved from scientific databases that include PubMed, Google Scholar, Scopus, IEEE and Science Direct using a custom web-mining algorithm. These innovations were either new or a modification of existing technologies. Only innovations that were being piloted, transition-to-scale or have been fully adopted by the market were considered for further analysis. A descriptive analysis was performed to further understand the geographical distribution of these innovations, and the underlying technological platforms for instance Artificial Intelligence, Robotics, Mechatronics, Information and Communication Technology, 3D printing etc.

Observations from the study: The COVID-19 emergence response focuses mainly on three broad areas, which are prevention, detection and containment. The study showed majority of the innovations mainly focused on preventive interventions (63%), for instance 3D printed face masks/face shields; contactless sanitizer dispensers and social distancing mobile application tools. Interestingly, the COVID-19 context saw emergence of several innovations in e-commerce, Telehealth, e-learning and virtual meetings as one of the social distancing measures of controlling the spread of the pandemic. Risk communication & community engagement was also at the center of the COVID-19 response as a preventative measure. This has led to the development of information and communication technologies (ICT) to drive mass communication through SMS alerts, Chatbots and WhatsApp based platforms; and several other information tools to fight misinformation and false rumors. Majority of these innovations came from developed nations like USA, Europe and China. It was noted that most of these technologies leveraged existing technological platforms like robotics, artificial intelligence, 3D printing, mechatronics, and ICT. Despite the potential impact of innovation in controlling the pandemic, Africa is still lagging in developing and adoption of technological innovations, accounting only for 12.8% of all the technologies identified from the study.

Discussion: This study presented on a web platform *https://innov.afro.who.int/global-innovation/index* was undertaken to bring to the surface potential impactful and contextually relevant innovations that can be adapted in Africa. This was in response to the existing knowledge gap about the technological landscape as it relates to COVID-19. The platform provided the much-needed information for countries including other key stakeholders to make informed decisions in adopting some of these technologies as part of the COVID-19 response in their respective countries. It is envisaged that countries and local innovators can approach the Intellectual Property owners of the profiled innovations for further collaboration in bringing these technologies to the African market. For instance, countries like the United Kingdom came up with an innovative device that provide a continuous positive airway pressure (CPAP), which is a breathing apparatus that pushes oxygen to the lungs without needing a ventilator. The design has been made open-source so that other countries can reproduce the equipment where needed.

Furthermore, this study complements global efforts by WHO in setting up the COVID-19 Technology Access Pool (C-TAP), which is an initiative aimed at compiling pledges of commitment made under the Solidarity Call to Action to voluntarily share COVID-19 health technology related knowledge, intellectual property and data. The database generated through this study can be proactively applied to identify and engage the Intellectual Property owners to partner with WHO through the C-TAP initiative.

Meanwhile, many factors are attributed to Africa not having enjoyed the spring up of technological developments for COVID-19 emerging from the continent. However, it suffices to say most of the technologies observed in the study relied heavily on the foundation of existing technological infrastructures, which made it possible to spin off various innovations for COVID-19. It is therefore important for African countries to prioritize investment in key infrastructural developments such as ICT, Drone technology, Robotics, AI, mechatronics etc. All these investments should be accompanied by the right policies and incentive frameworks to stimulate creativity and entrepreneurship among their population. Recently WHO in the African region developed a regional strategy for scaling up health innovations, which was adopted by all the 47 Member states of the African region. The strategy was premised on the need for member states to build capacities and institutional mechanisms to harness and manage innovations that are tailored to local needs and to prepare for health emergencies like COVID-19 pandemic. It is with the hope that when African countries are supported to implement the regional strategy, we may experience positive changes in the innovation ecosystem in fostering development and scaling up of innovations, not only to respond to emergencies, but to accelerate health improvements for vulnerable populations in the region.

Keywords: *COVID-19Innovations, COVID-19 Technologies, COVID-19 Digital Health*

1. Introduction

The COVID-19 outbreak was declared a global pandemic by the WHO on 30th January 2020 (WHO, 2020). After the declaration, many researchers, innovators and companies across the world spearheaded development of innovative solutions to respond to the pandemic (Greenhalgh et al., 2020). These innovations are currently being used across the continuum of the response, which include surveillance, contact tracing, point of entry, risk communication &community engagement, infection prevention & control, case management, and laboratory services which are consistent with the WHO preparedness and response strategy (World Health Organization, 2020).

Several reports and studies have shown that innovations have played significant roles in responding to COVID-19 pandemic especially in developed countries (John, 2020) (Ohannessian et al., 2020). For example, in China, robots like the one developed by *Medical Robots*[1] have been widely used for infection prevention & control and case management. In addition, China used social networking technologies to compile and disseminate COVID-19 related information updates in real-time on the transmission dynamics of the virus (Chan et al., 2020). On the other hand, the United Kingdom came up with an innovative device that provide a *continuous positive airway pressure (CPAP)*[2], which is a breathing apparatus that pushes oxygen to the lungs without needing a ventilator. The design has been made open-source so that other companies can reproduce the equipment where needed. Some of the COVID-19 technological innovations were newly developed in response to specific needs using a user centered design approach (Rau, 2016); while others are a modification of existing technologies re-engineered to respond to the COVID-19 utilizing the principles of frugal design (Radjou & Prabhu, 2015).

The same level of creative outputs and innovations was expected from Africa given its demography that is skewed towards young people and high penetration information and communication technologies, which are the basis for fostering creativity and ingenuity. Unfortunately, the picture is contrary to the expected. However, one of the mechanisms to stimulate demand for COVID-19 innovations in Africa would be to provide a global landscape of what technologies other regions of the world have developed and encourage both African countries and innovators on the continent to adopt or adapt these innovations to tailor to their contextual setting. This study will also provide additional impetus to many African innovators to make informed decisions on what works, how best it can work and consequently apply frugal design to manufacture affordable, local, functional, sustainable technological innovations fit for African context.

In view of the above, this paper presents an analysis of compilation of key technological innovations that have been developed across the world currently being used to address COVID-19 pandemic targeting various areas of the response as adopted from the *WHO COVID-19 response strategy*[3].

1 https://www.sohu.com/a/378301359_100256408
2 https://www.formula1.com/en/latest/article.mercedes-to-begin-delivery-of-10-000-breathing-aids-to-nhs-as-part-of.2xDeE5gsLUrSX7zmE4MeCx.html
3 https://www.who.int/publications/i/item/strategic-preparedness-and-response-plan-for-the-new-coronavirus

2. Study Design

2.1 Data Collection

The study was designed to collate and analytically review one-thousand COVID-19 technological innovations obtained electronically from scientific databases that included PubMed, Google Scholar, Scopus, IEEE and Science Direct using a custom web-mining algorithm to search the web for text, image, audio or videos of the innovations as shown in Figure 1. The web-mining algorithm also searched for all COVID-19 related technologies published on different organizational websites, social media channels like twitter, and on various media channels both local and international. These technological innovations were collated between July 2020 and September 2020, which surpassed the 1000 mark. However, for the purpose of this study only 1000 key technological innovations were selected that best fit the selection criteria as highlighted in section 2.2.

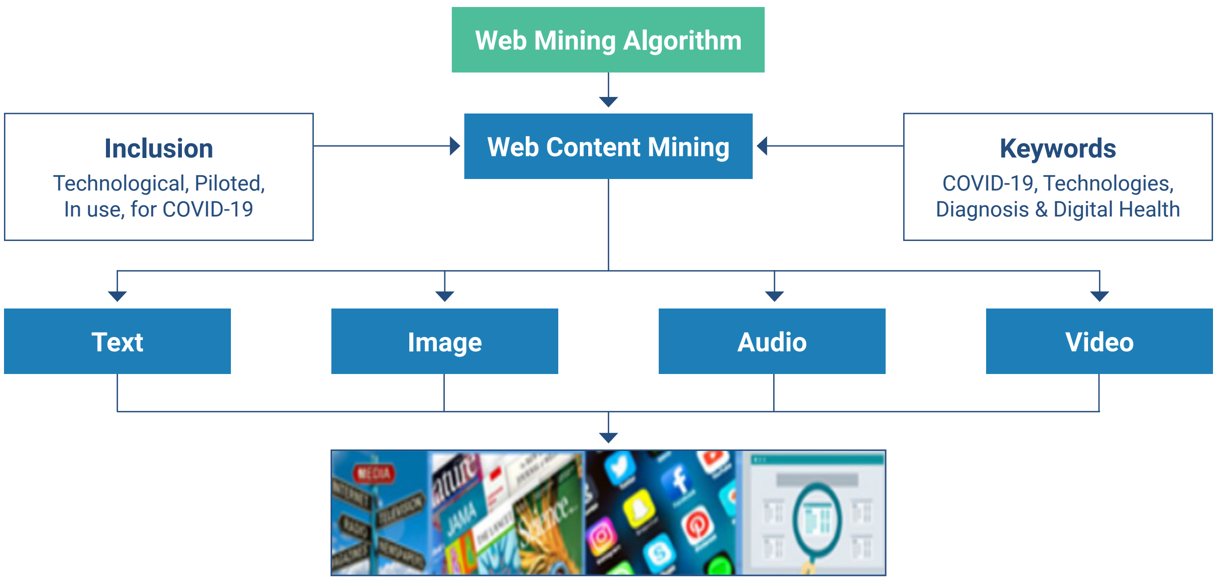

Figure 1: Web Mining Framework

2.2 Inclusion and Exclusion Criteria

The innovations included in the study are only those that are technologically driven and are either being piloted, transition to scale or fully adopted by the market. The study excluded innovations that were presented as theoretical framework or at the proof of concept phase.

2.3 Data Analysis

The innovations were analyzed and grouped according to COVID-19 intervention areas as they related to the WHO preparedness and response strategy (World Health Organization, 2020) as shown In Figure 2. The areas covered included prevention, detection and treatment & management. Descriptive statistics were used to describe the basic features of the data providing summaries about the sample and the measures.

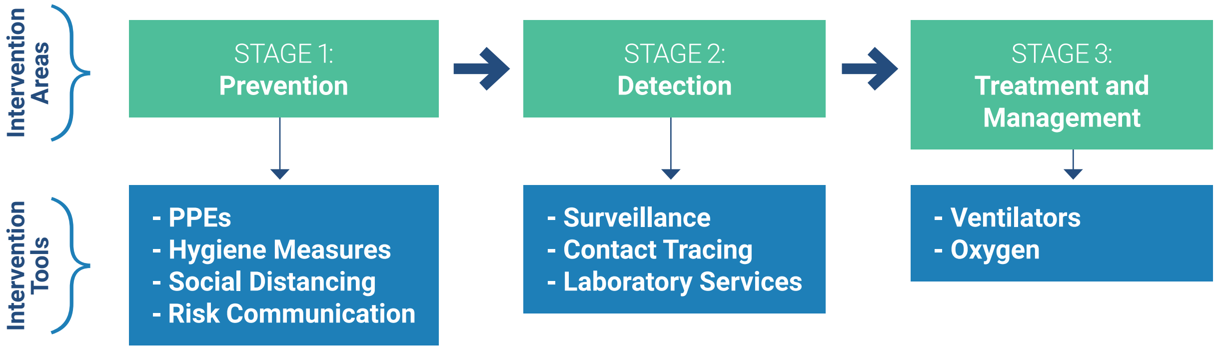

Figure 2: Different levels of COVID-19 intervention areas

3. Observations and Discussions

The analysis reveals that more than half of the innovations (63%) were deployed to support and argument preventive interventions. These innovations included personal protective equipment (PPEs), automated sanitizer dispensers, social distancing and risk communication platforms. Twenty six percent (26%) of the innovations were deployed to support case detection and investigation and these included tools used for surveillance, contact tracing, and laboratory services, whereas only 12% supported treatment and management of COVID-19 cases that required hospitalization as highlighted in Figure 3.

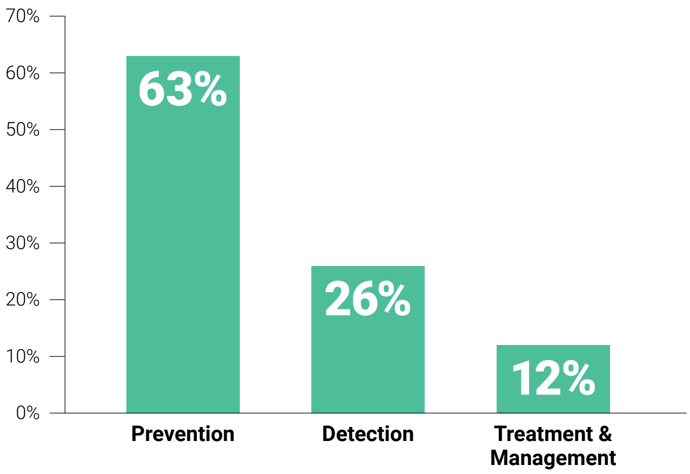

Figure 3: Distribution of the COVID-19 innovations across the continuum of prevention, detection & management

3.1 Highlighted Technological COVID-19 Innovations for Prevention

The analysis of the distribution of technologies that targeted prevention area revealed that majority (45%) were used to strengthen risk communication & community engagement approaches, other innovations focused on personal protective equipment (19%), social distancing platforms (24%) and hygiene interventions (12%).

3.1.1 Risk Communication

The upsurge in the development of risk communication innovative tools highlights the importance of the area in dealing with emergencies and disease outbreaks as indicated in broader health emergency preparedness and response action plan (The World Health Organisation, 2020). Although a lot of innovations were developed in North America, Europe and Asia, we also noted few emerging from Africa, for instance, Angola launching the *COVID-19 AO*[4], a digital platform for self-diagnosis; the Ministry of Health, Ghana launched *GH COVID-19 Tracker App*[5], used for contact tracing, the Nigerian government also launched the COVID-19 information management and communication tool called *CommCare*[6] and; the *WhatsApp interactive Chatbot and COVID-19 HealthAlert*[7] being used in South Africa. These examples demonstrated of how countries embarked on a drive for mass communication through SMS alerts, Chatbots and WhatsApp based platforms; and several other information tools to provide correct information about the pandemic and also to fight misinformation as shown in Figure 4.

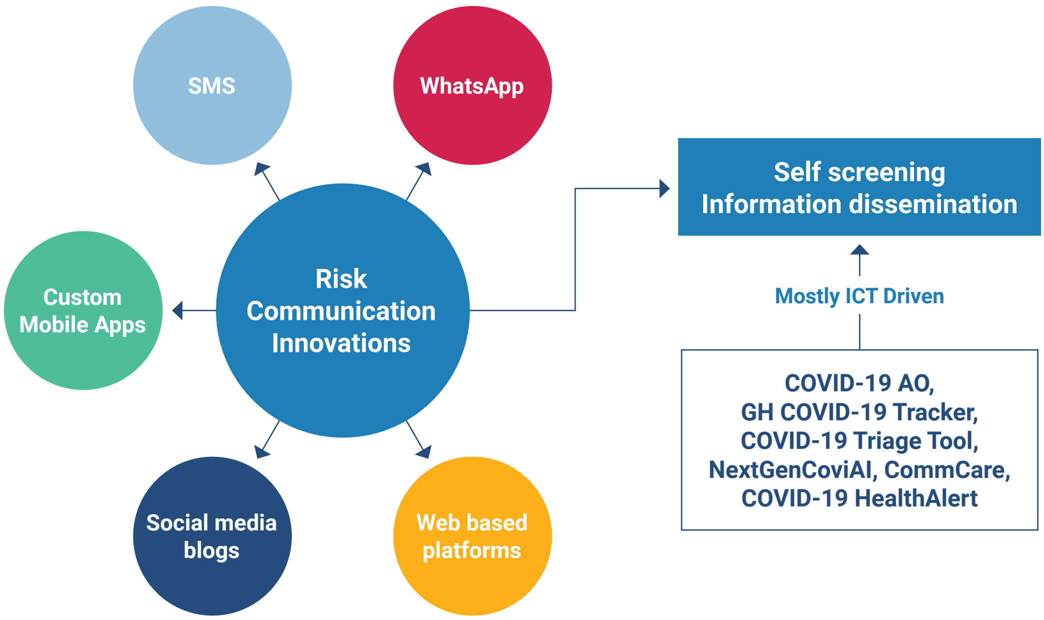

Figure 4: Tools used for risk communication

4 https://covid19ao.com
5 https://ghcovid19.com
6 https://dimagi.com
7 https://api.whatsapp.com/send?phone=27600123456&text=check&source=&data=&app_absent=

3.1.2 Social Distancing

Governments around the world encouraged their citizens to adhere to social distancing guidelines in order to limit the spread of the COVID-19 (Greenstone & Nigam, 2020). To empower communities to sustain livelihoods in the face of restrictions on movement and lockdown measures, we noted several technological innovations that were developed mainly focusing on e-commerce, telehealth, e-learning and virtual meetings to facilitate business continuity in the context of the pandemic as shown in Figure 5. Recently the South African government launched a Bluetooth-enabled social distancing mobile application dubbed *COVID Alert South Africa*[8], which will strengthen South Africa's contact tracing efforts. However, majority of these innovations came from developed nations like USA, Europe and China leveraging their strong technological platforms like 5G technology and robotics.

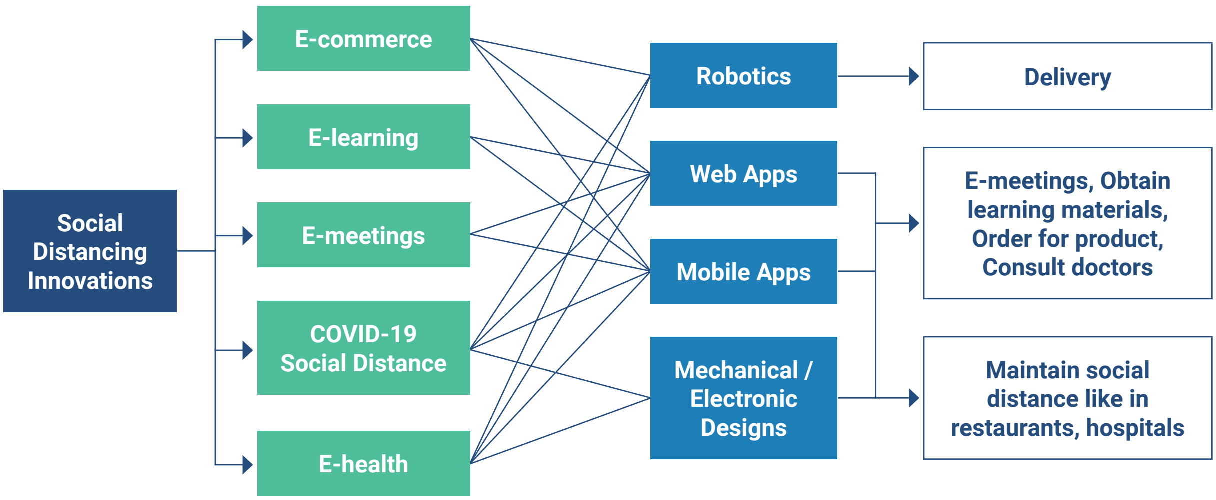

Figure 5: Deployment of Social distancing COV-19 Innovations

Specific highlights of some of the technological innovations include *Sentosa Crossing*[9] by Creative Agency BBH for guests to visit Singapore's Sentosa Island virtually, using the Nintendo game Animal Crossing. The app's virtual experience allows people to experience the holiday destination while staying safe in their own homes; restaurants in Maryland, USA, introduced "*socially distanced restaurant bumper tables*" a Coronavirus invention which uses a large inner tube to keep diners apart; *RomwareCovid Radius* created by *Rombit*[10] in Belgium is a digital bracelet that ensures social distancing whenever employees come closer to each other than 1.5 metres, they feel a vibration and receive a visual warning signal; the *SmartEagle distance Sensor* by *SmartEagle*[11] in Netherlands lets people know whether they are at the right distance from other people. The sensor sounds an alarm when people are closer than 1.4 metres; the *SmartDome* developed by the San Diego-based tech company *Indyme*[12] is a camera that watches customers and sends out messages if they are disobeying the rules of social-distancing; *AxelHire*[13] in San Francisco innovated *a suite of tools* that enables consumers to sign for their deliveries using a mobile device, allowing them to avoid touching

8 https://play.google.com/store/apps/details?id=za.gov.health.covidconnect&hl=en
9 https://www.sentosa.com.sg/
10 https://rombit.be/covid-solutions/
11 https://smarteagle.nl/
12 https://indyme.com/
13 https://axlehire.com/

the driver's mobile device or even opening the door; *Sodar*[14] created by Google is an augmented reality tool which uses WebXR to visualize 2m social distancing guidelines in your environment by creating an augmented reality two metre radius around you on android smart phones; and finally *Ubongo*[15] implemented in Tanzania is an e-education platform that leverages the power of entertainment, the reach of mass media, and the connectivity of mobile devices, to deliver effective, localized learning to African families at low cost & massive scale.

3.1.3 Protective Equipment

Personal protective equipment (PPEs) has been proven to reduce the spread of the COVID-19 virus. Common types of PPEs include masks, face shields, goggles, gowns, aprons, and gloves (Silman, 2014). Several national and international organizations have published guidelines on the design, manufacture, use, and re-use of PPE for both medical and community settings for example the WHO curated standards and regulations pertaining to the design of PPEs (WHO, 2020). In response to the increased demand for the PPEs, several innovations have been developed. The results from this analysis show that 3D printing technology has made possible the design of face mask and shields that have been deployed in the different countries. For instance, the *Fitz Protect*[16] is a line of custom 3D-printed protective eyewear being implemented in USA, *3D non-invasive ventilation masks* in South Africa, *headbands* for protective face shields in UK, *3D-printed door openers* by *Materialise*[17] in Belgium, *3D-printed quarantine rooms* by *WinSun*[18] in China and *3D-printed nasal swabs* by *Northwell Health*[19] in the USA.

As masks are critical for infection prevention, it was observed that high-quality PPEs have been in short supply especially in low middle income countries. The PPEs available to the public are of low quality with users complaining that cheap cloth masks, although widely available and recommended by public health agencies, are uncomfortable, hamper social interactions, and have limited effectiveness. These types of masks are found on streets in most of the African countries. However, more focus is shifting to the development of 3D-printed masks that are tailored to each individual's face using artificial intelligence and creating transparent masks that facilitate better communication. Examples of the 3D printed masks include the *UVMask* developed by Colorado-based optical and biotechnology company *UM Systems*[20] that allows air coming into the mask to pass through an N95-equivalent replaceable filter and then enters a "sterile vortex" where it is treated with UV-C light, which can inactivate viruses by damaging their genetic material. In the UK, an *Injection Molded Autoclavable, Scalable, Conformable (iMASC)* mask which is easier and more cost-effective to reuse has been developed. It is made of clear silicone rubber and has two circular filters located near the mouth giving it an excellent breathability. The *SEEUS95*[21] mask is marketed as a "radical alternative to traditional N95". The SEEUS95 is made of clear silicone, uses "proprietary N95 biofilters," and attaches to the face with a sticky "skin therapy layer" that supposedly produces an airtight seal.

14 https://sodar.withgoogle.com/
15 https://www.ubongo.org/
16 https://www.fitzframes.com/fitz-protect
17 https://www.materialise.com/en
18 http://www.winsun3d.com/En/About/
19 https://www.northwell.edu/
20 https://www.um.systems/
21 https://seeus-95.com/

In addition to face masks, face shields are being widely used especially by frontline healthcare workers. The COVID-19 unveiled an opportunity for global innovation network to design and construct different types of face shields. Examples are the *Corran face shields*[22] developed by 4c Engineering, Aseptium and Lifescan. These have provided open source designs and guidelines for local assembly of face shields. This saw many African countries benefitting from this including Uganda by *Global Auto Systems*, South Africa by *University of Cape Town* and in Zimbabwe by *Medical Solutions Zimbabwe*.

Innovative designs for protective goggles also emerged and these include *Magid Y50 Design Series Safety Glasses* by Magid Glove and Safety in USA, and Uvex Ultra-Spec 100 OTG Safety Glasses by Uvex in USA.

In the US, *Aegle Gear*[23] makes *antimicrobial and water repellent scrubs* for healthcare professionals. The antimicrobial property in scrubs is obtained by the treatment with Protx2, a proprietary technology that controls microbial growth over the long term. In addition to gowns, aprons are also being increasingly used for protection by healthcare workers, and a number of innovations have been observed. The US-based startup *Eagle Protect*[24] develops disposable smocks, aprons, jackets, beard covers, hats, and balaclavas aimed at the food safety and food processing industry. These are also being used for protection against COVID-19.

Lastly, Gloves are primarily used by medical care workers but have become more prevalent in public settings such as in markets, restaurants, and other small businesses. Double gloving is recommended by the World Health Organization (WHO) for healthcare professionals while handling patients during pandemics like COVID-19 (Varghese et al., 2020). A German startup *Smarterials Technology*[25] creates gloves with perforation indicators and a higher level of protection using double gloving.

Despite the availability of open source models and guidelines of producing PPEs, there is still non-availability or inadequate supply of good PPEs in Africa. This could be attributed to the slow manufacturing plans, lack of ready infrastructure including machinery and poor supply chain of PPEs.

3.1.4 Hygiene Products

Hands' washing using soap or alcohol-based gels were encouraged as one of the effective methods to limit the spread of COVID-19. In light of this, several technological innovations were developed presenting novel disinfectants or approaches to disinfect surfaces. Such innovations include the *Vehicle Disinfectant Bay* in India, which is a device that disinfects vehicles automatically reducing the time and energy by completing the disinfection process of a vehicle in a very short time without much effort. The foot-operated Height Adjustable Hands-Free Sanitizer Dispenser Stand by Vissco Rehabilitation Aids Pvt.Ltd in India is a hygiene solution for residential, commercial, and industrial applications. In Uganda, a pharmaceutical company (PHARMBIOTRAC) produced *PharmSan Innovations*, a low cost novel Liquid and Gel formulation Hand Sanitizer that has been scaled up in the country. In the UK, Lifestyle Packaging has designed *Snappd*[26], a novel one-hand dispensing mechanism for alcohol-based hand sanitizer.

22 https://aseptium.com/corran/
23 https://aeglegear.com/
24 https://eagleprotect.com/
25 https://smarterials.berlin/en/smarterials-technology-2/
26 https://www.originltd.com/snappd-single-dose-dispenser/

In France, *LVMH* a perfume and cosmetics giant *produced hydro alcoholic hand gel to prevent the spread of COVID-19*. In UK, the *InKey List* came up with an anti-viral hand cream with added moisturizing benefits to counteract the drying effects of alcohol-based products. Other innovations include *Coronavirus-popping surface coating* by Researchers at Virginia Tech; an anti-microbial coating that is believed to eliminate the virus. The coating is made of synthetic antimicrobial peptides (mini-proteins), which pop the outer lipid membrane of the virus, effectively killing it. Other examples include the *UVD Robots*[27] *in Denmark* to disinfect the rooms using ultraviolet-C light to destroy the viral RNA; the Infection proof transportation pod developed by *EpiShuttle*[28], which is an isolated single patient transportation pod that has been used by air ambulances crews to transport infected patients out of Coronavirus hotspots to regions with more capacity to treat them.

3.2 COVID-19 Detection Tools

Effective detection methods should help in the early identification of cases through surveillance, contact tracing and laboratory testing. Various innovative tools were developed to strengthen early detection as demonstrated in the following sections.

3.2.1 Surveillance

The objectives of COVID-19 surveillance include enabling rapid detection and isolation guiding the implementation of control measures, detecting and containing outbreaks among vulnerable populations, evaluating the impact of the pandemic on health-care systems and society, monitoring longer term epidemiologic trends and evolution of COVID-19 virus, and understanding the co-circulation of COVID-19 virus, influenza and other respiratory viruses (Incident Room Surveillance Team, 2020). As per WHO's recommendation surveillance systems should be geographically comprehensive and include all persons and communities at risk (WHO, 2006).

The database unveiled various technological innovations that include online data sources for early disease detection, which are population based surveillance systems that typically rely on health-related data from laboratories, notifications of cases diagnosed by clinicians and syndromic surveillance networks; for example the *WHO's platform EPI-BRAIN*[29] brings together diverse datasets for infectious-disease emergency preparedness and response, including environmental and meteorological data. Other examples include data-aggregation systems, like *ProMED-mail*, *HealthMap* and *EIOS*[30], that uses natural language processing (Hirschberg & Manning, 2015) and machine learning to process and filter online data to provide epidemiological insight; data-visualization dashboards to help collate real-time public-health data, including confirmed cases, deaths and testing figures, to keep the public informed and support policymakers in refining interventions for instance the *Latest situation of novel coronavirus infection in Hong Kong dashboard*, and the *covid19 SG-Dashboard of the COVID-19 virus outbreak in Singapore*.

A number of symptom-based case identification tools were developed and made available to communities for self evaluation, which are linked to automate reporting to public-health databases

27 https://www.uvd-robots.com/about-us
28 https://epiguard.com/
29 https://www.epi-brain.com/
30 https://www.who.int/eios

for example the Singapore COVID-19 Symptom Checker, *COVID-19 Symptom Trackerapp* developed by King's College London and health science company ZOEbeing used in the USA and UK. The '*Covid Near You*[31]' map is another interesting technology that was developed by Boston Children's Hospital and Harvard Medical School where community members can self-register whether they have had symptoms that met the COVID-19 case definition. The *NHS Corona virus Status Checker* in the UK and *Alipay Health Code* in China were also developed to monitor the spread of COVID-19 through opaque algorithms and data sources to make assessments about the potential risk of infection. Several countries like Norway, India, South Africa, Uganda, Kenya and Nigeria have already launched self screening mobile applications, while other countries like Australia and New Zealand repurposed previously existing platforms like *FluTracking – an influenza monitoring application*[32] and the use of robotics like the *Marut drones*[33] in India for surveillance by checking people's temperature using thermal imaging.

3.2.2 Contact Tracing

Contact tracing is a complicated and time-consuming activity (Eames & Keeling, 2003). To cut down on the man-power needed to manage the process, a number of tools have been developed all over the world. Such tools include adaptation of *Go.Data*[34] and Geographical Information System developed by the WHO for public health practitioners and field responders to apply in contact tracing. These tools have been used for initial case investigation, transmission pathway visualization, and contact follow-up. Other tools like *SaferMe*[35] *in New Zealand* made by MBIE COVID-19 Fund provide employers with a database of regularly updated contact tracing from employees and a place to input daily health surveys; and *exposure notification apps*[36] developed by Apple and Google have been used by user to alert them when they come into contact with a COVID-19 positive person, advising them on next steps. South Africa through the System one's company developed *Aspect Software* platform that has been adapted to report numerous infectious diseases including Zika, Ebola, HIV, Malaria and Hepatitis C. The organization has now adapted the platform to test and track COVID-19 cases, providing real-time dashboards to inform preparedness, response and tracking of outcomes.

In Uganda, *DHIS2 Tracker and the DHIS2 Android Capture App*[37] used by the Ministry of Health to collect, manage and analyze transactional, case-based data records has been *reconfigured for real-time data capture, COVID-19 surveillance* and printing of traveler's passes for drivers and truck occupants who were cleared for entry. Similarly, DHIS2 has been used in Sri Lanka for COVID-19 surveillance. In Norway, the Norwegian Red Cross is using *Nyss (short video introduction)*[38] which allows real-time detection, reporting, aggregation, and analysis of community health risks. In Australia, the Austrian Red Cross launched an application called *Stopp Corona* which contains a contact diary, where personal encounters are saved anonymously. If someone tests positive to COVID-19, or begins to show symptoms, all contacts from the past 54 hours will be notified.

31 https://covidnearyou.org/
32 https://info.flutracking.net/
33 https://marutdrones.com/
34 https://www.who.int/godata
35 https://www.safer.me/
36 https://www.google.com/covid19/exposurenotifications/select/
37 https://play.google.com/store/apps/details?id=org.hisp.dhis.android.trackercapture&hl=en&gl=US
38 https://www.cbsrc.org/what-is-nyss

3.2.3 Laboratory Services

The global spread of COVID-19 dramatically increased the number of suspected cases and the geographic area where laboratory testing needed to be implemented (Tang et al., 2020). The need of intensive COVID-19 molecular testing led to shortages of molecular testing reagents globally for COVID-19, especially in low- and middle-income countries (Yong et al., 2020). Several innovations have been developed to facilitate the testing of COVID-19 in labs. Amidst the increasing number of COVID-19 cases, testing of COVID-19 has also expanded to even happen outside laboratories to community levels by trained health workers using point of care technologies. In Senegal, Institut Pasteur de Dakar (IPD) developed a *one dollar 10-minute COVID-19 testing kit* that detects the Corona virus using saliva or blood drops, In USA, *GenoSensor*[39] has developed *COVID-19 RT-PCR KIT* for detection of COVID-19. Several laboratory services innovations have been developed in China including, a *One Step Test for Novel Coronavirus (Real time RT-PCR KIT)*[40], Accurate detection of the SARS-CoV-2 virus (RT-qPCR kit), and Rapid test kit for diagnosis by *Everest Links Pte Ltd*[41]. In USA, *InBios International Inc*[42] developed a real-time RT-PCR test for COVID-19 (COVID-19 Detection Kit), *Remote Blood Sample Collection* by *Sandstone*[43] which helps support response activities by enabling remote blood sample collection and stabilization in non-hospital and in-home settings. In Japan, *Takeda Pharmaceutical Company*[44] has developed *a potential plasma-derived therapy* for treating COVID-19. Again In Japan, *Gencurix Inc* developed detection test (COVID-19 Detection Kit) for COVID-19. In Asia, a *COVID-19 qPCR Multi Kit* that allows qualitative detection of genes of COVID-19 with real-time qPCR via RNA extracted from a specimen (Nasopharyngeal swab, Oropharyngeal swab) of suspected respiratory infectious disease patient has been developed.

With the emerging technologies, AI is has also been used for COVID-19 diagnostics. In Belgium, *Robovision*[45] launched an Imaging COVID-19 AI initiative to train AI to detect COVID-19 in lung scans. Engineers in Tunisia have created an online platform that *scans lung X-rays* to try to determine if a person could be suffering from coronavirus. Drones have also been used to speed up COVID-19 testing, for example *Zipline* in Ghana is using drones to deliver samples collected in more than 1,000 health facilities across the country. In Italy, a drone company, Elite Consulting designed a *box suitable for the transport of swabs and small medicines* with an industrial drone.

39 https://genosensorcorp.com/
40 https://www.fda.gov/media/136472/download
41 http://everestlinks.com/index.php?route=product/category&path=73_90
42 https://inbios.com/
43 https://sandstonedx.com/
44 https://www.takeda.com/
45 https://robovision.ai/

3.3 Treatment and Management

COVID-19 is respiratory disease which manifest in shortness of breath as a result of inadequate supply of oxygen to the lungs. So, placing patients on oxygen supply is one of the recommended non therapeutic interventions in the management of COVID-19 cases (Rothan & Byrareddy, 2020). In respect of this, a number of innovations to support ventilation of severe COVID-19 patients were developed and deployed in various settings.

The traditional process of making oxygen is passing air through lithium X-zeolite which filters oxygen from the air and subsequently concentrates it (Perez-Carbajo et al., 2018). This is an expensive process and monopolized by few companies. Amidst the COVID-19 several researchers have come up with alternative approaches to produce oxygen. In Switzerland, researchers at *UniSieve*[46] came up with an alternative to the zeolite. They modified a filtering membrane they had developed to separate carbon dioxide from hydrocarbons for *oxygen filtration*. Researchers at the University of Arizona College Of Medicine in Tucson developed a system that delivers a mix of helium and oxygen. The mix is lighter than regular air, and *it takes less effort to breathe it in*. The shortage of reliable power supply in Africa also makes oxygen delivery inefficient; hence different innovations have been developed to provide an alternative source of energy. *Solar oxygen systems* provide a consistent supply of oxygen off the grid, combining renewable energy with effective storage to offer patients 24/7 access to therapy (Conradi et al., 2019). Such systems have been implemented in Africa like in Uganda[47].

Alternative to oxygen supply is to assist patients to breathe through a ventilator. In the USA, Georgia Tech Research Institute in collaboration with Emory University in the United States and Cranfield University in England developed a simple and low-cost ventilator *based on the resuscitation bags* carried in ambulances, the *VentilAid*[48] project which is an open source ventilator that can be made anywhere locally with a 3D printer in Europe. Amid a shortage of ventilators on COVID-19 wards in Nigeria, engineering students developed a *Respire-19 portable ventilator* to help people with respiratory problems. Also, a team of anesthesiologists, pulmonologists, sleep and critical care specialists and medical students at the Mount Sinai Health System *reconfigured donated variable positive airway pressure (VPAP) machines originally designed for sleep apnea care into ventilators for use on the most severely ill patients* hospitalized for COVID-19. In Singapore, clinicians developed innovative ventilator called Innovative "SG-Inspire" designed and custom-built by *SingHealth*[49] clinician innovators and engineers for remote monitoring. In the UK, a consortium under the "*VentilatorChallengeUK*" is working to produce medical ventilators for the NHS. The 'VentilatorChallengeUK' includes Airbus, BAE Systems, Ford and Siemens. *OxyGEN*[50] is an open hardware project in Spain to build an emergency mechanism that automates an AMBU type manual ventilator in extreme shortage situations such as the one caused by coronavirus (COVID-19) in some parts of the world.

46 https://www.unisieve.com/
47 https://www.solaroxygen.org/
48 https://www.ventilaid.org/
49 https://www.singhealth.com.sg/
50 https://github.com/ProtofyTeam/OxyGEN

4. Conclusion and Recommendations

This research has culminated into insightful conclusions from the global database for COVID-19 Technological Innovations accessed via (*https://innov.afro.who.int/global-innovation/index*). The findings provide leverage point and empower innovators on the continent to make informed decisions on applying frugal design to manufacture affordable, local, functional, sustainable technological innovations fit for African continent. Furthermore, the platform provides implementation insights to African nations on the adoption of some of the technological innovations surfaced from this study.

As most innovations emerged from North America, Europe and Asia, it is believed that this study will challenge many African nations to support universities and innovators to conduct research and develop innovations that are more relevant in responding to African challenges. Many factors are attributed to Africa not having enjoyed the spring up of technological developments from the continent. However, it suffices to say most of the technologies collated in the study relied heavily on the foundation of technological infrastructure that made it possible to spin off various innovations for COVID-19. It is therefore important for African countries to prioritize investment in key infrastructural developments such as ICT, Drone technology, Robotics, AI, mechatronics etc. All these investments should be accompanied by the right policies and incentive frameworks to stimulate creativity and entrepreneurship among their population as shown in Figure 6.

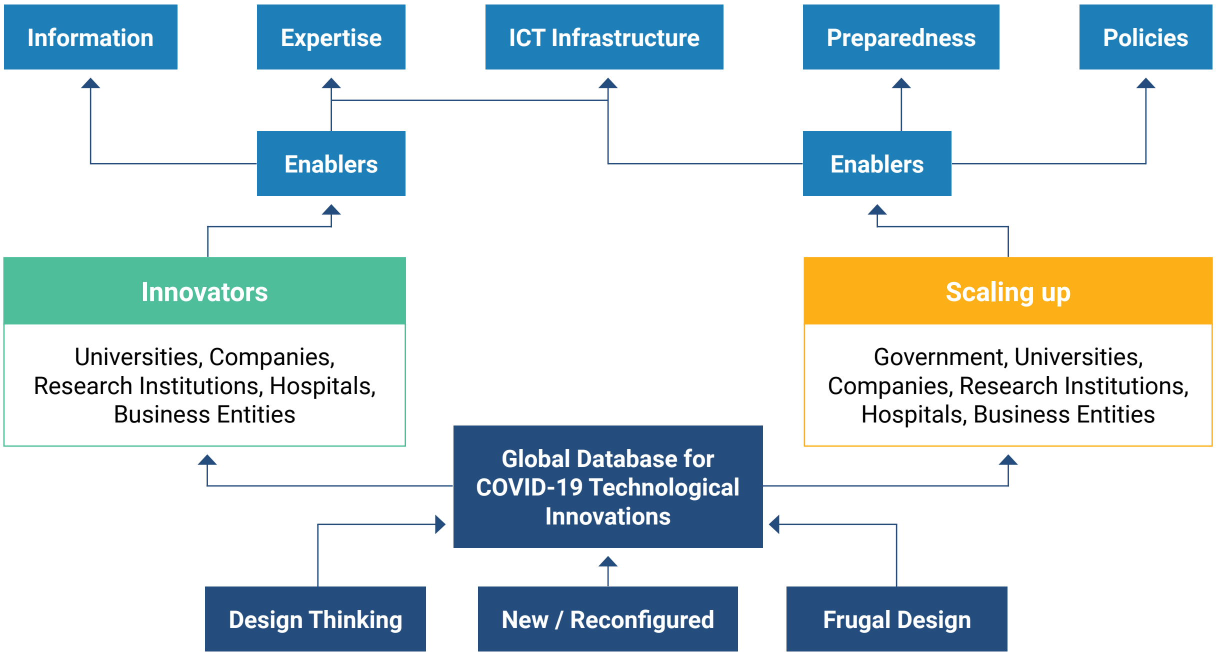

Figure 6: Highlights from the COVID-19 technological innovations database

Recently WHO in the African developed a regional strategy for Scaling up Health Innovations and was adopted by all the 47 Member states of the African region. The strategy was premised on the need for Member States to build capacities and institutional mechanisms to harness and manage innovations that are tailored to local needs and to prepare for health emergencies like COVID-19 pandemic. It is with the hope that when African countries are supported to implement the regional strategy, we may experience positive changes in the innovation ecosystem in fostering development and scaling up of innovations, not only to respond to emergencies, but to accelerate health improvements for vulnerable populations in the region.

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