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What Ukraine Can Teach the World About Resilience and Civil Engineering

Bringing sociology into civil engineering helps explain how Ukraine's social and physical systems work together to keep lights on amid constant attacks.

When Russian airstrikes cut off water to 80% of Kyiv at the end of October 2022, utility workers were able to restore the flow within 24 hours. Against a steady barrage of missiles, drones, artillery, and cyberattacks, the country's infrastructure has proven remarkably resilient. Real-time monitoring shows that the Ukrainian rail system had, as of August 2023, experienced only one complete shutdown since the start of the war, lasting just two hours. Early on, the country's ability to rapidly adapt—for example, using commercial drones on the battlefield and modified jet skis for sea attacks—helped it handle military strikes and shifting front lines. A war that was expected to end with Ukraine's defeat in only three days is, as of this writing, entering its twentieth month.

There is no denying the physical devastation. As of April 2023, the Kyiv School of Economics estimated $150 billion in infrastructure damage in Ukraine, with damage to or destruction of about 170,000 residential buildings (including almost 20,000 apartment buildings), plus over 1,300 schools that have also been destroyed, according to UNICEF. This makes the resilience of the nation's services and utilities even more remarkable.

Our point here is not to minimize the pain, damage, and trauma the war has wrought. In fact, what we find remarkable is the opposite: how Ukraine prevented the toll from being far worse. Two of us (Christensen and Tymoshenko) are management and development consultants working in Ukraine who focus on reconstruction planning, energy infrastructure, and managing large portfolios of development projects. Several months ago, we got in touch with Armanios, who studies how organizational sociology applies to large-scale engineering systems. We were all looking to explore how under-recognized mechanisms of resilience might be applied to rebuilding Ukraine. Here is our synthesis of many months of discussions.

Ukraine's resilience in the face of Russian attacks has been accomplished via a remarkably adaptable assemblage of local, national, and transnational infrastructure. Sociologists have written extensively about situations in which multiple levels of society, each with its own systems of organization, work together (the technical term in sociology is "hinged ecologies"). Ukraine's experience reveals several factors that help catalyze and smooth interactions between these multiple levels: societal solidarity, informal networks, decentralization, learning spillovers, and modular, distributed infrastructure. From these factors, we developed five propositions, grounded in Ukraine's experience, with the preservation of physical infrastructure playing a pivotal role. Each proposition has a lesson for other societies facing threats, whether from war, climate change, or economic disruption.

Illustration by Shonagh Rae

PROPOSITION 1:

A common threat brings people together

Longstanding research shows that shared threats drive social cohesion. Ukraine saw an unprecedented surge in solidarity after the Russian invasion. Polling data a few months into the war showed a record high of 85% of Ukrainians self-identifying foremost as Ukrainian citizens (instead of as members of a minority group or residents of their regions)—up from 64% the previous year. The army had the trust of 97% of the population; President Volodymyr Zelensky, 85%. Before the war, Zelensky's approval rating was just 30%.

These levels of trust are remarkable given that the country experienced two revolutions since the turn of the century: the 2004–2005 Orange Revolution and the 2014 Revolution of Dignity, both of which reflected high levels of social discontent. Just as with other post-Communist countries, Soviet rule instilled and perpetuated deep distrust, with Ukrainians having some of the lowest levels of trust in their fellow citizens compared with other post-Soviet nations prior to the current war. The Kremlin's invasion plans relied on this distrust, expecting Ukrainians' uneasy support for their government to collapse after the invasion, with Ukrainians further receding into their households and families.

Instead, Ukrainians came together across political and social divides to fight for the survival of their state and society. Tens of thousands queued up to join the armed forces—so many that volunteers were turned away. We (Christensen and Tymoshenko) saw social groups interacting more broadly post-invasion as they joined efforts to impede the invasion and adapt in the face of adversity. Anticipating that moving people to hospitals would become difficult, some families even assembled first aid kits and organized volunteer training to allow emergency care to happen within their neighborhoods. An art collective in Kyiv sent the group's artworks off to safety and began welding tank-stopping barricades and making bulletproof vests. Local organizations, and even Ukrainians returning from abroad, began producing military barricades and sewing camouflage netting. People in villages, together with internally displaced Ukrainians, built checkpoints and staffed them together. Despite physical danger, volunteers gathered and delivered food to people in towns under siege, as happened in Chernihiv. In these examples, we see the insights of management scholar John Kotter—that threats breed urgency. The newfound social cohesion that arose from this urgency expressed itself in diverse, improvised, and collaborative efforts to shore up infrastructure and provide community services.

PROPOSITION 2:

Informal supply networks boost adaptability

Within 24 hours of the invasion, Kyiv's deputy mayor, with some national assistance, modified the app used to buy tickets on public transit to give warnings for air raids and directions to the closest bomb shelter. It could also help people find the nearest working gas station. Another government app, Diia, which civilians used to pay taxes and apply for passports, was quickly adapted so citizens could report enemy movements to assist in Ukrainian reconnaissance, listen to the radio during blackouts, apply for relief funds, to name a few improvisations. Research has documented how technologies can change social processes and how social processes can, in turn, change technologies (the technical term in sociology is "imbrication"). The Ukrainian experience has shown how informal networks can boost and catalyze these cycles of mutual social-technological adaptation and, in so doing, increase resilience to attack.

Citizens turned fishing nets into camouflage nets and car batteries into backup power stations. Entrepreneurs and volunteers launched projects to supply drones, medical supplies, electric bikes, and cars to assist in the war effort. Existing social networks joined across national, regional, and local levels; new networks formed across sectors as people in private companies, nonprofit organizations, and government teamed up. Crowd-sourced projects brought together individuals with no direct connections. One existing European network mobilized to distribute donated generators to Ukrainian cities, for instance.

When attacks disrupted critical supply chains, networks pivoted to restore them. Sometimes they revived conventional suppliers; sometimes, they found ingenious new ways to provide essential materials and capabilities. For example, a beer brewery used its equipment to make Molotov cocktails. (Similar processes were seen in US breweries during the Prohibition era when they adapted their machinery to produce soft drinks instead of banned beer.) Undergirding these many efforts in Ukraine were crosscutting groups of volunteers, foundations, nongovernmental organizations, and various companies working together to shore up supply and service gaps to ensure civilians could get necessities and the military could maintain the fight.

The common thread across these examples is well established in both sociology and anthropology: when there are resource gaps, informal networks can creatively recombine what is at hand to come up with "good enough" solutions. During crises, fulfilling precise specifications for optimal operation is often impossible. There must be contingencies to make do with nontraditional supplies, especially for frequently required repairs. However, to do so, people often must go beyond their typical channels.

In such situations, informal networks reveal unexplored channels with analogous skills and capacity. Research in Africa has found that such efforts can lead

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to pathbreaking and scalable innovations in realms as diverse as moviemaking and workforce training. Replete in examples across Ukraine are citizens leveraging social networks that transcend typical infrastructure sectors in construction and transportation. These networks linked automotive, information technology, manufacturing, and even artists' groups in metalworking and sculpting to identify untapped resources that could lead to adequate solutions for shoring up Ukrainian infrastructure—and defense.

Policymakers can facilitate this search for untapped potential. For instance, documenting who knows what and who has what with something as simple as a spreadsheet can help people identify, create, and navigate such networks. The International Association for Public Transport provides a downloadable Excel master list of organizations with spare parts that can meet local Ukrainian infrastructure needs. In Ukraine, the company Nonsilo created a tool to update such an Excel sheet in real time, allowing any company wanting to support Ukraine's efforts to list what they have to contribute. These networks were improvised in crisis. Policymakers can help bolster such lists even before crises hit by cultivating linkages across networks of experts, communities of practice, industry associations, and even artist collectives.

PROPOSITION 3:
Decentralized management enables more agile response

After the 2014 revolution, fiscal management in Ukraine was shifted from the central level to groups of local municipalities, called amalgamated territorial communities (ATCs), with greater decisionmaking, tax-collecting, and self-governing powers than were previously ceded to provinces, or oblasts. That shift allowed ATCs to keep more of their tax revenues so they could increasingly self-manage and deliver local public services.

While difficult at the time, decentralization has engendered trust and empowered Ukrainian communities to repair damaged infrastructure much more quickly. A 2023 survey found high levels of social cohesion, with support for local institutions even higher than for most centralized ones—and this trust has paid dividends. For example, Ukrainian forces restored some power to Kharkiv's damaged electricity grid within a day of recapturing the oblast. Local authorities and private companies worked together to restore power across Kyiv and major cities after the October 2022 missile and drone strikes. By November, local authorities had organized thousands of "Points of Invincibility" for recharging gadgets, getting warm, and going online, often in local health facilities and businesses.

This mix of greater social cohesion and more agile decentralized governance catalyzed smaller-scale local adaptations throughout society that only further enhanced resilience. For instance, one cafe owner bought thermoses to keep coffee warm during blackouts and switched to desserts that didn't need refrigeration. Such flexibility would not have been possible with purchases and menus decided centrally.

Although local control can increase social cohesion, it can also complicate larger-scale coordination. Prior to the Russian invasion, intergovernmental organizations such as the Organisation for Economic Co-operation and Development (OECD) recommended that Ukraine strengthen centralized governance; the OECD continued to express those concerns even as the war unfolded.

Getting the right balance will be pivotal in sustaining and rebuilding Ukraine. In other contexts, such as rural water systems in Egypt, decentralizing regionally (rather than centralizing nationally) is proposed to sustain system agility. As Ukraine gains experience in coordinating across ATCs, these regional governance structures can achieve economies of scale while leveraging the social proximity needed to better adapt infrastructure to local needs and capabilities. In so doing, coherent national efforts can be achieved without compromising the flexibility needed when local attacks or disasters destroy essential infrastructure.

PROPOSITION 4:
Learning, especially from prior crises, enhances response

Learning can spill across crises. Before the Russian invasion, the COVID-19 pandemic prompted Ukrainian companies, schools, and government authorities

to transition to remote work and transfer computing operations into secure cloud systems. So when the attacks came, companies knew which functions to prioritize, how to reorient their operations, and how to build transnational networks to deliver their services. In fact, Ukrainian exports of information technology services in the first six months of 2022 were reported to have actually increased by 23% over the same period the year before. Utilities suppliers also drew on lessons learned during the 2014 Russian occupation of Crimea and fighting in the Donbas region to recover from hostile attacks. Hydropower operators, for example, gained experience working on mined land during these crises.

Such learning across crises in Ukraine is consistent with sociological research, especially on social movements, describing how lessons can be transferred across organizations. Studies have shown how social movements can help identify and share knowledge on effective tactics among participating groups, and even across movements.

Collecting such information more strategically is increasingly important. In the United States, the National Science Foundation has proposed a federal program to create "critical technology analytics" that would generate and share data and analysis, such as anticipating bottlenecks. In response to COVID-19, the CHIPS and Science Act and the Inflation Reduction Act both emphasize greater focus on shoring up vulnerabilities identified in global supply chains across critical technologies.

PROPOSITION 5:

Modular, distributed, and renewable energy infrastructure is more resilient

Although the country relies on large nuclear power plants to meet electricity demand, Ukraine's renewable energy production has been increasing. The head of Ukraine's largest renewable energy company estimates that his firm alone has produced over 200 million kilowatt-hours of green electricity since the start of the Russian invasion—with a significant part of it coming from wind farms and solar power plants in occupied areas in Ukraine's south and southeast.

Renewable energy, such as from wind or solar, is both modular and distributed, so when individual units are destroyed, they can be replaced independently of the entire system. As a result, damage to a single wind turbine or solar panel (or even solar farm) has much less impact on the energy system overall. Moreover, renewable energy can be generated closer to the point of use, avoiding the need to carry energy over long distances and reducing reliance on vulnerable transmission lines. Similarly, renewable energy sources do not require fuel deliveries and require less maintenance, so they can continue to function when supply chains elsewhere are disrupted.

Energy infrastructure that combines all these features (i.e., generated close to users, made of independently operable units, and renewable) is much harder for aggressors to disable over long periods. It is more difficult

DAMS AND GRIDS: HOW RESILIENCE FACTORS PLAY OUT

To help see the combined value of our propositions, we apply them to two examples: the Russian energy infrastructure attacks in October 2022 and the collapse of the Nova Kakhovka dam in June 2023 (with the caveat that there are significant differences between dams and electrical grids).

In October 2022, heavy damage had been done to at least 30% of Ukraine's energy infrastructure, and by November, around 50% was significantly damaged. Yet the system was able to remain operational through self-instituted rolling or emergency blackouts to reduce the peak load. By mid-December, most of Ukraine's large generation and transmission capacities were affected, along with significant amounts of the country's oil and gas infrastructure. These systems mobilized quickly in response and leveraged the decentralized ATCs to do so. Informal supply networks were able to provide many of the more standardized or extra spare parts. While there were some vulnerabilities around centralized grids, infrastructure was adequately distributed to maintain at least some minimum viable operation. Moreover, after over eight months of conflict and prior aggression, there was ample experience and learning for how to deploy fixes quickly. By April 2023, Ukraine had stabilized its domestic power supply and even resumed exporting electricity.

The collapse of the Nova Kakhovka dam in June 2023 offers a valuable counterpoint of fragility. Due to the size and operations of the dam, the project is overseen by the state-owned hydroelectricity company Ukrhydroenergo. Moreover, the dam provides electricity and flood protection to three ATCs: Kherson, Zaporizhzhia, and Dnipro. Thus, completely decentralized authority was not

to target, harder to disrupt, and easier to fix. Ukraine's grid infrastructure is already experiencing some of these benefits, which will only further accrue as more renewable energy sources come online.

This demonstrates that distributed, modular energy systems could be significant in strategic defense. Historically, major infrastructure projects have been taken up under a similar pretense of national defense. For example, President Eisenhower, himself a former general, successfully argued for building interstate highways, still the United States' biggest public works project, on national defense grounds. Similarly, energy security is used to make the case for more renewable energy in the United States, and even for Ukraine's entry into the European Union.

Communities and infrastructure need one another

In armed conflicts, infrastructure is both a target and a defense. The same is true amid disasters such as floods, hurricanes, and earthquakes. Between calamities, though, infrastructure rarely garners attention and is often taken for granted—as seen in society's slow-walked responses to the challenges of climate change. Despite ongoing efforts to raise awareness, such as the American Society of Civil Engineers' Infrastructure Report Cards, it often takes disasters like high-profile bridge failures to stir up popular willingness to invest in infrastructure.

Observing the reciprocal resilience between infrastructure and society in wartime can help explain how it can better function during peacetime. During many months of discussions among ourselves (and with generous colleagues, including economic sociologist Marc Ventresca, psychologist and decision scientist Baruch Fischhoff, and former Ukrainian deputy minister Dmytro Romanovych), we came to appreciate how the Ukrainian experience provides vivid, elevating, and tragic examples of the role that infrastructure plays in those processes.

Ukraine's resilience is grounded in a remarkably synergistic amalgam of local, national, and transnational systems. Each system helps catalyze and coordinate activities across diverse organizations, groups, and individuals. They range from local volunteers delivering supplies for national aid workers to company executives repurposing factories. The success of their efforts demonstrates in practice the theories embodied in our five propositions. Each proposition reveals details worthy of further study and improves understanding of how to make civil infrastructure more adaptable in the face of crises. These lessons could inform the decisions made by funders such as the World Bank, International Monetary Fund, and United Nations when making investments in infrastructure, so that they enhance the physical and social networks essential to sustained resilience amid disruption.

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possible. Even if the dam was salvageable after its collapse (and Ukrhydroenergo deemed it "beyond repair"), the engineering and parts for such dams are highly specialized, so only a few entities have the capability to provide assistance. This means informal supply networks are infeasible. That said, there is potential for learning spillovers from the nearby Dniepier Hydroelectric Station, which was destroyed twice during World War II, such as how to use temporary cofferdams and bridging works to facilitate inspection and repair.

The table to the right synthesizes our insights across these two case study vignettes.

Proposed Factors for Infrastructure Resilience	Strikes on Energy Infrastructure (October 2022)	Collapse of Nova Kakhovka Dam (June 2023)
Mobilization to shared threat	☑	☑
Decentralized management	☑	○
Informal supply networks	☑	○
Learning spillovers	☑	☑
Distributed, modular infrastructure	☑	○
Recovery speed	Faster	Slower