Digital Cities, Resilient Cities

Delivering urban resilience through digital solutions

OCTOBER 2023

RESILIENT CITIES NETWORK

ARUP

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Foreword

In Greater Manchester, we are doing digital differently. We are committed to being a digital city-region that puts our residents at the heart of our plans and we are working towards our ambitions to be recognised as a world-leading digital city-region. Our digital priorities are clearly focused on delivering benefits that help our city-region's people lead healthier and happier lives.

We recognise that the digital environment continues to evolve rapidly, bringing both opportunities and potential risks for urban resilience. Digital systems are dependent on infrastructure such as power networks, are themselves interdependent on one another, and are also a key dependency of many other urban systems, whether economic, societal or part of the built environment. Digital can therefore be part of building resilient cities but, conversely, can also be the cause of emergencies or can contribute to amplifying their impacts and consequences.

In Greater Manchester digital systems are often at the heart of disaster management. River telemetry and meteorological modelling enable early warning of emergencies; automated analysis of data feeds can help to provide situational awareness in crises; while digital platforms support communication both between emergency responders and with the public. However, emergencies such as Storm Eva which interrupted power supplies and led to a loss of telemetry, in turn affecting water supplies, or Storm Arwen which brought down power lines and led to people having significant challenges in communicating with emergency services, have underscored how disasters can impact our digital world.

As a Resilience Hub within the UN Office For Disaster Risk Reduction's (UNDRR) Making Cities Resilient 2030 (MCR2030) initiative, we wanted to help to explore the topic of digital resilience when it was chosen as a thematic priority by the MCR2030 Regional Coordinating Committee for Europe and Central Asia. We therefore reached out to Arup, who chairs our Digital Infrastructure Advisory Group, part of the governance arrangements in Greater Manchester, and also to our partner the Resilient Cities Network. We are delighted that this paper summarises the outcome of that collaboration. We hope that other cities find it useful in thinking through city-led activity to build digital resilience and, through this, urban resilience.

Dr Kathryn Oldham OBE
Greater Manchester Chief Resilience Officer

Foreword

As our world evolves, becomes more interconnected and new critical challenges emerge, digital resilience has become a need rather than a 'nice-to-have'. Digital and data has become a vital element of resilient systems, whether it's energy, transport or security (amongst many others), having the power to both support and compromise city resilience. This report showcases the global relevance and applicability of digital resilience in the urban realm, drawing upon several international examples ranging from North and South America, to Europe, Africa, Asia, and Australia. It also reinforces the importance of integrated planning, design, delivery and operations in fostering resilient and sustainable urban systems. We hope this report provides valuable insights and practical recommendations for policymakers, practitioners and the general public to leverage digital technologies and harness the power of data in decision-making, that will create resilient communities and healthier cities for all.

Cities face unprecedented challenges: climate change, rapid urbanization, and social and economic disparities. Digital systems can either bolster the resilience of cities or disrupt their fragile equilibrium. Recognizing the urgency, we provide insights and recommendations to cities worldwide. The report stems from the needs of our member cities and their Chief Resilience Officers, seeking support and knowledge on digital solutions. It offers comprehensive analysis and practical recommendations to enhance cities' resilience. We are committed to the equitable distribution of digital solution benefits. Through the Future Ready Cities program in collaboration with Visa, we support our member cities with tools and skills for the digital era, addressing the digital divide and empowering vulnerable communities. The recommendations in the report emphasize inclusivity and equitable access. Delve into the report, explore findings, and embrace the possibilities at the intersection of digital systems and urban resilience. By working together, we can build technologically advanced, socially inclusive, environmentally sustainable, and economically prosperous cities.

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ARUP

Arup is a purpose driven firm: we work to shape a better world. We do this by creating a sustainable future -for people, places and the planet. Creativity, lateral thinking and embracing the new are central to everything we do. We are collaborative in nature.

RESILIENT CITIES NETWORK

Resilient Cities Network is the world's leading urban resilience network. We bring together global knowledge, practice, partnerships, and funding to empower our member cities to build safe and equitable cities for all.

1. Introduction

Cities are home to over 50% of the world's population, a figure likely to rise to almost 70% by 2050.[1] Supporting this trend requires urban development that is 'smart', efficient, sustainable and resilient. These objectives are intrinsically linked to digital innovation.

Cities and city-regions globally are embedding digital technologies and introducing new digital services to serve government, business and community users. People in cities depend on effective critical infrastructure systems (e.g. energy, water, transport, wastewater, solid waste and communications) and social infrastructure (e.g. health and social care, police and prisons, fire and emergency services) in their daily lives. All of these services are increasingly underpinned by digital technologies. For example, digital systems enable financial transactions, remote communications between people and businesses, and the security and safety of our buildings. They also allow the automation and management of essential services like public transport and energy transmission and provide advanced analytics to anticipate changes in baseline conditions or behaviors that may affect city services.[2]

This shift towards digital solutions has accelerated in recent years as new digital capabilities come on stream and technologies become more widely available and affordable. The push towards digital solutions became particularly evident during and following the Covid-19 pandemic. Today, it is easy to take the seemingly 'invisible' digital services for granted. User experience and ubiquitous connectivity create a seamless digital layer in many cities (especially in the Global North). A city's digital foundation is not really felt until something goes wrong. Reliable, robust and resilient infrastructure has been acknowledged – among other things – as a key driver of local and national economic growth[3] and a low carbon economy; cities need to take a resilience-centered approach to implementing digital solutions across all aspects of their lifecycle (i.e. planning, designing, operating and maintaining).

A resilient city requires a systemic approach to digital development. It is a complex interconnected system with its own unique context and characteristics.

This report explores the complex yet integral role of digital systems in our cities and reflects on the way digital technologies can both support and compromise urban resilience. It provides recommendations for cities to support the integration of digital technologies and solutions in a manner that can enhance resilience.

DIGITAL RESILIENCE IN AN URBAN CONTEXT

This paper considers 'digital resilience' from the following perspectives:

▶ **Resilience *of* digital systems:** The ability of information and communications technology (ICT) systems to withstand and recover from external threats, such as cyber attacks or natural disasters.

▶ **Resilience *through* digital solutions:** The application of digital systems and technologies to holistically build resilience in the local context.[4]

Digital systems have been defined to include the physical assets, devices and networks through which we access the digital realm; the data generated; the services that are created; and enabling factors for people, such as widespread access, digital literacy and data training. All of these components contribute to the 'digital resilience' of a city or city-region.

FIGURE 1 DIGITAL SYSTEMS

Digital layer components

🔴 Enablement *Policies, programmes and trainings that support implementation of digital tools and platforms*

🟠 Digital interventions

🟢 Devices

🔵 Data & software

🔵 Connectivity & network

⚫ Physical assets & infrastructure *Physical fabric of the city that can be enhanced by digital systems*

DIGITAL AS A COMPLEX, INTERDEPENDENT SYSTEM

To achieve a resilient urban environment and to ensure a holistic response to any shock or stress situation, all urban systems, organizations (including city and city-region leadership) and citizens need to interact with each other. In the last two decades there has been an acceleration towards the vision of 'smart and sustainable cities',[5] leading to the increased coupling of digital systems within and across networks and organizations, creating critical and complex interdependencies. For example, built assets (roads, rails, buildings, water, energy, etc.) often rely on operational technologies (sensors, surveillance, controls), communication technologies (WiFi, 4G, GPS) and information technology (processing, anonymization, analytics, programming)[6] to function. Digital technologies are enmeshed in the system-of-systems that makes up our urban areas and is now vital due to the complexity, scale and level of connection we all benefit from and experience in our lives. However, as systems become increasingly sophisticated (and, conversely, easier to use), their complexity increases. A characteristic of digital networks is that they suffer 'brittle' failure, with a failure point that can be conceptualized but is currently hard to predict even when a system is operating near failure point. This has led to these issues being referred to as 'wicked problems', defined as a problem that is difficult or impossible to solve because of incomplete and contradictory knowledge, the number of people and opinions involved, the large economic burden, and the interconnected nature of this problem with other issues.[7] In all cases, when dealing with complex and interdependent systems and 'wicked problems', there is value in taking a resilience-based approach, i.e. in understanding the ability to anticipate, absorb, respond to, recover from and adapt to shocks with minimal disruption to services, accepting that unexpected events – and events with unexpected consequences – are almost inevitable.

THE ROLE OF DIGITAL SYSTEMS IN URBAN RESILIENCE

Urban resilience is the capacity of a city's systems, businesses, institutions, communities, and individuals to survive, adapt, and thrive, no matter what chronic stresses and acute shocks they experience.[8]

There are seven qualities of resilient systems, as set out in the City Resilience Framework[8], which underpin the Resilient Cities Network approach. By keeping these qualities in mind, governments can look at their cities through a resilience lens and are able to design best-suited interventions to enhance resilience across systems. Digital technologies can help to deliver these qualities. For example:

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1. INTRODUCTION | 2. HOW CAN DIGITAL SYSTEMS SUPPORT CITY RESILIENCE? | 3. HOW CAN DIGITAL SYSTEMS COMPROMISE CITY RESILIENCE? | 4. WHAT ROLE CAN CITIES PLAY IN IMPROVING DIGITAL RESILIENCE? | 5. CONCLUSION

Flexibility: Data platforms, digital connectivity and devices can help respond to changing demand on transport networks by diverting travelers away from congestion, using sensor technologies, real time movement visualizations and communication through apps and other services. *e.g. Google Maps provides real-time travel information, gained through user data, to (re)direct travelers along the fastest route to their destination.*

Redundancy: Having multiple forms of connectivity, for example including wired and mobile networks that provide redundancy should one fail. Or the practice of keeping data in two or more places within a database or data storage system This will ensure continuity in service. *e.g. Internet service providers linking up with mobile network providers to provide a seamless internet service.*

Robustness: Sensors on major infrastructure assets, like bridges and buildings, can be used to monitor the performance of the asset and alert operators to imminent problems. *e.g. The Osman Gazi Suspension Bridge in Istanbul is fitted with 390 integrated seismic sensors to continuously monitor stress loads and stability across the structure and raise the alarm in cases of excessive vibration resulting from seismic activity.[9]*

Resourcefulness: Data platforms and end-user services allow people to quickly access information about alternative ways to address their needs. *e.g. Airbnb leveraged its online homestay and experience platform and network to provide over 100,000 people fleeing the Ukraine conflict with temporary accommodation.[10]*

Reflectiveness: Data integration can bring together data from a range of sources to review performance across intersecting systems. Machine learning and Artificial Intelligence can be used to adjust operations in light of past experience. *e.g. The use of digital twins for cities to understand how specific interventions would play out on the ground, and the feasibility of planning and development options.[11]*

Inclusion: Digital services and digital enablement can allow more effective and more inclusive engagement with people and communities, including the most vulnerable groups, to disseminate information or emergency messages, advise on individual response and to crowd-source contributions for a joint vision of city resilience. The design of digital systems should be mindful to include all levels of digital literacy and those who might experience challenges in accessing hardware. *e.g. A pilot project in Freetown, Sierra Leone used verified satellite images of waste accumulation to create opportunities for local women to participate in local waste management employment, in a way that could integrate with family schedules and other commitments.*

Integration: Data platforms allow resources and services to be pooled to build capacity in systems, while digital devices enable greater integration of operations between different systems and operators. *e.g. In China, the manufacturing sector pooled resources through digital platforms to accelerate the resumption of production following disruption to supply chains from Covid-19.*

2. How can digital systems support city resilience?

Digital systems can improve urban resilience by managing component systems more efficiently, creating greater integration between systems, helping to smooth out stresses and raise the alarm in shock scenarios. Digitalization is also key to accelerating the green transition, for example by reducing the need for resource-intensive engineered solutions, better managing energy use and transportation, and influencing more sustainable behaviors. This ultimately supports the wellbeing of residents, the economy and the urban environment.

ENABLING FACTORS

Digital development in cities is changing our cultural interactions between people, government and organizations. As digitization penetrates our social-cultural world, our lives are moving online; arguably accelerated since the Covid-19 pandemic.

This move requires high levels of digital literacy and access to devices to ensure everybody can participate in this hybrid city system. By enabling all citizens to enhance their digital skills, we create more resilient and collaborative cities where everyone can be an active participant.

Development of digital access and the skills to leverage new services can not only benefit communities, but also government processes. More efficient use of technology can release internal resources to focus on innovation and investment into key city areas. For example, Robotic Process Automation (RPA) can handle repeatable and transactional tasks and free up to 40% of internal capacity for local authorities. This can lead to improved staff engagement and retention, as they can instead focus on value-adding activities, such as supporting citizens with complex issues, or those who are in vulnerable positions.[12] It is important that this internal digital transformation is accompanied by skill support for public officers and also community residents so that the local authority and community are embedded in this process of digital transformation.

Better Reykjavik[13]

Better Reykjavik is an online community voting and engagement platform. Launched in 2010, it was part of a strategy to restore public trust in Iceland's political institutions. The first 'community' (message forum for city development ideas) was set up on the website Open Consultations. The city has since deployed more communities, such as a yearly participatory budgeting forum. In 2017, the city crowdsourced/co-created the City's education policy.

Democratizing digital literacy

In Brazil, the city of Salvador's departments of Sustainability and Resilience (SECIS) and Innovation and Technology (SEMIT), in collaboration with Visa, Resilient Cities Network, Via Varejo Marketplace, Fundação Casas Bahia and Hub Salvador, implemented a Free Digital School initiative offered to participants from vulnerable groups. Through this initiative, the program provided tools and trainings to strengthen the necessary soft and hard skills needed to give backing to local talent, entrepreneurs and markets, creating new economic opportunities for themselves and their communities.

Screens over shovels – Using digital technology to modernize public work

Cities generate a large amount of data that can be used to better understand city dynamics to make better informed decisions on planning and policy making. A number of pilot projects have been exploring ways that publicly sourced data can be used to modernize public works. The use of remote data is especially important in areas that may be difficult to access (e.g. conflict zones). Visa and the Resilient Cities Network invite member cities to identify challenges and develop innovative solutions that envision their city as a digital leader, reflecting the hurdles that citizens, in particular those in vulnerable communities, are coping with. For this first edition, three cities were selected to collaborate with a team of experts in order to find the best strategies to tackle their challenges. This initiative also looks to support the growth of local economies, especially their vulnerable groups, to help close the digital divide.

DIGITAL SERVICES

Digitally enabled services, such as transport-as-a-service apps for citizens, predictive street maintenance for local authorities, or remote doctor consultations, have an important role to play in urban resilience. They support proactive management of capacity for service provision and ensure services can continue even when physical assets are unavailable. Internet banking, for example, has allowed us to use banking services even when the physical bank is not open. Contactless payments have been vital during the pandemic, by minimizing contact between people. In addition, this digital layer supports more immediate feedback loops between citizens and cities, capturing how people experience things but also how they use services.

Local governments are using digital services to strengthen democratic governance, improve communication between authorities and residents, and promote citizen participation and accountability to help strategic planning. For example, communities can understand, inform and accept major projects, plans and policies, contribute online to causes they support, and share their input through digital platforms that help to hold public institutions to account.[14]

Digital platforms also provide a way for people to connect in an emergency. Social media can be incredibly helpful in connecting disaster response, sharing critical service information and tracking how a disaster unfolds. Through its informality and crowdsourcing, social media platforms can provide updates faster than formal media channels. As recently as February 2023, Vodafone used Twitter to share information on the cell network outage caused by storms in New Zealand.

FIGURE 2 VODAFONE NEW ZEALAND RESPONSE TO CYCLONE
GABRIEL (FEBRUARY 2023) (SOURCE: TWITTER.COM)

For people in societies without access to conventional documentation, blockchain IDs have been used to unlock better healthcare, education, employment, property rights and the right to vote. The World Food Programme has already established a closed blockchain ID system to support Syrian refugees in Jordan.

Strengthening urban food governance in Cape Town[15]

Although the Western Cape province is a surplus food producer, a vast amount of Capetonians suffer from food insecurity, malnutrition, and hunger. The Covid-19 pandemic severely impacted Cape Town's food system. Overnight, job losses and movement restrictions pushed many additional people into poverty and food insecurity. The lockdown regulations also restricted economic activity, including food markets and informal traders which are critical to the food security of low-income communities. Moreover, school closures meant that children in need did not receive the school meals they depended on. To avoid people queuing up for food in times of physical distancing, an innovative food voucher system was piloted. The digital food vouchers allowed citizens to regain agency and purchase food at their convenience in local markets and informal stores, while also stimulating the local economy. Due to its success, the voucher system is now used by the City of Cape Town to fund community kitchens.

Supporting small businesses in the food production sector through digital tools[16]

The Metropolitan District of Quito (MDQ), through its Participative Urban Agriculture Program (AGRUPAR) has developed a dynamic ecosystem of small-scale agriculture centers in urban peri-urban and rural areas with the objective of strengthening food security and sovereignty and providing jobs and new sources of income for vulnerable groups in the city.

Due to the coronavirus pandemic, small businesses in the food production sector struggled to survive. To support these small businesses, the Economic Promotion Agency of the Municipality of the Metropolitan District of Quito (ConQuito) – with the support of Visa and R-Cities – connected small-scale producers through a digital payment service and the implementation of digital tools for better management of finances and inventories for important ConQuito initiatives, such as the bioferias or bio-markets. Through this work they are helping to close the digital gap in the city, safely reactivate the local economy and increase small businesses' sales opportunities, for growth and prosperity.

Social media for market sales in Singapore

During the Covid-19 pandemic, connectivity through digital platforms contributed to the improvement of urban resilience in Singapore. Infocomm Media Development Authority teamed up with vendors at a fresh produce market to sell fresh produce on Facebook. This collaboration helped the vendors develop new sales models, whilst also allowing for daily life to maintain a degree of normality during the pandemic.[17]

DEVICES

Many devices, including sensors or drones, can be designed or repurposed to contribute to resilience. Drones have been used to: assess the vulnerability of remote infrastructure by creating 3D maps; deliver critical and lifesaving products precisely where and when they are needed; and for surveillance. For example, during the Covid-19 pandemic, robots were used in China to deliver food to patient rooms and medical supplies within hospitals to guarantee contactless delivery and therefore the safety of the medical staff. In addition to robotics, our mobile devices can provide an instant and sustained connection between governments and communities during extreme events.

Drones and citizen scientists helping to reduce flood risk[18]

Low-cost digital tools are helping bridge an important data gap as towns and cities continue to grow in an unplanned, unsurveyed manner. In Dar es Salaam, for example, where informal settlements along the banks of the Msimbazi River are vulnerable to flooding during the rainy season, citizen scientists and drones were mobilized to help improve the accuracy of soil maps to better guide urban decision making.

This program has also created an innovative Resilience Academy, where students learn practical digital skills while working to make their countries safer from climate change. Using drones and household surveys, students mapped the whole island of Zanzibar. By digitizing 500,000 buildings, their work increased the previous building register of only 163,000 dwellings.

DATA AND INSIGHTS

Data is often regarded as 'infrastructure' in its own right, and needs to be treated as such (i.e. maintained, updated and secured).[19] Cities can use data analytics to manage their operations efficiently, creating flexibility and integration between systems. This includes managing real-time demand on transport networks and informing decision makers about requirements for infrastructure upgrades. Energy smart grids and dynamic pricing can monitor energy demand over time and distribute it more effectively, ensuring continuity in energy provision and reducing energy loads and prices. Data can also provide information and insights to help manage risks to key projects and enable costs to be quantified more accurately, which can subsequently attract increased private investment in projects such as major infrastructure schemes.[20]

Big and open data – including the use of remote sensing and satellite data – offer considerable potential for analyzing conditions on a city scale (and beyond), projecting future conditions, identifying georeferenced resilience responses, and predicting human behavior. Opening data to the public further allows novel solutions to emerge from communities or businesses with skills in data synthesis and analysis.

Data is instrumental in planning disaster recovery, for example in the 2023 Turkey-Syria Earthquake, satellite data from NASA supported aid agencies in understanding critical areas to focus the response. During the Covid-19 pandemic, data was also critical to leverage location data for proximity and contact tracing and using AI-based thermal and

HD cameras to raise an alarm when the temperature of a person indicated potential infection.

Most disaster risk management plans are 'static', assuming fixed times and locations of people and activities. In reality, human behavior is nonlinear, chaotic, and spans across temporal and spatial scales. With the use of data, Disaster Risk Reduction planning can become 'dynamic' to reflect reality. This can be achieved through data and analysis, which can improve the accuracy of damage prediction and allow for the service level of emergency response to be increased accordingly, resulting in improvement of existing disaster risk assessment and management strategies.[21] Digital twins for cities[22] can also be used to analyze, stimulate and visualize planning scenarios and test the feasibility of new urban projects.

Resilient Sydney Platform[23]

Australia's experience of intense bushfires, storms, flooding and heat is driving increasingly urgent city action to address the climate emergency.

The Resilient Sydney Platform is an online data portal that allows for the visualization of city-scale environmental footprints for use in the strategic planning of climate actions at the city council level. The Platform has enabled city-wide transparency of risks and opportunities, and growing accountability for tangible action on the ground. Launched in 2019, the Platform hosts geo-tagged data, visualizations and tools to enable city governments to understand the key environmental impacts in their communities.

The Platform has already seen some important uses, with 14 councils now actively pursuing major net zero plans, and 16 councils developing local Resilience Plans.

Disruptive Technologies for Development Challenge[24]

Developments in smart phone technology have enhanced the availability and practical relevance of people movement data. Mobility patterns, captured through GPS on phones, are increasingly used for urban planning and resilience, from modelling commuting flows to evaluating the impact of urban regeneration investments on local foot traffic. The Disruptive Technologies for Development (DT4D) challenge explored how human mobility data can become a mainstream part of the analytical toolkit for urban and Disaster Risk Management specialists. This can be used to understand where people are when a disaster takes place and how people access services after a disaster. For example, the study tracked how different economic groups accessed hospital facilities during Cyclone Nivar, which struck Tamil Nadu and Andhra Pradesh in India in November 2020.

CONNECTIVITY AND NETWORKS

Connectivity and networks play a major role in our day to day lives. They enable us to move through the physical city, supported seamlessly by real-time services. Most digital services that we use rely on network connectivity. This is only going to increase, with technologies such as artificial intelligence (AI) and Internet of Things (IoT) creating new applications that rely on connectivity, such as driverless cars or the increased use of virtual reality. Connectivity can improve urban resilience by connecting components of the digital system – such as the physical assets, infrastructure or devices – to networks, and therefore enabling them to work and support the end-user services we rely on.

Resilience in connectivity implies creating a telecommunications network that builds in significant redundancy and diversity, with a fallback plan to maintain services when crises hit. This would incorporate a blend of 4G/5G, WiFi and wired networks. Some internet providers now offer mobile internet connections when wired solutions fail, allowing the digital backbone to flex and adapt as needed. In addition, developments like SpaceX's satellite-based internet service, Starlink, are providing connectivity without the physical infrastructure on the ground required for traditional internet provision. For example, connectivity has been provided to many in Ukraine since the start of the Russian invasion, and the service also recently launched in Nigeria.[25]
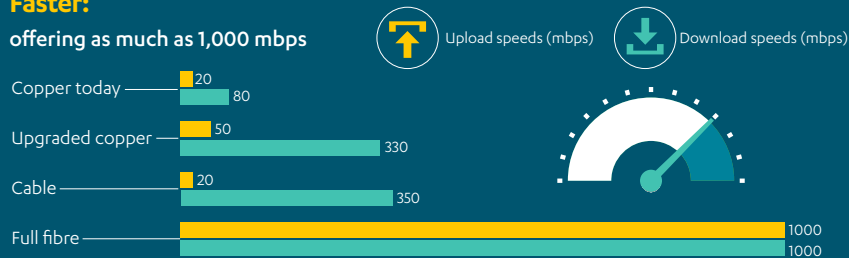
Early warning systems – Saving lives through mobile connections[26]

Today, three out of four people around the world own a mobile phone and 95% of the world's population has access to mobile broadband networks. This opens new opportunities for the use of mobile networks to share public warnings and save lives.

The UN's newly launched Early Warnings for All (EW4A) initiative stipulates that every person in the world should be protected by an early warning system by 2027. The initiative's Action Plan puts the International Telecommunication Union (ITU) in the leading role on 'Warning Dissemination and Communication' – a critical component of early warning systems that ensures alerts reach the people at risk in time to take action.

The superfast broadband programme is coming to an end and full fibre is the next step

Faster:
offering as much as 1,000 mbps

Upload speeds (mbps)

Download speeds (mbps)

	Upload	Download
Copper today	20	80
Upgraded copper	50	330
Cable	20	350
Full fibre	1000	1000

More reliable:
fibre has 5 times fewer faults than copper connections

Cheaper to run:
Fibre would save up to £5bn in operating costs over 30 years

The benefits will take time, as full fibre speeds are not yet needed, but delivery will take 10-20 years

Investment must start now
to avoid being left behind

UK National Infrastructure Assessment

Connectivity is one of thirteen policy recommendations made by the UK's first National Infrastructure Assessment, and is seen as key to a resilient UK; this has been strengthened in the recently published UK Government Resilience Framework.[27] The National Infrastructure Commission recommended that government should set out a nationwide full fiber connectivity plan, which would ensure that full fiber connectivity is available to 15 million homes and businesses by 2025, 25 million by 2030, and all homes and businesses by 2033.[28] The Levelling Up White Paper published in February 2022 set a new target for gigabit-broadband to be available nationwide (at least 99% of premises) by 2030,[29] a major step forward in facilitating digital access and enablement. The Levelling Up agenda is now a key tenet of the UK's National Resilience Framework.

DIGITAL ASSETS AND INFRASTRUCTURE

Cities are made up of infrastructure assets, systems and networks, including energy, water and transport. Traditionally, the management of infrastructure networks has relied heavily on visual inspection, manual measurements and expert judgement within a particular sector/organization.[30]

The emergence of digitally connected infrastructure, sometimes referred to as 'Infratech',[31] provides opportunities to increase efficiency, flexibility and the ability to anticipate issues and respond quickly. This involves the integration of digital components – sensors, internet connectivity, etc. – into all physical assets of the city, allowing remote monitoring and management. For example, using data from sensors in sewer systems to improve their management, and sending alerts to responsible engineers to take on-time actions to mitigate potential adverse consequences,[32] which in turn may result in better surface water quality, while also being used to monitor water levels and inform real-time flood warnings.

As a result of this digital integration, infrastructure assets, networks and systems are becoming more complex and tightly interconnected, forming a public/private system-of-systems which contributes to providing key services within a city.

Rio de Janeiro's Centre of Operations (COR)[33]

Rio de Janeiro's Centre of Operations (COR) takes advantage of a network of digital sensors and surveillance cameras embedded across the city's infrastructure systems to gather data and information into a single management center. The COR allows emergency services, transport operators, utilities, and other critical service providers to co-locate and receive real-time information about operations across the city, allowing rapid and joined-up decision making and communications throughout the city. This helps to pre-empt shock/stress situations and provides real-time situational awareness during disasters.

3. How can digital systems compromise city resilience?

All components of a digital system can enhance urban resilience within cities. However, they can also create or exacerbate vulnerabilities through their deployment. The ongoing integration of digital technologies within cities is creating a tightly coupled system of systems, where digital presents one overarching link between all other systems. This can make such systems increasingly prone to cascading failures, which can affect multiple services and ultimately the safety and livelihood of people.

ENABLING FACTORS

During a shock or stress situation, being able to connect online and leverage digital technologies can ensure the resilience of public services and coordination of public action. However, digitalization has exposed public administrations to new challenges, such as the exclusion of people who do not hold the skills and understanding required to use digital tools effectively.[34] For example, the Digital Nation infographic for 2022 – created annually by the Good Things Foundation – found that there are 10 million people in the

UK who lack the most basic digital skills, and 36% of workers lack essential digital skills for work. Moreover, 5.8 million people in the UK will remain digitally excluded in 2032 if nothing is done to help them.[35] People who are already at a disadvantage – through age, education, income, disability, or unemployment – are most likely to miss out, which could further widen the existing social inequality gap.[36]

A shortage of digital skills may not only affect a person's life directly – leading to isolation and reduced access to jobs, democratic processes, and education – but it can also compromise the smooth running of digital systems that require specialist skills. Digital solutions will only be effective if the people operating them possess a full understanding of the system.

Digital Exclusion Risk Index

The Digital Exclusion Risk Index (DERI) tool,[37] for England, Wales and Scotland, was developed in alignment with a similar tool used by Salford Council in response to the experience of digital exclusion as a significant challenge for residents and communities during the pandemic. Local authorities found they were unable to understand the scale of the challenge locally, and there was no single consistent view or understanding of digital exclusion as a facet of broader social inequalities. Through a collaboration with other Combined Authorities and Local Authorities nationally, the DERI tool was developed to provide local authorities with detailed insight into where digital inclusion initiatives are needed most.

Review of the preparedness for and emergency response to the Manchester Arena Attack

At just after 10:30 p.m. on Mon., 22 May 2017, a suicide bomber detonated an improvised device in the Manchester Arena foyer following a music concert. The explosion killed twenty-two people, over one hundred were physically injured, and many more suffered psychological and emotional trauma.

The set-up of the Casualty Bureau was seriously hampered by the complete failure of the National Mutual Aid Telephony system. As a consequence, communication with the families caught up in the attack was badly affected. A restricted local telephone contact service was not up and running until around 3 a.m. A major learning from the review is that there must be tested back-up systems in place that eliminate the chance of another failure.

Amazon Web Services outage

On 28 Feb. 2017, a four-hour outage impacted one of Amazon Web Services' (AWS) largest cloud regions, USEAST-1 in North America. The cause of the outage was reported by Amazon to be human error.

As AWS had not completely restarted the affected system for some years, "the process of restarting these services and running the necessary safety checks to validate the integrity of the metadata took longer than expected." Many users of AWS were affected, including 'Internet of Things' providers such as Nest who provide thermostats, CCTV cameras and smoke alarms that are all controlled remotely using AWS capabilities.

The company had not fully understood the complexities of restarting the servers. Changes were implemented as a result, including limiting the amount of capacity that can be removed at one time, and preventing capacity from being removed when it takes any subsystem below its minimum required capacity level. Although Amazon claims to have 11 lines of redundancy, this outage highlights that there is still potential for a single point of failure to result in significant resilience impacts.

DIGITAL SERVICES

Public-facing services are dependent on many components of a digital system. If any of the components fail, then digital services may become unavailable, potentially causing significant challenges to the city system.

Digital services can polarize communities, spread misinformation and incite violence. One challenge is that big tech companies (e.g. Facebook, Twitter, Instagram etc.) have a key role as gatekeepers to information in the public realm. They have the ability to select and curate information which is shared on social media platforms, targeting it to specific audiences and having an influence on public opinion, the political debate and potentially even on electoral results.[38]

There is also a risk of people becoming reliant on digital platforms for transactions. For example, paying through apps and cards means that we now carry less, if any, cash. This was exacerbated through the Covid-19 pandemic, where many places only accepted card payments. However, if payment systems should fail, individuals and businesses would not be able to readily access their money and would therefore be unable to pay for goods/services. Moreover, those people without digital devices, connectivity or a bank account may be excluded in a more digital economy.

DEVICES

The resilience of a digital city arguably requires citizens to have inclusive and universal access to digital infrastructure. Lack of access to devices is a significant part of digital exclusion. A large proportion of the world's population still lacks internet access[39] – even in the United States, more than 6% of the population (21 million people) have no high-speed connection; in Australia this figure is 13%.[40] Internet penetration in Bangladesh and Afghanistan is 15% and 14% respectively.[41] Lack of access may be due to affordability or insufficient infrastructure. Nevertheless, the ability of people to actively participate, receive updates and flag issues relies on them being able to access digital devices, such as computers and phones. A study looking at school-aged children in Europe found that 5.4% are digitally deprived, which means that they live in a household that cannot afford a computer and/or internet access. This percentage, whilst seemingly low, varies greatly between countries, with Mediterranean countries and Eastern Europe having considerably higher numbers than the rest of Europe (2.4% in Denmark vs 23.1% in Romania).[42] The inequity in access to devices compromises the resilience of cities.

But at the city scale too, access to the most effective devices and compatibility between devices can be a problem. This has been highlighted in Global South cities, where different digital technologies have been introduced from different suppliers through internationally financed projects, but with no coherency in the types of devices deployed in different parts of the city-region. This can lead to devices effectively being stranded from other parts of the system due to different operating protocols; they don't 'talk to each other'. Holistic planning of digital systems and common standards are imperative to avoid this kind of outcome.

Tackling misinformation in Singapore

The Singapore government tackled the issue of fake news spreading through social media during the coronavirus crisis by communicating regularly with its citizens through popular mobile social apps such as WhatsApp, and promptly correcting misinformation whenever required.

Case study: Cities and counties help students learn online[43]

During Covid-19 the city of Minneapolis teamed up with the school districts to ease the technology burdens that came with remote learning, offering devices, resources and expertise to help school districts close a digital divide that the pandemic had made apparent. The city, the school district, the nonprofit and private sectors all worked together to provide devices to families in support of remote learning, along with needed technical assistance.

Minneapolis also stepped up to help schools deliver the broadband needed to keep students learning at home. The city served as an intermediary, negotiating for internet services in support of students learning at home.

DATA AND INSIGHTS

Data systems are reliant on cybersecurity to maintain data privacy. Cybersecurity threats to data are probably the most well-known risk to the resilience of a digital system. There have been many cases covered in the media of major companies and governments becoming victims of cyberattacks. One report stated that 2021 saw a sharp rise in the proportion of local governments hit by ransomware attacks, and an increase in the value and volume of ransomware payments as well. The number of attacks increased by 70% in just one year, from 34% to 58% of those surveyed.[44] When this happens, issues with privacy and data security arise, and if not dealt with properly, it can impact citizens' trust in the services and ways they interact, as well as trust in the governments themselves.

A lack of standardized governance of urban data – including for data quality, data storage and sharing, and data-led innovation processes – can compromise the operation and development of city-wide systems. Without a shared data framework, cities may struggle to capitalize on the benefits that data and the derived insights bring.

Ransomware attack on Ireland's Health Service Executive

On 14 May 2021, the Health Service Executive (HSE) of Ireland suffered a major ransomware cyberattack that caused all IT systems nationwide to be shut down. It became the most significant cyberattack on an Irish state agency, as well as the largest known attack against a health service computer system in history, occurring during the Covid-19 pandemic. The incident response was to switch off all HSE IT systems and disconnect the National Healthcare Network from the internet to remove the threat of access. This resulted in "healthcare professionals losing access to all HSE provided IT systems – including patient information systems, clinical care systems and laboratory systems". Non-clinical systems such as financial, procurement, and payment systems were also lost, along with communication channels at the HSE's national center and within operational services, disrupting healthcare centers across the country with real life consequences for thousands of people.[45] It took four months to completely recover from the attack, with the HSE sustaining numerous impacts to healthcare delivery during this timeframe.

Thessaloniki ransomware attack, 2021

The Municipality of Thessaloniki was faced with a ransomware attack during the summer of 2021. This resulted in the collapse of the city's IT systems and platforms.

The first priority for the city was to ensure the maintenance of critical services while restoring the damage to its systems and recovering lost data. Some of the immediate actions taken included:

- Opening a dedicated online service area for citizens and city departments, until the city servers were safe again.

- Formatting more than 100 servers in various municipal buildings, procuring new PCs where needed.

For Thessaloniki the attack was a wake-up call on the importance of strengthening its digital systems, establishing robust internal policies, training and raising digital awareness of the city staff, and having an up-to-date continuity plan that will ensure the resilience of the city during a shock event.

After the event, the city reached out to other R-Cities member cities to get advice and support, and also shared its experience with the rest of the network.

Gender biased data

"The vast majority of information that we have collected globally and continue to collect – everything from economic data to urban planning data to medical data – has been collected on men, male bodies, and typical male lifestyle patterns," according to Criado Perez, author of Invisible Women.[46] For example, many cities have been designed around the car. Men are more likely to drive compared to women, who are more likely to walk or take public transport. One of the arguments Perez brings forward is that this car-centric design may lead to more injuries for women – a study of pedestrian injuries in Sweden found that 79% took place in winter, and 69% of people injured in single-person incidents, such as a fall, were women.[47] Awareness of the inherent biases within data sets is critical to allowing informed decision making that adequately compensates for bias. Data should not be adopted as 'evidence' without appropriate review and interrogation.

Hacking The Hague

In The Hague a hacking competition called 'Hack The Hague' is organized every year. The local authority invites ethical hackers to the public area of city hall to hack the live IT systems, applications, and websites of the city and its suppliers. Having such an event out in the open fuels the dialogue about cyber resilience and increases the awareness and preparedness of the city, its employees, and the citizens of The Hague.

Connectivity and networks

Connectivity is the glue that links all the other components of a digital system together. Therefore, when connectivity fails, it has the potential to damage the whole city system and to compromise its resilience. Without connectivity and networks, devices and physical assets cannot connect to the internet, and therefore are not able to access data and services or perform their normal tasks. Sensors could fail to notify engineers of mechanical issues with infrastructure such as bridges, buildings, or tunnels, or notify them of gas or water leaks – all of which could potentially lead to disastrous accidents and loss of life.

Yet connectivity is neither universal nor constant. Many emergency and disaster management plans are prepared during times of stability, with the assumption that digital systems will be available during a crisis. There need only be a failure in energy supplies, and digital connectivity would also be lost. There is a need for cities to develop contingency plans – and training – to ensure that an alternative response (potentially an analogue response) is ready to deploy in case of lost connectivity. For example, Storm Arwen in the UK resulted in extensive power cuts, exposing the implications of phasing out traditional landline telephones in favor of broadband-enabled smart phones that rely on an electricity supply; communities were left unable to communicate.[48]

Lancaster flooding[49]

During severe floods in Lancaster, UK, in 2015, many people who had replaced wired telephone handsets with wireless suddenly discovered that these do not work without a mains electricity supply. On most mobile phone networks, the base station (the transmitter that provides the radio signal to communicate with phones in that area) is powered from the local 230V electricity supply. Some have a battery back-up that continues to provide a service for an hour or two but few, if any, cope with the 30-hour loss or supply experienced over much of Lancaster. Inevitably, the loss of a mobile signal resulted in the inability to send or receive text messages or to use 3G and 4G internet services.

Most domestic internet connections were also lost. This is because the equipment case (usually on the pavement) that houses the routers linking the high-speed fiber connections with the copper wires going to individual houses is powered from the 230V supply. The loss of communication services was one of the most significant problems reported by many people.

DIGITAL ASSETS AND INFRASTRUCTURE

Physical assets and infrastructure can undermine urban resilience if they are outdated, stranded from other assets in the system due to incompatibility, or have not been designed to withstand shocks and stresses. Extreme weather events and climate change are a growing threat to physical assets and infrastructure around the world. Data centers are increasingly vulnerable to overheating, water ingress and flooding. When these risks occur, for example during a flood, the downtime of the data center has a significant economic cost, with the average data center outage being costed at over USD 700,000.[50] With infrastructure having a long design life (ranging from 10-100 years typically), we must ensure digital technologies can adapt to the new risks emerging through the climate crisis during those timescales, and that they are regularly checked, maintained and upgraded.[51]

It is important to keep in mind that infrastructure is affected by a wide range of extreme events (e.g. cyber or terrorist attacks or earthquakes) and owners and operators should consider an 'all hazard' approach when developing or updating preparedness and response plans. It is argued that critical infrastructure assets must ideally be kept separate from the internet wherever possible. Where connectivity is required, adequate security controls and segregation must be implemented to ensure their continuity under shock events. For example, ethical hackers recently exposed a security weakness in cycle traffic lights in the Netherlands after hacking the system to give priority to non-existent cyclists and thereby slow the flow of motorized vehicles.[52] While this was a 'friendly' attack, it highlighted questions about what the optimal level of connectivity between assets is. Regular stress testing of systems is required to ensure network security.

Superstorm Sandy

Superstorm Sandy was one of the United States' deadliest hurricanes. It caused 147 deaths, $70.2 billion worth of damage, destroyed 650,000 homes, and left 8.5 million people without power[53]. In New York City, it flooded the streets and tunnels of Lower Manhattan, parts of subway lines and forced the closure of the New York Stock Exchange[54]. In terms of digital infrastructure, Sandy's impact resulted in at least eight data center outages. Many failed even if they had backup power systems and continuity processes in place, while some stayed down for several days. This case study also illustrates the reliance of communities on the internet for news updates and information sharing. The loss of connectivity severely impacted on organizations' web presence. Companies such as the Huffington Post, Gawker, Gizmodo and BuzzFeed were all affected. A record number of people used social media to view eyewitness accounts and updates on the crisis, while individuals and organizations felt the loss of an essential service[55].

Cyber attack on San Francisco's municipal railway[56]

In 2016, hackers used ransomware called Mamba to compromise San Francisco's Municipal Railway (MUNI), breaching the system to access and encrypt over 2000 office systems. The ticketing systems had to shut for four days; an example of how physical assets can be affected by digital failures. This impacted rail travel across the city and meant that many people travelled for free. No customer or transaction data was compromised in the attack, and back-ups allowed the transit authority to recover function on most of the systems soon after the attack was discovered.

4. What role can cities play in improving digital resilience?

Digital technologies and systems alone cannot build digital resilience in the urban context. Going forward, cities need to balance the vulnerabilities of digital systems with the opportunities that they can provide, drawing on a broader enabling toolkit which includes end-to-end and multi-system planning, policy and regulation; effective skills and capability building; and an integrated approach to city leadership and management, bringing together public and private sector asset owners and network operators.

The governance of digital systems is a challenge, as many different organizations are responsible for digital assets, data and information both in the public and private sectors. This is largely unregulated in many countries and could lead to blind spots in the resilience of a digital system, which could propagate impacts of shocks across multiple systems. Local governments have an important role as a convenor and facilitator between stakeholders to drive more joined-up planning, decision making and standardized digital protocols which will help to address many of the risks highlighted in this paper.

The table below sets out a series of recommendations for cities and city-regions, acknowledging that powers and levers vary between cities in different geographies, and some cities may have greater opportunity to act than others.

Digital Component	Local government action
Enabling factors	▶ Involve everybody in digital life, providing a digital literacy learning pathway in schools, further education, community programs (especially targeting minority or vulnerable groups) and employment-based training.
	▶ Build capacity among government officials and leaders to understand complex multi-system risks and opportunities, and to implement effective solutions in a digital shock/stress situation.
	▶ Develop digital economies and the technological innovation sector, supported by a qualified workforce.
	▶ Facilitate affordable access to digital devices, assets and services, through public services, subsidies, private partnerships, etc.
Digital services	▶ Collaborate across sectors, with governments at all scales, and with communities to develop effective, accessible and secure digital services.
	▶ Ensure that back-up plans – which may include analogue solutions – are in place in the event of a failure in any digital service.
	▶ Facilitate experimentation and innovation through a combination of formal mechanisms (e.g. procurement) and voluntary mechanisms (e.g. open data for public innovation, hackathons, etc.)
Devices	▶ Roll out digital devices across public service areas to enable real time monitoring and information sharing, for example in schools, healthcare settings, etc.
	▶ Explore private sector partnerships to make devices available in communities (e.g. through community facilities or elected community leaders), so that all people can access critical communications during times of emergency.
	▶ In collaboration with the private sector, infrastructure operators and other government bodies, develop standards to ensure compatibility of digital devices deployed across the city/city-region, so that all devices can integrate effectively.
	▶ Explore the use of 'service contracts' for digital infrastructure, so that suppliers are required to update devices over time in order to maintain the effectiveness of the procured service.

Digital Component	Local government action
Data and insights	▶ Support and develop policy/protocols for open data platforms, integrating this into wider data strategies and resilience plans. Ensure this also supports broader innovation and data-driven decision making. See the <u>Open Government Data Toolkit</u> and <u>Open data infrastructure for city resilience: a roadmap, showcase and guide</u>
	▶ Ensure effective security of city-held data, with suitably qualified leadership, management and appropriate governance. See <u>6 Steps to Smart City Cyber Resilience guidance</u>
	▶ Coordinate effective data sharing between public and private institutions to solve complex problems. Broker access to privately held data sets. See <u>GrowSmarter 'Big consolidated open data platform' initiative</u>
	▶ Compile and analyze data to inform public policies. Develop a digital city twin to allow systems to be stress tested and to better understand the impacts of interventions across the city.
Connectivity	▶ Identify funding and lobby national government and digital service providers to deploy appropriate internet services to all communities and citizens.
	▶ Develop shared contingency plans with digital providers in the event that connectivity and networks should fail across a city. For example, a <u>Network Disaster Recovery Plan</u> that ensures services and resources that rely on networks and connectivity can be quickly recovered.
	▶ Undertake stress testing to ensure contingency plans are fit for purpose. This should include coordination of key organizations and agencies responsible for digital technology within the city.
Digital assets and infrastructure	▶ Establish alternative methods of communication and analogue back-up management procedures for all digitally enabled systems.
	▶ Develop policy and plans to ensure that new urban developments, technologies and assets fit into existing digital infrastructure networks.
	▶ Undertake <u>digital master planning</u> to ensure that digital solutions are embedded across city systems securely and improve understanding of where physical assets are located, how they are performing and how they are affected by shock/stress events.

5. Conclusion

The journey towards becoming a resilient city is continuous; as the context of shocks and stresses shifts over time, cities and city-regions must continuously grow and adapt their resilience processes. While a city will never be 100% digitally resilient, a resilience-based approach to digital systems will help ensure that they can benefit from the efficiencies that digital solutions bring, whilst also being prepared for crises, ready to respond and able to learn. This needs to be achieved by making the right investments in physical assets, people and virtual services. And the time is now; it is imperative that local leaders establish a digital resilience agenda now, being proactive rather than reacting later to a major crisis.

We have set out a number of key actions for cities and city-regions going forward. However, there is also a range of parallel initiatives currently underway to support cities and city-regions in building digital resilience. The findings of this paper directly support the Resilient Cities Network's (R-Cities) programmatic work around how the benefits of digital solutions are equitably distributed to all communities, such as R-Cities' Future Ready Cities in partnership with Visa, a multi-city program that co-creates digital solutions with cities, partners and key stakeholders to improve urban resilience worldwide through the development of innovative practices, knowledge sharing, technical support and funding. The findings of this paper will also inform the Making Cities Resilient (MCR) 2030 members who have identified digital resilience as a priority thematic area.

The findings of this paper are also important for R-Cities and Arup's ongoing partnership, and our work to refresh and re-imagine city resilience practice for the next phases of strategy-making, action implementation, monitoring and evaluation. The digital world has evolved rapidly since the original definition of the City Resilience Framework, as presented by Arup and The Rockefeller Foundation in 2013. Every indicator in the Framework could be viewed with a digital lens. This will be fundamental to the future framing of city resilience, and to the guidance and recommendations presented to cities.

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