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Building Digital Resilience to Combat Pandemics: Comparison of South Korea, Sri Lanka and Rwanda

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Abstract: Use of digital technologies for management of COVID-19 pandemic was widely observed across the globe. However, building resilient digital systems to better manage the pandemic based on country contexts was a challenge. The objective of this study is to identify socio-technical determinants of building resilient digital technologies based on a comparative study of three countries. Case study method was utilized with qualitative data collection methods to identify thematic areas for comparison. The study revealed that resilient digital pandemic responses will rely on a plurality of technologies, and on agility, flexibility and capacity in producing these solutions.

Keywords: Sri Lanka, South Korea, Rwanda, resilience, COVID-19, pandemic.

1. INTRODUCTION

Resilience in health IT has been defined as “institutions’ and health actors’ capacities to prepare for, recover from and absorb shocks, while maintaining core functions and serving the ongoing and acute care needs of their communities” (Haldane et al., 2021). The resilience of health systems in low- and middle-income countries (LMICs) has become an increasingly important research topic since the 2014 Ebola Virus Disease (EVD) outbreaks in West Africa (Haldane et al., 2017a) and is now magnified with the current COVID-19 pandemic.

A basic vulnerability-resilience duality characterizes the process of creating and deploying resilience, comprising aspects of both a 'bounce back' to re-establish stability and a 'bounce forward' to adapt to changing situations. This duality is exemplified in the Paris Climate Agreement, where the term "climate-resilient development" refers to both mitigation of climate change hazards and

adaptation by "fully realizing technology development and transfer to improve climate change resilience and reduce greenhouse gas emissions" (The Paris Agreement | UNFCCC, 2015). The COVID-19 epidemic, which is still sweeping the globe and disproportionately affecting communities, has comparable issues in terms of resilience, in that it necessitates quick action to mitigate the vulnerabilities produced by this shock. This goes hand in hand with the need to provide creative and agile solutions to respond to the changing environment.

In response to the COVID-19 pandemic, a 2020 WHO policy brief highlighted the need for effective 'information systems and flows' and strong epidemiological surveillance as key resilience-building strategies (Thomas et al., 2020). The pandemic has been characterized by high levels of uncertainty with rapid changes in policies and urgent demand for data and digital technology responses. In early 2020, Sri Lanka developed an effective digital platform for responding to the emerging pandemic using the open source DHIS2 platform (*District Health Information Software 2*, n.d.). The system provided an effective and agile response, with the ability to support case surveillance and contact tracing, and integrating disparate information systems to ensure critical lab test results could be used in the COVID-19 response (Kobayashi et al., 2021). Using the same DHIS2 platform and having developed strong capacity in its application, Rwanda quickly adopted the Sri Lanka COVID-19 apps, which were distributed in the global DHIS2 network, and managed to establish a resilient digital pandemic response. In this paper we present and discuss the successful digital responses using the open-source platform approach by these two LMICs, and compare them with the case of South Korea, which was also able to provide a resilient digital pandemic response through a plethora of different solutions fostered through a private-public partnership and better economic strength to power digital innovation. In the discussion, the three cases will be used to identify key determinants for digital resilience and to indicate the advantages of South-South-North network and platform approaches in building digital resilience, in particular in the global south. We hypothesize that in order to achieve an efficient digital response in times of a pandemic agility and plurality of digital solutions are required in contexts of LMIC or developed countries. In addition, such efficient responses may be backed by low-cost, opensource solutions in a LMIC setting with community driven implementations while high-tech technology with better resources can be used in the context of developed countries. The paper primarily focus around testing the above hypothesis and to understanding the socio-technical determinants of building resilient digital technologies to better manage the pandemics.

2. REVIEW OF LITERATURE

2.1. Resilience

Resilience is a term that has been studied across numerous fields such as ecology, sociology, engineering, public health, psychology, etc. The phrase 'resilience' comes from the Latin root "resilire," which refers to the ability to 'bounce back' from adversity as well as 'bounce forward' to altered systems that can cope with changing circumstances (Longstaff et al., 2013). The term "resilience" was used in ecology to characterize complex natural systems that can absorb perturbations and yet maintain equilibrium, as well as the speed at which equilibrium is reestablished (Rose, 2017).

Folke et al. (2010) propose a 'resilience thinking' process framework for complex social–ecological systems (SES) that integrates resilience, adaptation, and transformability. The ability of the SES to evolve and adapt while staying within crucial thresholds is referred to as resilience. The capacity to alter reactions to changing environmental factors and internal processes is referred to as adaptability. Finally, transformability refers to the ability to cross boundaries and embark on new development paths. Change at lesser scales allows for greater resilience at significantly larger scales, while crises provide windows of opportunity for uniqueness and invention.

Since the 2014 Ebola outbreaks in West Africa, discussions on resilience have dominated health systems research, and the current COVID-19 pandemic has amplified this trend (Haldane et al.,

2017b). As essential resilience-building initiatives, a WHO strategy brief from 2020 emphasized the importance of efficient "information systems and flows" as well as strong epidemiological surveillance (Thomas et al., 2020). The Lancet defines resilient health systems as having the ability to plan for and respond to crises, sustain normal fundamental operations when a crisis occurs, and reconfigure itself based on lessons learned (Kruk et al., 2015).

As an 'active process inside a dynamic health system that is continually navigating problems by getting better,' resilience is an emergent property of Complex Adaptive Systems (CAS), requiring adaptation, learning, and transformation (Barasa et al., 2017). Blanchet et al. (2017) describe resilience as a health system's ability to absorb, adapt, and transform when subjected to stress while maintaining control over its structure and functions, based on ecology and complexity research.

Many scholars define resilience in terms of traits or properties such as robustness, redundancy, resourcefulness, and speed (Bruneau et al., 2003). An attribute-focused approach, it is said, is too broad, undermining the concept's analytical precision, and labeling anything as "resilience" is redundant. Adaptive capacity, as proposed by Klein et al. (2003), is an umbrella concept for resilience that includes difficulties outlined by Bruneau et al (2003). Decreased vulnerability, flexibility, adaptability, agility, and self-organization were all mentioned (Erol et al., 2010; Heeks & Ospina, 2019). However, the process of establishment of resilience of digital systems from a socio-technical perspective is still an under-researched area specially in the domain of the health sector. We try to focus on exploring this dimension with three case studies from the Global North and South.

3. METHODS

For this article, we used a case study methodology since it allowed us to delve at the context and dynamics of the phenomena – agile development of resilient digital technologies in a pandemic situation – in three different countries. According to Darke et al (1998), such an approach is advantageous in emerging and less researched research areas, such as the phenomena studied in this paper. According to Yin's (2014) definition of a case study, our method was an empirical investigation of a current occurrence in a real-life setting.

To test the hypothesis we needed to select countries representing LMIC and developed settings. South Korea, Sri Lanka and Rwanda were selected based on convenience and access to conduct qualitative research during times of a pandemic by the authors. The authors in general have had long-term academic and information system engagements in the 3 countries involved with the case studies. Two of the authors were actively engaged with the implementation process of the COVID-19 related digital health response in Sri Lanka and Rwanda. According to Yin, the data collection methods in this case were diverse, covering socio-technical methodologies. Some of the authors had personal anecdotes with system development efforts, which they shared in the form of narratives. Memos were also compiled from observations made during stakeholder meetings throughout the implementation of the digital solutions. Interviews were conducted with key stakeholders at national and district level engaged with the implementations. Secondary data sources included publications released by public health organizations, materials presented at stakeholder meetings, and notes taken during informal discussions with stakeholders. The data collection methods devised in the three countries are summarized in the Table 1 below.

Table 1: Data Collection Methods used in the 3 settings

South Korea	Sri Lanka	Rwanda
Interviews <ul style="list-style-type: none"> • Government Officer, Ministry of Science and ICT • Administrator, National Information Society Agency 	Interviews <ul style="list-style-type: none"> • National level health and ICT sector administrators • National level system implementers • District level health administrators 	Interviews <ul style="list-style-type: none"> • Key implementers and administrators at national, district levels and at Rwanda Biomedical Centre • System end users at vaccination centres and

<ul style="list-style-type: none"> • ICT Developer • Public Health expert in academia 	<ul style="list-style-type: none"> • District level system implementers • Field level system users 	<ul style="list-style-type: none"> • clinics, immigration at airport
Document Analysis <ul style="list-style-type: none"> • Government policy reports • Press release • Government's website • KCDC's statistics 	Meeting Notes <ul style="list-style-type: none"> • Notes from high level policy and system design meetings 	Meeting Notes <ul style="list-style-type: none"> • From high-level meetings with national task force and health administrators • System design meetings
	Observations <ul style="list-style-type: none"> • Stakeholder engagement at planning meetings • End user training programs • System use at field level 	Observations <ul style="list-style-type: none"> • Stakeholder meetings related to policy and system design • Training programs • End user engagement at field level
	Document Analysis <ul style="list-style-type: none"> • Government policy documents • Government website with official statistics 	Document and data analysis <ul style="list-style-type: none"> • Following the daily updates of cases and vaccination

Throughout the data analysis process, we were continually communicating our experiences and perspectives on the information we had acquired. The case story was then jointly developed, and thematic analysis techniques were employed to identify patterns appearing in the presentation of this study, as indicated by Braun et al (2014).

4. CASE STUDIES

We present the three cases and thereafter we compare and discuss their implications.

4.1. South Korea

4.1.1. Background

South Korea's pandemic strategy, particularly during the early stages, has been lauded by international organizations and the media (World Health Organization, 2020). The first patient confirmed as a case of COVID-19 was announced on January 20, 2020. Korea was successfully able to control and mitigate the spread of the epidemic without the need for a lockdown or restrictions on movement (D. Lee et al., 2020). The case of Korea case provides several important policy implications and empirical evidences on effective data governance and digital resilience. First of all, the government responded to the COVID-19 pandemic in an agile and collaborative manner (Moon 2020). During its response, various digital technologies were applied (Government of the Republic of Korea, 2020). Conducting an interpretive case study of Korea, Park et al. (2021) identify key features of digital resilience including agility, plurality - enabled by active roles of diverse stakeholders including citizens, research communities, and private sector.

4.1.2. Massive applications of digital technologies

The utilization of various digital innovations including information systems, mobile applications and medical devices was crucial in testing, tracing, and treatment. This study particularly focuses on the use of ICTs in sharing information and improving government's response as well as in treatment of COVID-19. First, in order to enhance government to government (G2G) and government to citizen (G2C) communications, Ministry of Land and Transportation (MOLIT) developed the Smart Management System (SMS) in collaboration with the Korea Disease Control and Prevention Agency (KDCA) and the Ministry of Science & ICT (MSIT) – (Ministry of Science & ICT - Republic of Korea - Republic of Korea, 2020). Since February 2020, sending emergency alerts and messages via mobile phone text messages has been a promising communication tool to

rapidly disseminate information and promote preventive behavior among the public during the pandemic outbreak in South Korea. The SMS collects big data, such as mobile phone location, hot spot usage, CCTV recordings, and credit card usage within 10 minutes (Ministry of Health & Welfare : News & Welfare Services, 2020). Second, artificial Intelligence played an important role in supporting the diagnosis and treatment. AI based medical imaging including x-ray and CT scan analysis devices were developed to detect major lung abnormalities, and assist doctors in making quick diagnosis during the pandemic (Ministry of Science & ICT - Republic of Korea, 2020).

4.1.3. Agility

Learning from the MERS outbreak, the government had significantly ramped up its testing capacity drawing upon all available resources and supported by advanced ICTs to geo-locate positive cases (Moon, 2020; Park et al., 2020). The government enacted a policy on emergency use authorization which enabled the use of pre-approved diagnostic kits in conditions of emergency. The agility was built by the use of multiple apps for different purposes, each built through multiple actors and partnerships. Different forms of learnings contributed to providing the basis for agility in both target and object system responses, which were socio-technical in nature (Amarakoon et al., 2020).

Regarding the institutional change in governance, it is also notable that each local government established a Local Disaster and Safety Management Headquarters to secure the capacity of healthcare services and beds (Ministry of Foreign Affairs- Republic of Korea, 2020). The government established drive-thru and walk-thru screening stations by late February which shortened testing time and scaled testing capacity nationally, without putting health workers at risk (S. M. Lee & Lee, 2020; Ministry of Health & Welfare, 2020; Moon, 2020). Tests lasted 10 mins on average, per person, whereas previous tests and registration lasted 30 mins (Ministry of Health and Welfare, 2020). Korea was capable of conducting over 23,000 diagnostic tests free of charge per day.

4.1.4. Citizens' participation

Although using ICTs for sharing information is not new in the crisis, citizen generated applications of the Korea case is quite unique. A couple of notable geographic information system (GIS)-based applications and websites developed by citizens aimed to support people access and share information on COVID-19 and masks. Among them, 'Corona Map' attracted many users as supplementary sources for information. After the first outbreak in Korea in 2020, the KDCA published the trajectory history of patients on its website. After 10 days of the first case, a college student developed 'Corona Map', a web-based map services that visualizes COVID-19 patients' travel history. The service hit 2.4 million views on its first day and attracted a large number of users. Later, the information on the map was also found on the website provided by KDCA. In addition, the developer and other civil society leaders were invited to engage with shaping process of government policy. In order to tackle concerns over privacy and human rights, the government worked together with civil society and tried to set up policy balancing public health needs and human right issues. Although the service gradually lost its attention, it served as one of the agile information providing channels during the pandemic. Understanding citizens' participation and how this transforms knowledge, and social norms is crucial for analyzing the effective response to the pandemic. Citizen participation can provide alternative way of information sharing and suggest implications for the data governance policy in public health crisis.

4.1.5. Public-Private Partnerships (PPP)

PPP were effectively leveraged to support different interventions in an agile manner. A key intervention was the Epidemic Investigation Support System (EISS), which enabled information sharing between government authorities and private sector including credit card companies and mobile network operators. Park et al. (Park et al., 2020) state that about 2,000 daily cases were tracked by mobile tracking applications, which reduced the time of epidemiological investigation to 10 mins, using information based on latitude and longitude, as well as of visit duration (Park et al.,

2020; You, 2020). In addition, the government collaborated with private sector in the making of COVID-19 treatments and vaccines. In order to widely implement the diagnostic method, the KDCA collaborated with the biotech industry. Ministry of Food and Drug Safety (MFDS) approved the fast review for six diagnostic companies including Seegene, Kogene Biotech, SolGent, SD Biosensor, Bioseum and Biocore) and granted emergency use authorization for COVID-19 detection kits (MFDS, 2020). Later, the number of exports of these test kit as well as export destinations including Vietnam, the US, Italy, and Spain increased rapidly. The total value of the Korean-developed test kits exported has grown to exceed 250 million USD as of January 2022 (Statista, 2022).

In April 2021, the KDCA announced the launch of COOV (Corona Overcome), an electronic vaccination certificate for COVID-19 vaccines. With the PPP between KDCA and Blockchain Labs Inc. a decentralized identifier (DID), a blockchain-based identification technology was applied to prevent forgery and falsification of the COVID-19 electronic vaccination certificate and to confirm its authenticity (COOV, 2021)¹. Citizens were able to reserve vaccinations through social media such as Naver and Kakao applications as well. Another key aspect of the context relevant for the COVID-19 response was the government's investment in research and development in science, technology and innovation (Park, 2022). The government, collaborating with private sectors, was able to effectively respond to the pandemic by investing in technology and facilitating diverse stakeholders' engagement.

4.2. Sri Lanka

4.2.1. Background

The COVID-19 pandemic that emerged in China in December 2019 rapidly spread across several countries in the Southeast Asia in first two months of the year 2020. Sri Lanka, being a country that heavily depends on tourism was at risk of COVID-19 in early 2020 due high number of incoming tourists especially from China. Controlling the COVID-19 required rapid detection and action by multiple stakeholders led by the health sector. The country lacked a digital information system for such surveillance activities which was typically present in most of the developed countries. Establishing such a system in the light of a pandemic in the context of a low and middle-income country was challenging. However, the Ministry of Health together with the multisector stakeholders were able to establish a digital surveillance system for COVID-19 in a short span of time backed by open-source solutions, existing country capacity and governance mechanisms.

4.2.2. Agility in Design & Implementation

In January 2020 the Ministry of Health had a crucial meeting to decide on the technical aspects of designing a digital surveillance system. It was identified that the development of the system had to be rapid and subjected to frequent changes following the implementation due to poor understanding of the requirements of a pandemic surveillance system at that time. The existing capacity of the country as well as training requirements were also considered. Having analyzed these requirements the ministry decided to use the free and open source health management information platform DHIS2 to design the backbone of the surveillance system. The country already had capacity and experience in using this platform for aggregate and case-based data collection in multiple use cases in the domain of health. In addition, medical officers of health informatics were the key human resources backing the implementation of this platform at national and district level. The first module of the platform was aimed at fulfilling requirements at ports of entry to track tourists for COVID-19 once they arrive in the country. This module was designed and implemented by end of January 2020, one day before the country reported its first COVID-19 confirmed case. The core team driving the design and implementation consisted of HISP Sri Lanka, the local node of the global HISP (Health Information Systems Program) network driving the implementation of DHIS2, health informaticians from the Ministry of health as well as the ICT agency of Sri Lanka. The team was

¹ COOV System, Apr. 2022, [online] Available: <https://en.coov.kr>.

quickly able to customize the DHIS2 platform for the changing epidemiological requirements of the country. Within a period of three months, the team was able to incorporate data modules into the system to cover the requirements around quarantine, case registration and tracking, contact tracing, community surveillance, laboratory data collection and ICU bed monitoring. In the meantime, when inbuilt features of DHIS2 was not sufficient to serve the requirements, the national core team worked with the ICT agency to organize a hackathon to find volunteer developers to design web apps that ran on top of the DHIS2 platform. Contact mapping visualization, ICU bed monitoring and contact tracing using mobile tower location are examples of the applications developed from the hackathon. The drive for customization and implementation continued in the third quarter of 2020 even though the disease burden was much less. The continuing efforts helped the country to develop a steady response to strengthen laboratory monitoring and integration of community testing platforms in the second wave of COVID-19 in fourth quarter of 2020. The team was able to integrate a laboratory information system to the central DHIS2 platform for COVID-19 to establish an integrated ecosystem of COVID-19 digital systems. The platform expanded further in 2021 with the addition of the immunization module with preregistration of the entire adult population of Sri Lanka (close to 19 million). The module, which was rapidly developed, was ready to be used on the first day the COVID vaccination campaign was launched in Sri Lanka. The vaccination module was expanded further in mid-2021 with the inclusion of a component to produce cryptographically verifiable digital vaccination certificates. The team with the support of ICT Agency, implemented the global digital public goods platform, DIVOC, for generating certificates and integrated it with the vaccination module of the DHIS2. The integrated solution provided a robust digital system to capture and visualization COVID vaccination information to track the rapid vaccination program as well to produce digital vaccination certificates for citizens for travel purposes.

4.2.3. Local Capacity & Multisector Engagement

The COVID-19 surveillance system was an advanced implementation of DHIS2 which had customised DHIS2 components, custom-made web applications as well as integrations with government-owned systems and third-party solutions making it a robust information ecosystem with multisector collaboration. The salient features which enabled this ecosystem was the agile and dedicated collaboration between the ministry of health, the government stakeholders, private sector as well as international networks backed by the governance and leadership of the COVID-19 steering committee headed by the president. The long-term capacity building in health informatics by the country was a key driver in designing and implementing the system within the resources of the ministry. The major impact brought about by the system was the availability of up-to-date dashboards customized to the role of the user, which provided decision-makers the information to take proper actions.

The solution developed in Sri Lanka was not nurtured solely with in-country resources. There was constant communication with the open source DHIS2 community and the experts at the University of Oslo, Norway that facilitated rapid development and implementation. The experience in Sri Lanka and the metadata that was developed was shared with the DHIS2 community and the University of Oslo which was further developed and released as a generic metadata package. This package has facilitated more than 50 countries in adopting DHIS2-based solutions for COVID-19 surveillance. The feedback received from the DHIS2 community further contributed to enhancing the products that were developed in Sri Lanka such as the contact tracing web application.

Information Systems implementations in Sri Lanka were traditionally involved with extensive training programs that were conducted at the district level. However, COVID-19 related restrictions brought about major challenges in conducting physical training programs. The country quickly adopted video conferencing platforms coupled with simple user guides and instant messaging support groups as solutions for facilitating training and the provision of support. Quite surprisingly, the health care workers rapidly responded to the change brought about by new technologies and adopted the platform.

ICT infrastructure that was required for data collection at different levels of institutes including hospitals, laboratories, community centers, quarantine centers as well as ports of entry was a constant challenge for scaling up the implementation. In addition, the constant requirement for integration with the existing and emerging information systems was a challenge that the core team successfully managed. Prioritization of requirements and managing the existing administrative and hierarchical establishments has been one of the toughest challenges in implementation.

4.3. Rwanda

4.3.1. Adapting Global Solutions to Local Context

Sharing solutions and experience from the Sri Lanka case through the DHIS2 global network, Rwanda also embarked on a process to develop a digital health response to COVID-19 using the DHIS2 platform. From March 2020, the Rwanda DHIS2 team implemented a case surveillance and contact tracing system, using software developed through the Sri Lanka initiative and enhanced through global collaboration, and included in the new WHO digital health packages (Pope et al., 2021). These open-source packages consist of health program specific standardized metadata sets that can be downloaded and installed in DHIS2. The Rwandan Ministry of Health reported that they saved considerable time by downloading the WHO metadata and then adding additional data variables they already used in their paper based reporting, and which were not part of the standard package:

“We saved time by not having to argue too much with multiple stakeholders on what data to include or not, since the standards were recommended by WHO and it was easy to include additional needed data variables.”

Rwanda Ministry of Health (MoH) Team Member

The lab system work-process, from taking the sample, transporting to the lab, and the dissemination of results, however, turned out to be the biggest bottleneck. Turnaround times of up to one week made real time surveillance impossible. The MoH team then embarked on a full revamp of the lab system at the Rwanda Biomedical Centre, reducing and optimizing the work-processes, deploying Android tablet computers for end users, installing workstations in the labs, and establishing a public portal for booking a COVID-19 test, online payment, and checking of results. The entire system was based on the Open Source DHIS2 platform.

When vaccination became possible in March 2021, the MoH team started to develop a vaccination support module in the DHIS2 linked to the lab module with the same unique identifier. There were initially several competing systems suggested by development partners and one of these was first selected as the COVID-19 vaccination system. With developers based in the US and with little local knowledge, this “development from a distance” approach, however, failed to respond to the needs of the MoH and the evolving requirements of the COVID-19 vaccination campaign, such as the need for QR coded certificates and interoperability with the lab system. Given this development and the positive results from the implementation of the DHIS2 lab system, the MoH selected the DHIS2 platform for COVID-19 vaccination support and later decided that all Covid related systems should be based on the DHIS2 platform. The need for local ownership, control and experience of the technology were seen as key reasons leading to this decision.

4.3.2. Expansion of Solutions

An entire ecosystem of COVID related apps, modules and services has now been developed and are currently in operation for such tasks as: tracking of cross-border trucks and drivers, QR coded certificates, self-registration for travelers to Rwanda for their health declaration, uploading of documents, payment for rapid test at arrival, and for SMS text messaging of results. The vaccination campaign targeted the adult population of approximately 7.5 million people and had reached 7 million doses by mid-November, 2021. Several vaccines were used, including: Pfizer, Moderna, Johnson & Johnson, and Sputnik, with the majority requiring two doses.

During one week in November, 1 million doses were given, providing pressure on server and team, as the approach of using real-time online registration of vaccination, meant that if the server was down, users had to change their work process and keep notes on paper, which is complicated because each dose is to be linked to a unique identifier. Response time was critical, and the global DHIS2 open-source network was engaged in supporting the Rwanda team in addressing server bottlenecks, such as to terminate processes lasting more than one minute, and removing the autocomplete function on search fields which can create high server loads.

The Rwanda DHIS2 team has provided an effective and agile information and digital response to the pandemic and thereby contributed greatly to the resilience of the Rwanda health system and society during the COVID-19 pandemic (see rbc.gov.rw for daily updated data on cases and vaccination). The open-source capacity and quality of the DHIS2 platform have been a prerequisite for building capacity in developing and mastering systems in the Rwanda team as well as for establishing a reciprocal collaborative global network for sharing digital solutions, best practices, support and learning. The platform aspects of the DHIS2 have also been important in building a plurality of apps needed for responding to the pandemic on top of the DHIS2 and interacting through the open API.

5. Discussion

The case studies reveal that the selected countries used slightly different methods in deploying digital technologies based on availability of resources and country strategies. The success of digital tools in controlling the pandemic in the 3 settings have been documented in several publications. Rwanda's success during the pandemic, especially in COVID-19 vaccination has been highlighted as a lesson for the entire Africa and use of digital tools has been attributed as a key determinant of the success (*Vaccinating Africa: What Governments Can Learn From Rwanda's Effective Rollout* | Institute for Global Change, n.d.). Sri Lanka's COVID-19 control and vaccination has been highlighted as extremely efficient in the South Asian region and this was driven by several digital tools acting in synergy (*WHO Dialogues: Sri Lanka Shares Digital Innovations Made during Pandemic - Sri Lanka* | ReliefWeb, n.d.). World bank spotlights effective use of digital tools in Korea as an example other countries can learn from (*Learning from Korea's Digital Response to COVID-19: Details on Public Health Measures through Open Data and the Contact Tracing System (English)* | World Bank Group, n.d.).

The case studies from the 3 countries depicts that an efficient digital response at a pandemic situation requires plurality of factors whether it be a LMIC like Sri Lanka or Rwanda, or a developed country like South Korea. The analysis of the case studies enabled us to identify 3 broader themes based on which we could prove the hypothesis and identify the enabling factors for digital resilience. We discuss the case studies along the following perspectives; agility, flexible use of digital technologies and networks; and optimum use of local capacity.

5.1. Agility of Response

COVID-19 surfaced in the world in a completely unexpected manner in the late 2019. Countries had to prepare for the adversities imposed by the pandemic, the livelihood and the economy of the people. In the preparation for the pandemic information plays a pivotal role and the countries had to decide on best use of information in an agile manner amidst the uncertainties caused by the pandemic. The case study from Korea depicts how the country built upon the experiences and preparations from the MERS epidemic and deployed its resources in ramping up testing, developing and deploying multiple apps by the government as well as partnerships with the private sector stakeholders. This highlights the agility of response in the early phase of pandemic which could be attributed to the application of learnings from the previous pandemics and adoption and implementation of the policies in a high resource, developed country context.

However, the case studies from Sri Lanka and Rwanda reveal that these countries did not have prior preparation, governance or policies to deploy digital technologies to monitor and manage the limited

resources in times of a pandemic. However, while it is generally expected that such countries in the Global South with low resources and poor governance would collapse in the context of a pandemic, we observe the agility in decision-making, governance of information management as well as engagement with the stakeholders observed in the early phase of the pandemic. Sri Lanka set up a steering committee to engage with different ministries and the private sector to deploy the available resources to design a variety of apps on an open source platform and deployed across the countries. Rwanda materialized on learnings from deployments in other countries such as Sri Lanka and adopting the solutions which better suited the country context within short span of time. The swift response observed in these two case studies highlights how countries with limited resources could build resilient informatics solutions to manage the pandemic to a satisfactory level as well as contribute these learnings to sustain routine information systems.

5.2. Flexible use of Digital Technologies and Networking

South Korea spearheaded development of digital technologies to manage COVID 19 related information based on state of the art technologies adhering to robust privacy standards. These enabled the country to design and implement the systems in the early pandemic which was also supported by extensive public private partnerships and citizen driven approaches. However, this is contrasting with the LMIC context of Sri Lanka and Rwanda which did not possess the technologies or the resources to build solutions that can be designed from the scratch. Instead, they built on their own solution on the widely established open-source platform DHIS2 which was robust and flexible enough to cater the changing requirements around COVID-19. The platform supported customization using the front-end tools and development of web applications and integrations to serve additional requirements. The knowledge sharing and integral connectivity of these countries with the global open-source community made it possible to leverage lack of in country expertise by connecting with a pool of experts from around the globe. Thus, use of flexible open source digital platforms and networking with the global communities supported these countries to rapidly develop and implement digital solutions for COVID-19 at the same pace of that of developed countries such as South Korea.

The COVID-19 DHIS2 contact tracing tool of Sri Lanka, which is utilized by numerous countries, is a prime example of a product of hackathon, which is a classic example of agile software development process (Alkema et al., 2017). Kruk et al. (2015) define health system resilience as the ability to both effectively respond to crises and retain fundamental functioning when a crisis occurs, based on lessons learned from Ebola. When the pandemic struck, we faced similar issues in stabilizing and maintaining normal systems ('bouncing back'), as well as developing new digital capabilities to respond to the pandemic ('bouncing forward'). While South Korea displayed its bouncing back and bouncing forward characteristics of use of digital technologies from the lessons learned from previous MERS epidemic, the use of technologies in Sri Lanka and Rwanda reveals how they used frugal digital technologies to efficiently manage the pandemic while they also helped continue the routine information systems at level of pre-pandemic status.

5.3. Optimum use of Local Capacity

Folke et al.(2010) define resilience as a capability that evolves through time as a result of establishing readiness, using it, and evolving it to produce transformability potential. Resilience and adaptability, which they consider to be part of resilience, as well as transformability, reflect many sorts of capacities that emerge over time, frequently in response to external events such as the COVID-19 pandemic.

The case studies from both Global North and South reveals that the optimum use of local capacity was a key determinant of successful implementation of digital technologies for COVID-19. South Korea utilized its existing knowledge and resources in technology for development of the digital solutions. In addition, the citizens and the academia were actively involved in designing as well as contributing in testing and deployment of the solutions. The government was keen to provide

sufficient resources for the private sector to develop technologies and conduct research. Research and development was a key focus on the governments' involvement in providing support for digital interventions for COVID-19.

In the context of Sri Lanka, its leveraged on long-term capacity building in health informatics in the government sector for leading the development of solutions with the contribution of other stakeholders in the government as well as the private sector. The health informatics is produced from the long-term capacity building efforts were also the key resources driving the implementation is at the district level. In the case of Rwanda, the local HISP team which was instrumental in implementing digital solutions in the health sector led to the interventions which was closely connected to the global open-source community. Therefore, the LMICs mostly utilized their human resources and long-term capacity building in open-source solutions and support networks in achieving resilience in building and implementing digital solutions.

6. Conclusion

The three cases show that resilient digital pandemic responses will rely on a plurality of solutions, and on agility, flexibility and capacity in producing these solutions. While South Korea was able to provide an effective digital pandemic response by mobilizing its industrial, technological and economic base through a public-private partnership, Rwanda and Sri Lanka were able to provide a similarly resilient digital pandemic response through an open-source platform approach combined with in-country capacity and global networking to enable a plurality of apps and solutions.

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