Global review of the engineering response to COVID-19: lessons learned for preparedness and resilience

EngineeringX

Royal Academy of Engineering

Engineering X

An international collaboration founded by the Royal Academy of Engineering and Lloyd's Register Foundation

We work in partnership to implement our vision of engineers playing their key role in addressing global challenges

We have a global network of expert engineers, academics, policymakers, NGOs, business leaders & more

We collect evidence, create diverse and global communities around the challenge, and amplify unheard voices

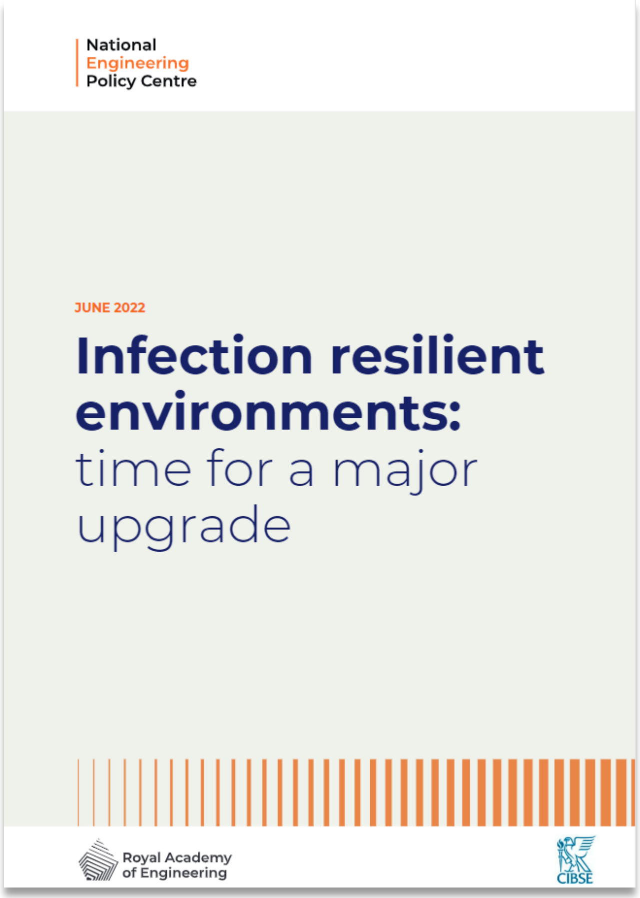
We have 5 missions currently running with ambitions to grow

Context and overview

Infection resilient environments

- March 2020 - Academy and partners in National Engineering Policy Centre commissioned to identify interventions to reduce infection transmission in UK built environment and transport.

- Two-phase programme in partnership with Chartered Institution of Building Services Engineers
  - Initial report - 'Infection Resilient Environments: Buildings that keep us healthy and safe'
  - June 2022 – 'Infection resilient environments, time for a major upgrade'



"The COVID-19 pandemic has made clear how important infrastructure and the built environment are for our health… We spend most of our time in indoor environments and making these healthier and more sustainable spaces will have wide benefits to our public health, wellbeing, and the economy. I hope this report encourages the coordinated system-wide approach, collaboration, and innovation required between government, academia, and industry to deliver the transformational change recommended."

Government Chief Scientific Adviser Sir Patrick Vallance FRS FMedS

Why a global review?

- Engineering X Pandemic Preparedness programme, launched in May 2020 to support engineering to play a key role in global efforts to prevent, respond to, prepare and build resilience to pandemics
  - Global pulse survey of engineer's experiences of the pandemic
  - Thematic calls with CAETS Academies
  - International grants supporting pandemic-related research and innovation

- Building on these learnings, commissioned the global review in December 2021, produced in partnership with Dalberg advisors

The report showcases the breadth of engineering contributions across the world.

This report highlights examples of valuable engineering contributions in responding to some of the most critical challenges during the pandemic. While not aiming to be comprehensive, this report seeks to demonstrate the breadth of contributions in both direct pandemic response and ensuring broader societal resilience. In addition, it aims to draw key lessons and insights to address future waves of COVID-19 or the next pandemic.

Some of the examples of valuable engineering contributions in this report:

- Improving ventilation systems in **Canada**
- Accelerating vaccine rollout using machine learning in the **US**
- Supporting the production of CPAP breathing devices in **Latin America**
- Printing nasal swabs using distributed networks of 3D printers across the **US** for COVID-19 tests
- Using wastewater analysis to monitor community spread of COVID-19 in **Ecuador** and **Brazil**
- Designing IoT devices to track vitals and tailor its use for diverse communities in **Peru**
- Developing rapid, portable lab-free, and cost-effective diagnostics in the **UK**
- Developing an AI-powered, digital recruitment platform in **Tunisia**
- Building new vaccine manufacturing facilities in **Senegal** (pg 67)
- Using drones to deliver tests, treatments and vaccines in **DRC**, **Mozambique**, and **Malawi**
- Enabling procurement of critical supplies through an AI-powered supplier discovery platform designed in **Germany** (pg 74)
- Using AI to improve COVID-19 testing on **Greek** borders
- Designing new edtech platforms for remote schooling in **Jordan**
- Repairing oxygen concentrators in **Malawi**
- Using geospatial and mobile data to close data gaps in **DRC**
- Developing an all-in-one, low-cost breathing device in **South Africa**
- Upgrading vaccination storage to be energy efficient, earthquake resistant, and hold larger capacities in **Mongolia**
- Pivoting high precision manufacturing factories to build ICU ventilators in **Pakistan**
- Designing a 'lab-in-a-suitcase' for COVID-19 testing in **India**
- Designing UV-C light devices to disinfect public escalators in **South Korea**
- Constructing emergency hospitals at speed in **China**
- Preventing zoonotic disease outbreaks through community reporting software solutions in **Cambodia** and **Thailand**
- Expanding digital food delivery platforms in **Fiji** during lockdowns
- Expanding telehealth in **Australia** for remote consultations

This report anchors on six major challenges faced during COVID-19 where engineers made key contributions:

Driving value from data:
High-quality and timely data was critical to orchestrating the pandemic response.[3] Engineers worked to ensure this was available and consolidated for public and private decision-makers in near real-time, and could be applied through digital, data-based tools – such as dashboards, models, or contact tracing apps.

Racing the virus:
The rapid spread of the virus required designing novel health tools at unprecedented speeds and in conditions of uncertainty. Together with scientists and clinicians, engineers were at the forefront of this innovation, supporting the design and production of both medical tools – such as vaccines, breathing aids and tests – as well as digital healthcare tools to support overburdened health workers.

Designing for equal access:
The pandemic affected people from all walks of life, all over the globe – yet people were not affected equally. Applying human-centred and context-sensitive design, engineers tailored products and services to meet the needs of diverse users and reduce inequality of access – such as portable labs for testing in areas with weak testing infrastructure, protective masks to fit a range of face shapes, or video calling devices for nursing home residents.

Ramping up production:
As global demand surged for essential health products, limited and concentrated production capacity led to shortages and geographic disparity.[4,5] Engineers pivoted existing industrial capacity – such as shifting automobile manufacturing to build ventilators – and built new capacity – such as expanding vaccine manufacturing facilities in Africa. Engineers also optimised production processes for speed and scale, for example, using 3D printing for rapid prototyping, or designing new processes to fill vaccines.

Streamlining delivery:
COVID-19 strained global supply chains and triggered delays and inequitable access to essential items, medical and non-medical alike.[6,7] Engineers mitigated these disruptions by accelerating the shift to networked, digitised supply chains, using drones and cold-chain innovations to get complex health products to remote areas, and leading emergency construction of critical infrastructure, including hospitals and test centres.

Strengthening society's systems:
To help society function in the chaos caused by the pandemic, engineers bolstered underlying systems and infrastructure. They ensured the resilience of essential utilities, strengthened society's buildings and transportation, and enhanced digital connectivity and its applications in remote education and work.

This review covers examples of engineering value in addressing these critical challenges, but also drivers of unrealised potential

PLAN

1

Critical data for prevention and response was **unavailable or of poor quality**

leveraging big data and mobile data; conducting epidemiological and population monitoring, modelling, and contact tracing; and developing dashboards and data analysis

DESIGN AND DEVELOP

2

The rapid spread of the virus left limited time to **design novel health solutions**

developing health innovations including in the design of PPE, diagnostics, vaccines, therapeutics, breathing aids, and digital health

3

Products and services needed to be designed for **different contexts and needs**

designing custom products and services for diverse environments and user bases, such as customised PPE, or wastewater testing for low-resource settings

4

Limited **production and manufacturing** constrained the scale-up of interventions

developing, redirecting, and repurposing the capacity of production and manufacturing, as well as optimising production techniques

MANUFACTURE AND SCALE

5

Supply chain and delivery issues resulted in delays and inequitable access

optimising supply chains; innovations that facilitated the delivery of health products (like drones for last mile delivery or cold-chains); and building emergency construction

DELIVER

6

Society's underlying systems had to be stabilised to support societal resilience

maintaining society's essential services (such as energy or water); adapting the built environment; and expanding connectivity and digital solutions for remote education or working

ENABLE

Global review of engineering contributions to COVID-19 response and resilience

1 Driving value from data

Non-profit 'Ending Pandemics' co-created community surveillance tools to prevent zoonotic disease outbreaks in Thailand and Cambodia

Using 'EpiHacks' — a collaborative process to bring local software engineers and technologists together with public and animal health officials to problem-solve — Ending Pandemics supported communities to design and use digital apps and hotlines to report cases of animal and human disease outbreaks.

Impact at a glance

- Widespread adoption of community-based reporting, leading to the successful reporting and containment of hundreds of human and animal disease outbreaks.
- Rapid adaption of existing surveillance tools for COVID-19 reporting — representing 90% of detected cases in Cambodia.

"During the pandemic, data became a part of our daily life: from the food industry, to civil engineering consortia, to driving medical innovations."

Chair of a major international biomedical engineering association

3 Designing for equal access

Innovations in wastewater testing addressed gaps in testing access and uptake for underserved communities in the Americas

Engineers deployed wastewater testing technology to detect the amount of COVID-19 in sewage systems. Not only did wastewater testing help detect variants and provide an early indicator of a rise in infections, it also included underserved populations in COVID-19 surveillance.

Impact at a glance

- Facilitated the inclusion of underserved populations in COVID-19 community-level data.
- More easily able to track the presence of COVID-19 variants than traditional PCR testing.
- Successfully implemented in 50+ countries worldwide.

> **"Technologies are never neutral — the contexts they are being put in need to be carefully thought about so as not to cause unintentional harm."**
>
> *Executive Director of an international engineering non-profit*

4

Ramping up production

Multi-stakeholder initiatives have started to build vaccine manufacturing capacity on the African continent

COVID-19 underscored Africa's reliance on imported vaccines. Since the pandemic, public and private initiatives have started to build end-to-end vaccine development and manufacturing capability across the continent.

Impact at a glance

- Since the onset of the pandemic, stakeholders in Algeria, Egypt, Morocco, Rwanda, Nigeria, Senegal, and South Africa have committed to plans to expand vaccine manufacturing or have begun production.

"As we saw the urgency of the pandemic and that our traditional [trading] partners were struggling themselves, we knew we had to solve for our own problems ... this was the driver of the push for localisation."

Africa engagement lead for a major upstream vaccine partnership

Snapshots of key initiatives to increase vaccine manufacturing capacity in the African continent during the pandemic

Morocco is scaling up its vaccine production. Morocco's Sothema laboratory is producing the Chinese Sinopharm vaccines, manufacturing 3 million vaccines a month. In January 2022, Morocco started constructing a new manufacturing facility (Sensyo Pharmatech) with Swedish firm Recipharm for COVID-19 and other vaccines.[1,2]

Institut Pasteur de Dakar (IPD), is building a new regional vaccine manufacturing hub. With funding from several European institutions,[3] IPD has started construction of a new vaccine manufacturing facility (MADIBA) which could supply 300 million doses of vaccines annually. This will include COVID-19 vaccines (likely starting with fill and finish) as well as other diseases, including a high-volume site for yellow fever, and a training site for next generation vaccines.[4] Furthermore, the facility — which was built from converted shipping containers — is highly customisable, with modules that can be swapped in and out as the technologies and needs evolve.[5,6] Currently, the institute has MoUs with BioNTech *(see box on right)* and with CEPI for strategic and technical support.[7] Leveraging its expertise as an established WHO-prequalified manufacturer of yellow fever vaccines, this upgrade will position IPD as a regional hub and bolster the health security of the region.

Algeria is producing COVID-19 vaccines at state-owned company Saidal following an agreement with China Sinovac laboratories to produce the CoronaVac vaccine.[8]

The first vaccine production facility in Nigeria is being launched in collaboration with Merck and Innovative Biotech as part of the West African Pandemic Readiness Programme.[9]

Egypt is locally producing COVID-19 vaccines through multiple initiatives. The state-owned firm Vacsera has produced 25 million doses of the Sinovac vaccine. Private firm Minapharm Pharmaceuticals has completed a tech-transfer process to produce the Russian Sputnik V vaccine. There are also efforts to develop Egypt's own COVID-19 vaccine (EgyVax) through a public-private venture which started phase one clinical trials in December 2021.[6,10]

BioNtech has signed agreements to produce in Rwanda and Senegal. The agreements with BioNTech (the company producing mRNA vaccines for Pfizer) will go beyond fill and finish to include full production mRNA vaccine manufacturing facilities under license, with construction aiming to start in mid-2022. Initially, BioNTech staff will run the facility as the company trains local partners, who will then take over the vaccine manufacturing process.[6]

Fill and finish deals in South Africa have created greater supply for the continent. Aspen Pharmacare has helped produce over 120 million Johnson & Johnson vaccines, with aims to increase production to 1.3 billion doses a year.[6] Biovac has also struck a deal with Pfizer, and, following a supply chain integration process in 2021, will start supporting production this year.[6]

Lessons learned and calls to action

There is a need to invest in better planning and prioritisation of initiatives, in skills and capacity building, and in greater mechanisms for collaboration

CALLS TO ACTION

INTERLINKED AND MUTUALLY REINFORCING ACTIONS

IMPROVED PLANNING AND PRIORITISATION
Identify structural gaps in pandemic resilience and redirect funding toward addressing them; leveraging systems thinking to do so.

STRENGTHENED HUMAN CAPACITY
Invest in skills, training, and capacity of engineers and domestic engineering ecosystems.

EXPANDED MECHANISMS FOR WORKING TOGETHER
Invest in skills, training, and capacity of engineers and domestic engineering ecosystems.

TARGET STAKEHOLDERS

- **ENGINEERING COMMUNITY**
- **LOCAL AND NATIONAL GOVERNMENTS**
- **PUBLIC HEALTH DECISION-MAKERS**
- **FUNDERS**
- **ACADEMIA AND RESEARCH GROUPS**

Improved planning and prioritisation

1. Resilience audits which use a systems thinking approach to identify priority areas for strengthening institutions and response mechanisms
   a) **National and sub-national governments** to conduct risk and resilience audits
   b) **Engineering academies and academia** can support governments by translating research around national priorities and critical capabilities into tools for policymakers in emergency planning.
2. Removing bias from and improving core datasets and data systems
   a) **Engineers to work with health, government, and civil society stakeholders** to resolve identified data issues, e.g., better inclusion of marginalised groups and more rigorous data collection processes.
3. Orienting emergency response taskforces to have greater engineering capability
   a) **Engineers and industry representatives** to be included in government-created taskforces to support problem definition as well as problem-solving, and ensure engineering expertise is deployed rapidly and to maximum effect.

Strengthened human capacity

1. Pandemic workforce planning to identify and address skills gaps for future responses
   a) **Governments,** with support of **engineering** and **public health,** to undertake strategic workforce planning involving a review of **skills demand and supply factors,** embedded within wider national resilience plans

2. Short term: bridging capacity gaps via exchange programmes or one-off trainings
   a) **Engineering associations, academic institutions and private industry** to facilitate international training exchanges to close the pandemic preparedness skills gap

3. Long-term: supporting local universities and training institutions to design curricula, teacher training, and academic–industry linkages to fill pandemic-specific skills gaps
   a) **Academic institutions and engineering associations** to collaborate with **health and policy specialists** to develop curricula (e.g., dedicated courses on 'engineering in crises') to equip engineering students for future pandemics. To include technical courses ('hard skills') and critical engineering approaches e.g., human-centred design, systems thinking, circular economy, open science, practising data equity etc.

Expanded mechanisms for working together (1)

1. Designing and funding multi-sectoral innovation teams or programmes that link engineering with other disciplines
   a) Engineering academies and ecosystem partners to develop accelerators and incubators that provide long-term multisectoral inputs to startups innovating on pandemic recovery and prevention.
   b) Engineering academies, academia and ecosystem partners to design capacity-building programmes for public health actors and policymakers to better understand and engage with engineering inputs.
2. Creating or strengthening digital collaboration platforms, leveraging momentum started in the pandemic
   a) **Public health and engineering ecosystem players** to consolidate and publicise existing platforms or forums for pandemic preparedness, resilience, and response, such as those on technology transfer, capacity building efforts, research coordination, and review and evaluation of existing projects.

Expanded mechanisms for working together (2)

3. Supporting ongoing initiatives to increase the adoption and refining of open science and data sharing standards
    a) Engineering academies to raise awareness on how to conduct open science and ensure that the principles of open science are understood and well used by potential collaborators and decision-makers
4. Developing effective communication between technical experts, policymakers, and the general public
    a) **Engineering academies, and academic and research institutions** to run participatory sessions on effective science communication for **engineering, public health, government, and civil society stakeholders.** On topics e.g., consulting and building trust with communities and end-users, or how to interpret the limitations of data in policymaking.

Questions for the CAETS Council

- What does the Council think about the recommendations and calls to action?

- How did the role of engineering, and Academies' relationships with government change during COVID-19? What are Academies doing to maintain these lines of communication? How can we learn from each other?

- How can Academies build on our relationships with key stakeholders in government, the UN etc, to make sure engineering is in the decision-making room during future international crises?

Any questions?

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