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When boundaries are blurred: infrastructure needs in support of the climate displaced

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Interactions between climate change and human displacement are complex, yet it is clear that climate change has and will continue to alter patterns of mobility. This is true for both trans-border displacement and internal displacement within country borders. Very little attention has been given to the infrastructure needed to support the climate displaced during their journey as well as in communities where they may pause or settle. In contrast to the climate displaced, reasons for refugee flight can range from deprivation, poverty, war, or disasters, and the statutory definition of refugee entitles them to the protection and assistance of the United Nations. This definition does not currently apply to those who move or are displaced because of climate change, though their displacement is no less perilous or traumatic than those protected under the UN Refugee Convention. Regardless of the legal status, engineers are largely absent from conversations about how to support and protect those undergoing displacement from climate change. In this paper, we draw on the general literature of forced displacement and the existing legal processes for refugees to explore the stages in climate-related displacement. We propose a framework for understanding the basic infrastructure needs during four phases: initiation, mobilization, pause and settle. We identify critical infrastructure to support the climate displaced for each of these phases, calling out those aspects of the displacement process in which greater understanding of how engineers can contribute to protection of human rights is needed.

KEYWORDS

climate migrants, displacement, receiving communities, infrastructure, engineering

Introduction

Acting as an amplifier (Institute for Economics and Peace, 2024), climate change is projected to result in as many as 1 billion people being displaced by 2050 (McAllister, 2024). Water shortages, fires, floods, conflict, and food insecurity are just a few of the factors contributing to displacement, both crossing country borders, and internal within a home country. Those displaced by climate do not fit the definition of a refugee under the 1951 Convention or its 1967 Protocol relating to the Status of Stateless Persons, which results in protection gaps for those displaced by climate (Handayani and Fauziah, 2020; Raleigh, 2023; Vanhala and Calliari, 2022). While human rights law offers some protection, it is insufficient to address the complex needs of climate migrants (Atapattu, 2020; Ibarra Sarlat, 2020; McDonnell, 2024). The Global Compact for Safe, Orderly, and Regular Migration (GCM), was adopted by the United Nations in 2018 and does explicitly mention climate change as a driver of migration, but the GCM is not legally binding (McLeman, 2019). In a complex policy

environment, the internationally recognized legal status of the climate displaced remains unclear, which is particularly problematic if the displacement is external to a home country.

The concept of loss and damage is recognized in the international climate framework as a means for addressing issues of climate justice (Boyd et al., 2021; McNamara and Jackson, 2019). Loss and damage covers the effects of extreme events, for example, droughts and heat waves, that exceed adaptation levels. Compensation for lower income countries can occur through the loss and damage mechanism (Serdeczny and Lissner, 2023). In 2023, The Fund for Responding to Loss and Damage (FRLD) was operationalized to include scope for countries to address human mobility needs. The UN also launched the Climate Account of the Central Emergency Response Fund in 2023, creating a specific means for supporting needs related to humanitarian response after climate-related natural disasters. But despite these institutional developments, both funds have thus far fallen short of their financial goals. In this context of growing need and limited resources, targeting interventions effectively is of great importance. Yet we lack sufficient knowledge of the specific needs to support climate displaced people in both the short- and long-term. This is especially true when considering the infrastructure needed to support the climate displaced across stages of their experience, and engineers have largely been absent from related research and conversation.

Research suggests that most movement due to climate change is internal and across small distances (Eyer et al., 2018; Rigaud et al., 2018). Migration theory suggests that movement between areas can be conceptualized as a combination of push (negative conditions in an origin, such as climate stress, which pushes people to leave) and pull factors (positive conditions in a destination that draw people to that area). Push factors in the context of climate change might include any environmental variability that exceeds regional norms and creates instability in economies, social structures, and institutions (Burrows and Kinney, 2016; Kaczan and Orgill-Meyer, 2020; Maurel and Tuccio, 2016; Warner et al., 2010). Research is scarce about the timing of when push factors initiate migration (McLeman, 2018), especially in the case of slow-onset climate effects versus sudden onset hazards, and what kinds of infrastructure is needed to support this transition. Pull factors making a destination more attractive to the climate displaced include education, employment opportunities, healthcare, access to infrastructure, and safer environmental conditions (Marandi and Main, 2021). Migration due to climate change is also likely to interact with existing migration networks, with displaced people preferring to move to areas that preserve their social networks (Findlay, 2011; Wolsko and Marino, 2016). Little is known about differences between where climate-displaced people may choose to move temporarily versus permanently, and how infrastructure needs might differ between the two.

Our goal in this paper is to present some of the critical engineering infrastructure challenges and gaps in knowledge about climate displacement. We ask:

- What infrastructure is needed to support the climate displaced across multiple stages of displacement?
- What role do engineers play in addressing these infrastructure needs?

We propose a general four stage framework (Figure 1). The first stage is initiation where populations of climate displaced begin to leave their place of residence. This could be gradual as slow-onset effects of climate change become intolerable, or rapid in the case of a sudden-onset climate-related hazard. The second stage is movement in which a transition to a targeted destination occurs. In the third stage, which may not occur for all displaced populations, those who have been climate displaced pause at a destination – this destination may become a permanent home or serve as a step to an alternative destination. This pause stage could occur multiple times as some experience repeat displacement. The final stage is the point at which the climate displaced settle. The time periods associated with the third and fourth stages will be highly variable, and certainly the infrastructure challenges will be highly dependent on the time step involved. Nonetheless, there is a universality of basic needs that can be discerned. Engineers will need to be able to react quickly with rapidly deployable infrastructure, especially at the initiation and movement stages. As the climate displaced progress across the phases from initiation to halt, their infrastructure needs will change, especially as infrastructure shifts from temporary to permanent and from decentralized to centralized (Figure 1).

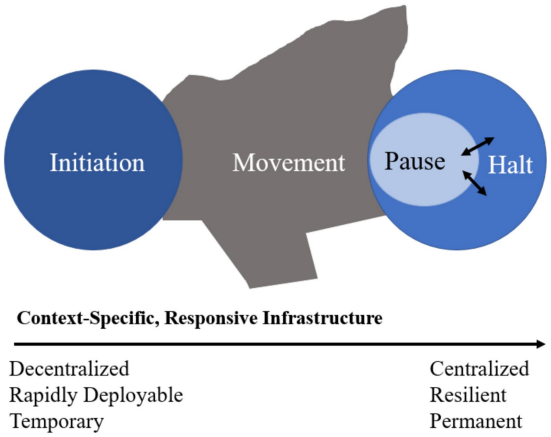


FIGURE 1
Conceptual framework of four stages of displacement from initiation to halt.

In the remaining sections of this paper, we draw on the general displacement and refugee literature to outline areas where climate displaced populations can be better supported with targeted infrastructure across the stages of displacement. We conclude with recommendations and critical gaps for engineers to expand their ability to support the climate displaced.

Stage 1: initiation

There can be many reasons why people are displaced due to climate change. Sea level rise, repeated flooding and drought can all give rise to displacement, ranging from planned and managed to a response to episodic events that increase in intensity. Research suggests that there are important distinctions between the types of initiation triggers. Wilkinson et al. (2016) define four mobility patterns for those who initiate a move as a result of climate pressure: (i) temporary moves; (ii) permanent moves due to recurrent events; (iii) moves motivated by environmental degradation and (iv) moves

as an adaptation strategy. While these mobilities capture motivation, Ajibade et al. (2020) point out that the lived experiences of those who migrant in response to the first three pressures are radically different from those who undertake resettlement via managed retreat programs, the fourth category. In many respects, the differences Ajibade et al. (2020) identify can be captured in categories as involuntary (displacement) and voluntary (migration) mobility (Schewel, 2020).

We argue that in the former, engineers must consider access to infrastructure ranging from satisfying basic needs, like access to food and water, to critical infrastructure which supports quality of life like broadband internet, educational or employment opportunities can be very different from migration under planned (voluntary) resettlement programs. Climate and migration scholars are often in tension, with the former arguing that natural disasters 'push' migration (Ahmed and McEvoy, 2014; Ajibade et al., 2020; Alexander et al., 2012), while the latter argues that secondary effects such as food scarcity, poverty, crop loss, and others gives rise to displacement (Black et al., 2013; Gray and Mueller, 2012; McLeman and Smit, 2006). This likely depends on the context, and, in a practical sense, these distinctions are immaterial to the infrastructure needs; a better distinction for engineers would be planned versus unplanned. If a household is displaced unexpectedly due to flooding or food scarcity, the need for access to basic goods and services is the same as managed displacement, but the urgency may be greater. In any case, those who are displaced will require (sometimes rapid) access to basic food, water, shelter, sanitation, and health services which engineers should be prepared to assist in providing.

The drivers of displacement will influence the severity of those needs and the specific urgency to meet them. Engineers must have a basic understanding of these primary and second drivers of displacement to respond appropriately. Yet, basic questions remain such as how do people plan for and access food and water under involuntary climate related displacement? How does this thinking vary under different kinds of initiation events? How does the specific nature of the initiation (for example, drought-induced crop loss vs. extreme heat vs. a damaging storm event) influence immediate infrastructure priorities? In an involuntary move, there is usually little time to think about how physical infrastructure will or will not be available for access, so engineers must be prepared to respond to a range of scenarios.

Phase 2: movement

Once household movement has been initiated, those displaced by climate change require support as they travel between the origin and a destination. This stage of the displacement process renders those who are displaced especially vulnerable to violence, exploitation, and abuse (Borges, 2024; Soria-Escalante et al., 2022; Vogt, 2013). The movement stage of displacement can be a challenging stage of displacement for engineers to respond to, as this stage uniquely manifests across space.

Access to safe, affordable transportation options is one of the most important considerations during the movement stage, and an area where transportation engineers and planners can make important contributions (Valdez et al., 2015). Research has shown that when migrants must walk, there are higher rates of generalized anxiety than when migrants are able to travel by vehicle (Carroll et al., 2020). Mobility solutions to assist people displaced by climate change must consider not only need, but also both the availability of networks (roads, bridges, etc.) and modes (vehicles, public transit). Planning for transportation infrastructure needs during the movement stage presents a challenge for engineers, planners, and humanitarian organizations, as it requires an understanding of where displaced people will go, which can be difficult to predict. There is a need for new kinds of transportation options that are cost efficient and can be quickly deployed.

Travel distance and time also have a significant effect on a displaced person's experience. When displacement occurs over large distances, resource requirements, including food, water, housing, and sanitation are significant. While most displacements are likely to be internal to countries and across short distances, basic resources are still required during the trip. As the movement stage is, by definition, transitory, these resources do not need to be permanent but must be safe, affordable, and rapidly deployable. Temporary housing options that are easily assembled and disassembled, are light-weight and transportable, and are durable can help ensure that displaced people are housed during the movement stage. Physical and mental health care options will also be critical. During the movement stage, people who are displaced may be dealing with initial stages of grief and trauma associated with their loss of home (Carroll et al., 2020; Freedman et al., 2020; Luci, 2020; Morina et al., 2018; Sagan and Palombo, 2024). Traveling with children, older family members, or family members with health problems can also increase the difficulty of the movement stage (Godfrey and Kalache, 1989; Thomas, 2004). We are in critical need of new infrastructure solutions that can be rapidly deployed and address potential mental and physical health.

Another major challenge for safe, legal movement of those who are forcibly displaced, especially across borders, can be a lack of identification (Manby, 2016). In the aftermath of a rapid-onset disaster such as a hurricane or flood event, documents may be lost or destroyed. A lack of identification can make it more difficult to access legal channels of migration, increasing the risk of trafficking. It can also present challenges for displaced people to prove their nationality, increasing the possibility of statelessness. While the 1951 Refugee Convention requires states to provide refugees with identification, it is unclear how this applies to people who are displaced due to climate change and might not have access to refugee status. Recently, UNHCR has deployed new technology-driven methods for refugee identification and tracking including biometrics, face recognition, blockchain, and AI, but these approaches are still largely experimental and pose practical and ethical challenges associated with privacy, data management, and perpetuating biases (Jacobsen, 2015, 2017; Madianou, 2019). Safe and legal movement would be facilitated by new technologies that are robust, rapidly deployable identification methods and that prioritize human rights, informed consent, and agency.

Support during movement will vary by the route taken, which may be conceptualized as displacement corridors. Many displacements will follow existing migration corridors such as common pathways for labor migration (Bardsley and Hugo, 2010; Entzinger and Scholten, 2022). Better understanding the needs of non-climate displaced migrants across existing major migration corridors would help to inform future responses to climate-related displacement. Qualitative and quantitative research in the form of interviews and surveys could focus on better understanding individual experiences of movement,

including how those experiences vary by both mobility context (e.g., mode and network) and individual characteristics such as age, sex and gender, ethnicity, income, etc. At the same time, it is likely that new corridors will also emerge as the effects of climate change worsen (Bardsley and Hugo, 2010). Researchers should continue to enhance our ability to predict and/or quickly identify likely spatial pathways of displacement (Beyer et al., 2023). In most displacement events, there are primary movement corridors that can be identified. Here, again, flexible and rapidly deployable transportation technologies and legal support will be critical.

Stage 3: pause

Many displaced people will make multiple moves, living in temporary locations and sometimes experiencing multiple displacements before ultimately settling in one place. We call the temporary relocation phase the pause stage. As an example, millions of Syrian refugees after the outbreak of civil war in 2011 were first displaced internally (pause) before later emigrating to Turkey, Lebanon, or Jordan (Valenta et al., 2020). While infrastructure at the pause stage needs to be more resilient and centralized than at the movement stage, it may still be transitional, presenting a critical design challenge for engineers. Adding complexity, the pause stage may also be voluntary or involuntary depending on the situation and context, or an individual may experience multiple pause stages in different locations.

Regardless, upon initial arrival, receiving communities will need to be prepared with immediate emergency services and resources (Junod et al., 2023). There will need to be processes to help the displaced find employment, housing, access to healthcare, and other support services. Especially when displacement is induced by a rapid-onset event or disaster, temporary housing solutions will be necessary to support affected populations (Lines et al., 2022; Tafti and Bashiri, 2022). Tents or pre-fabricated units (PFUs) may be able to meet immediate needs for housing (Félix et al., 2015). But planning for transitional/ temporary housing with the intention that it will be used for longer periods of time is also necessary so that higher quality construction and reliable provision of services can be prioritized. Eventually, these settlements may transition to permanent housing (Tafti and Bashiri, 2022; Wagemann, 2017).

Addressing infrastructure needs at the pause stage is especially challenging because the line between pause and permanent settlement is very often blurred. Traditional refugee camps are designed to temporarily meet the needs of displaced people but often become more permanent, with generations of refugees living and growing up in the camps (Feldman, 2015; Harrouk, 2021). When refugee camps become longer lived, residents often lack sufficient access to infrastructure, employment and economic opportunities, freedom of movement, health services, and education (UNHCR, 2020; Van De Wiel et al., 2021). In the case of climate-induced displacement, people may be initially displaced with the intention of eventually returning to their homes but may instead choose or be forced to settle permanently in their destination, as was the case for many people displaced by Hurricane Katrina (Weber and Peek, 2012). Similarly, many people displaced from rural areas of Bangladesh after the 1970 Bhola cyclone to urban informal settlements in the capital city, Dhaka, reported an inability to move back home due to a lack of resources or poor mental or physical health (Karlsson et al., 2020). As the effects of climate change worsen, including slow onset effects such as extreme heat and inundation due to sea level rise, it may be increasingly infeasible for displaced people to return to their original homes. In this way, the pause stage of displacement transitions, albeit unintentionally, into the halt stage. Where recovery and reconstruction is possible in places of origin, this should occur in parallel with temporary infrastructure support for temporarily displaced people, and their return should be facilitated. Basic infrastructure needs must be provided to those in a pause stage of displacement and must be flexible enough to make the transition towards more permanence if necessary.

In urban settings especially, where many displaced settle (Ahsan et al., 2011; Valenta et al., 2020), if the pause stage if protracted and there is not sufficient support, people may find themselves living in precarious informal settlements. Informality has widespread implications for wellbeing and, in many ways, reflects a failure of sufficiently flexible infrastructure, able to transition from temporary to permanent and centralized. Informal settlements often have poor sanitary conditions and inadequate access to water (Biran et al., 2012; Rashid, 2009; Zanuzdana et al., 2013). Similarly, protracted refugee camps often lack adequate water, sanitation, and hygiene (WASH) infrastructure due to aging infrastructure (initially intended to be temporary) and a lack of resources for maintenance or expansion (Akhter et al., 2020; Cooper et al., 2021; Yasmin et al., 2023). The health effects of inadequate WASH infrastructure are widespread, and include disease outbreak and spread and poor health outcomes (Calderón-Villarreal et al., 2022; Hsan et al., 2019; Yasmin et al., 2023).

People living in informal settlements also experience significant challenges associated with adequate, safe housing (Ahsan et al., 2011; Durst and Wegmann, 2017; Nasreen and Ruming, 2021). Within informal settlements in urban Bangladesh, where many people displaced by the effects of climate change reside, it is estimated that only 28% of residents live in permanent housing built with brick or cement walls and concrete roofs (Ahmad et al., 2013). Informal housing is more often constructed with low quality materials such as cardboard, polyurethane foam, and wood, and fires are both common and devastating occurrences (Dutta et al., 2024). Informal housing is often severely overcrowded, which can also contribute to adverse health outcomes (Rashid, 2009; Zanuzdana et al., 2013).

Energy access is another, frequently overlooked aspect for those in the pause stage; access to power has not been a focus of previous humanitarian support for the forcibly displaced (Baldi et al., 2022). It has been estimated that approximately 90% of displaced populations do not have reliable access to electricity, and 80% burn biomass for cooking (Baldi et al., 2022). Here, if connection to a centralized energy system is not possible, engineers should aim to support displaced people with more reliable sources of electricity such as photovoltaic mini-grids, which would also have the added benefit of avoiding greenhouse gas emissions (Baldi et al., 2022).

The pause stage of displacement presents specific challenges to engineers providing infrastructure. Access to basic water, food, shelter, and sanitation is still needed, but these services must be provided with the flexibility to transition from temporary to permanent. The pause stage should be considered dynamic, as a transition to full integration into a receiving community. In this transitional stage, the climate displaced will also require regular access to health services, transportation, and employment opportunities to successfully

transition into halt stage. Legally, people in the pause stage may also be especially vulnerable depending on the protections that they are granted in their host communities. In some cases, they may be subjected to coercive resettlement, resulting in further displacement (Valenta et al., 2020). Engineers must understand this local context to support those in the pause stage transition to halt.

Stage 4: halt

In the case of climate-related displacement, it is critical for displaced people to transition from the pause to the halt stage and integrate into receiving communities. This is especially true in cases where the effects of climate change have rendered original locations inhospitable or intolerable, and repatriation is not an option. Host communities will be looked to for access to permanent services and infrastructure, to provide stable employment opportunities, and to enable social integration (Junod et al., 2023). Necessary infrastructure will include housing, WASH, transportation, energy, social services, etc. For receiving communities, planning ahead can help mitigate potential stress to host infrastructure and promote better integration (Asad, 2015; Lujala et al., 2020; Phillimore, 2021; Rozo and Sviatschi, 2021).

Beyond housing and WASH infrastructure, which has been discussed, displaced people will require energy, transportation, employment, education, healthcare, and legal protection. Access to reliable energy has strong implications for health, education, and economic wellbeing. Additionally, access to air conditioning will become increasingly necessary as climate change makes parts of the world dangerously hot (Akpinar-Ferrand and Singh, 2010; Sherwood and Huber, 2010). At the halt stage, an influx of displaced people could place strain on a host community's existing power system.

Access to affordable transportation options within a destination will have significant effects on displaced peoples' ability to access economic and educational opportunities as well as health resources. The ability to move and access opportunities is important for helping people move from the pause stage to permanency. People living in Houston, TX who were displaced after Hurricane Katrina tended to cluster close to public transportation services because many migrants did not have access to a personal vehicle (Junod et al., 2023). Receiving communities may need to expand existing public transportation services and routes to support new residents.

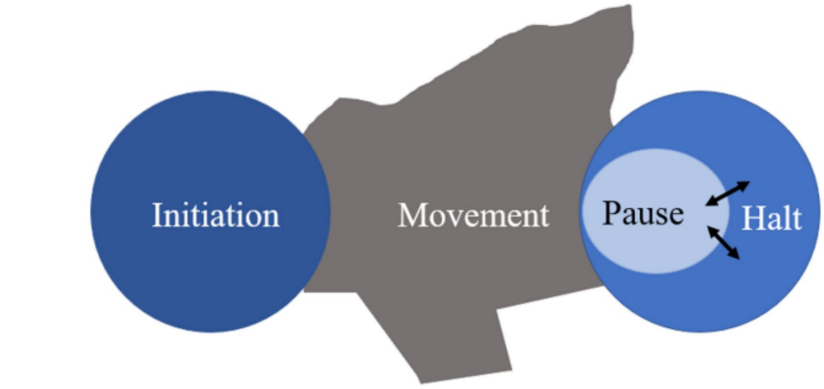
The health of the climate displaced will depend on initial health status, the initiator of the displacement, and experiences along all stages of displacement, health service availability in the destination, etc., but in all cases, access to health services will be critical (Miliband and Tessema, 2018). As displaced people settle in a destination, their access to safe housing, WASH, transportation, education, and employment will continue to impact their health and therefore, their need for access to healthcare. This is not dissimilar to the needs of communities responding to non-climate related displacement and development challenges. Unfortunately, it has been shown that displaced people are more likely to be discriminated against and denied healthcare compared to local residents (Abubakar et al., 2018), and physicians may lack awareness about the health needs of incoming displaced people, further hindering care (Müller et al., 2018). Receiving communities will need ways to build capacity to support the health needs of especially vulnerable displaced individuals, including women and children who are put at increasing risk of violence (Miliband and Tessema, 2018). Beyond physical healthcare, displaced people in destinations will require access to mental health support to address the trauma associated with displacement (Wolsko and Marino, 2016).

Finally, legal status and legal protection are critical. Without permanent refugee status, displaced people have less access to basic resources, rights, and legal employment (Valenta et al., 2020). In the case of protracted refugee status, many of the displaced may be trapped in "a long-standing and intractable state of limbo" (Erakat, 2014), which ultimately slows the social integration necessary to mitigate tensions between incoming and existing residents (Few et al., 2021; Long and Sabates-Wheeler, 2017; Lujala et al., 2020). Social cohesion initiatives for displaced people and host communities can help reduce this tension and the marginalization of incoming residents (Long and Sabates-Wheeler, 2017). Additionally, programs related to improving education, healthcare, and social acceptance of incoming displaced people have been shown to also contribute to benefits for host communities (Zhou et al., 2023).

Integration into receiving communities and successful transition into the halt stage will require widespread planning and investment into all elements of infrastructure. Engineers can help plan for necessary increases in housing, WASH, transportation, energy, health, and economic services to support incoming residents. This will require integration with population and migration researchers and advanced models to project future infrastructure needs. While social integration is necessary, engineers can also take an active role in promoting culturally appropriate infrastructure and communicating the needs of the climate displaced for local decisionmakers. At the same time, engineers must consider the challenges of infrastructure expansion that climate change may also pose in destinations. For example, locations will need to consider the specific ways that future climate change effects may interact with their ability to supply water to larger populations, as the challenge of providing WASH infrastructure for the climate-displaced may be exacerbated by the effects of climate change on water resources. Engineers must also carefully consider where to site new infrastructure and local climate risks to avoid placing the displaced in high-risk locations and perpetuating vulnerability (Fransen et al., 2024). Building for climate resilience should be embedded in any infrastructure expansion.

Conclusion

We have presented a framework for engineers to begin to more carefully consider the infrastructure needs of the climate displaced across four stages of displacement from initiation to settlement. As we have emphasized, the specific needs of the climate displaced will vary by the stage of displacement and the local context, however, access to affordable, reliable infrastructure and services is necessary regardless of context (Figure 2). What those needs look like will depend on the cultural, social, economic, and physical contexts of both displaced populations and destination communities. Among the solutions proposed by researchers are applying energy justice principles (Mastor et al., 2020), utilizing attribution science to strengthen protection claims (McDonnell, 2024), and developing new legal frameworks (Jolly and Ahmad, 2018; Khan, 2024). As climate change continues to displace millions, there is an urgent need for the



Infrastructure Needs	Infrastructure Needs
Mobility and Transportation	Mobility and Transportation
Health (services)	Health (services and infrastructure)
	Reliable energy
Access to Basic	**Access to Basic**
Water/Food/Shelter/Sanitation	Water/Food/Shelter/Sanitation
	Access to In-Place
	Employment; Mental Health Support; Safety and Legal Protection; Governance; Education

FIGURE 2
Conceptual framework of four stages of displacement from initiation to halt and a summary of the infrastructure needs associated with each stage.

international community to address this legal gap and provide adequate protection for climate refugees (Atapattu, 2020; Khan, 2024).

We argue that engineers must also be more directly engaged in conversations about how to support the climate displaced and protect their rights and wellbeing. Engineers play an essential role in providing infrastructure and services across the stages of displacement and must be prepared to adapt responses to the context and stage of displacement. This will include both decentralized, rapidly deployable, and temporary infrastructure as well planning for expanding centralized, resilient, and permanent infrastructure in receiving communities. This will require that engineers develop a deeper understanding of the lived experiences and unique challenges associated with forced displacement and embed a commitment to safeguarding human rights into their practice (Chacon-Hurtado et al., 2024).

Meeting the needs of those who are displaced by the effects of climate change will require a reimagining of how we think about displacement. Displacement does not just involve an origin and a destination, rather, our framework encourages engineers and planners to break the displacement process into distinct phases: initiation, movement, pause, and halt. Displaced people will have different needs during different phases, and engineers and planners will need to be nimble to support them along the way. Our current reliance on protracted, under-resourced refugee camps, represents a temporary fix and does not address the need for legal, inclusive integration into host communities. For this to be possible, host communities will also need to be proactive in their planning to ensure sufficient infrastructure and services when climate-related migrants do arrive.

One element that sets climate related displacement apart from other kinds of displacement is that engineers must center an understanding of climate risk and climate resilience in every dimension of their work. As a threat multiplier, climate change will pose new challenges for the climate displaced across every stage of displacement from new causes of initiation, new migration pathways and challenges along the way, and new risks within temporary and permanent receiving locations. Understanding these complex interactions between climate, displacement, and community resilience will require deep integration across disciplines and continuous engagement with local stakeholders, planners, and decisionmakers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KB: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. DN: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. JH: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The authors declare that no Gen AI was used in the creation of this manuscript.

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