Climate Adaptation Through Housing

Examples of Effective Interventions for Informal Settlements

WORKING PAPER

Loan Diep

Executive summary

Globally, an estimated 1.1 billion people live in inadequate housing conditions in informal settlements while bearing the brunt of climate change. Lack of access to adequate housing reinforces poverty conditions that are further amplified by the cascading effects of climate change. Faced with multiple vulnerabilities simultaneously, residents of informal settlements need to be better supported with regard to their living conditions so that they can build resilience to climate change. This working paper provides examples of interventions that have helped improve housing conditions while adapting to climate change in the context of informal settlements.

The techniques reviewed include solar home systems, insulated roof panels, solar-reflective paint, green roofs, bamboo-based structures, rainwater harvesting systems, elevated house foundations, waste-to-energy conversion with biogas technology, rain gardens, bioswales, permeable pavements and tree planting. The examples, together with illustrating cases, show how adapting to climate change through interventions in and around homes in informal settlements can be done in ways that co-create many benefits.

Since working in contexts with high urban informality presents unique challenges like land tenure insecurity, economic instability and sociopolitical conflicts, a number of underlying conditions must be ensured for the successful implementation of this type of interventions. Community engagement, partnerships, adequate support to help threatened communities navigate land and housing rights are all highlighted as accompanying approaches to ensure social inclusivity and ecological sustainability. The need to recognize context-specificity and the associated trade-offs and risks that can emerge is also emphasized. The report concludes with a set of policy implications and recommendations for different entities — U.N. agencies and multilateral financial entities, governments, and housing actors — to support climate adaptation action through housing interventions in the context of informal settlements.

Table of contents

Abbreviations

CBO	Community-based organization
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hour
NBS	Nature-based solutions
NGO	Nongovernmental organization
SME	Small and medium enterprises
UN	United Nations
UNEP	United Nations Environment Programme

Introduction

People living in informal settlements are bearing the brunt of climate change globally, and the number of people living in inadequate housing and informal settlements is on the rise. In rapidly urbanizing areas, formal housing supply is insufficient, leading a large proportion of the population to build their homes by themselves. Without support systems in place, this often results in large numbers of inadequate homes of low quality with issues such as poorly insulated walls, roofs that are not waterproof or windproof, dirt floors, rooms without ventilation, and unstable or unsafe electricity and water connections. These homes are also often located in hazard-prone areas. Despite overlapping challenges, households invest great efforts in their homes and their neighborhoods. Vulnerable populations residing in growing and densifying informal settlements are increasingly being exposed to hazards from climate change. And while communities, governments and market actors are deploying their capacities and efforts to adapt to these challenges, these efforts need to be more effective, more coordinated and better prioritized.

It is imperative that global climate actions put the most vulnerable people at the center, and this necessarily means increasing the level of priority of the adaptation agenda vis-à-vis and aligned with the mitigation agenda. Evidence collected in this working paper supports the idea that investing in greener approaches to housing adaptation will contribute to climate action while unlocking further opportunities that benefit the most vulnerable populations. Effective adaptation in informal settlements involves multifaceted strategies that encompass more than just physical infrastructure. Such adaptation actions help households reduce reliance on single systems. They consider social, economic and political capabilities that typically involve an inclusive, participatory process through which local residents actively engage in the planning and implementation phases. To effectively advance the 2030 Agenda of Sustainable Development, adaptation in informal settlements needs to be a more elevated priority for governments, civil society organizations and the international community.

To best address these issues, this working paper argues that climate adaptation can be effectively advanced though green housing approaches in informal settlements. Greening homes in informal settlements will not only reduce considerable risks affecting those most in need but also lead to great societal gains. This will support adaptation measures that aim at reducing climate risks and at building resilience. This report provides a collection of adaptation strategies for the context of informal settlements for which there is evidence of effective implementation around the world. It offers an illustrative collection of examples, ranging from solar home systems to green roofs, that highlight how communities living in informal settlements have already been taking incremental action around the world. The range of solutions and supporting approaches described in this document does not pretend to be exhaustive, it merely illustrates ways in which climate adaptation is currently happening in informal settlements though techniques that prioritize green housing.

1. Focusing on adaptation in informal settlements through green approaches to housing

1.1. Prioritizing climate adaptation for the most vulnerable

As the world prepares for the first stocktaking on the Paris Climate Accords, evidence on the global adaptation efforts shows that only 1% of the National Adaptation Plans, or NAP, prioritize vulnerable groups (UNEP, 2022). Compared with mitigation, adaptation receives a significantly lower level of priority. In fact, the world spends less than 10% of climate investment on adaptation (Buchner et al., 2021). This underfunding is problematic because the cost of adaptation will keep rising as climate change advances. According to the Global Commission on Adaptation, every dollar invested in adaptation could result in US$2 to $10 in net economic benefits (Global Commission on Adaptation, 2019). Furthermore, climate action needs to better integrate mitigation and adaptation. The urgency of connecting these agendas has become increasingly clear. As highlighted by the latest Intergovernmental Panel on Climate Change, or IPCC, report, adaptation measures represent opportunities to meet mitigation targets, and mitigation activities also represent opportunities to adapt to new climate realities (IPCC, 2023). This means that if the mitigation and adaptation are not working together, the efforts of one can stand in the way of the other.

Climate hazards have a disproportionately higher impact on populations living in informal settlements because they are often located in more hazard-prone areas. Compounding vulnerabilities make informal settlements particularly exposed and sensitive to the impacts of climate events. Residents of informal settlements often lack secure tenure, reliable infrastructure and formal sources of income. Such conditions create preexisting vulnerability to climate hazards, which richer populations — although also exposed to risks — do not necessarily face because they can afford strategies to reduce their vulnerability.

Even though mitigation and adaptation tend to operate in siloed funding, knowledge and policy streams, when it comes to the built environment, especially in the context of informal settlements, it becomes clear that the two are interdependent. The Sixth Assessment Report of the IPCC raised the urgent need to break patterns of vulnerability affecting populations in informal settlements (Dodman et al., 2022). Furthermore, the Global Alliance for Buildings and Construction explains that adapting buildings for a changing climate and reducing emissions from buildings go hand in hand as they mutually reinforce each other (GlobalABC, 2021). While mitigation action is continuing, it is crucial to prioritize building the adaptation capacity of the most vulnerable, particularly those living in informal settlements. To fund the necessary improvements to informal settlements, it is estimated that the total global investment needed was US$6 trillion in 2022 (Frediani et al., 2023). According to the Inter-American Development Bank, for every dollar invested in adaptation, US$3.50 of material losses can be avoided without even considering other non-monetized benefits (IDB; cited in Frediani et al., 2023).

1.2. The role of housing in climate action

For people living in informal settlements, limited capacity to adapt relates to low-quality housing, limited or no risk-reducing infrastructure, lack of secure tenure, and inadequate access to basic services, which compound vulnerability. These place a great burden on countries with large proportions of informal settlements. Between 0.1% and 0.2% of GDP could be lost each year because of unreliable infrastructure linked to electricity, water and transportation (Frediani et al., 2023). Residents of informal settlements in African cities spend between 15% and 30% of their income on materials for house repairs and improvements (ibid). Therefore, achieving adequate and resilient housing is both part of adapting to climate change and a necessary step to improve individual and community well-being.

The IPCC's Sixth Assessment Report calls for attention to the opportunities that exist to deliver climate action through investment into housing. Chapter 6 on "Cities, Settlements and Key Infrastructure" more specifically highlights the evidence that making affordable, adequate housing a priority holds the promise of providing significant benefits for the entire society (Dodman et al., 2022). Integrated housing solutions will leverage positive social and environmental outcomes that have higher potential benefits for those most vulnerable. As urban populations continue to grow in countries around the world, integrating inclusive adaptation strategies into plans for upgrading settlements will help meet needs for infrastructure and basic services while providing further sociopolitical and economic benefits (Dodman et al., 2022; Wolff et al., 2023).

The benefits of targeting adequate housing in informal settlements are far-reaching because of multiplier effects. Populations will reduce losses and increase their adaptive capacity as they gain better access to water, sanitation and hygiene services; health care; education; energy; greenery; and quite importantly, political recognition.

A study conducted in 2023 by Habitat for Humanity and the International Institute for Environment and Development highlights the societal returns of addressing issues in informal settlements and argues that "When residents of informal settlements do better, everyone does better" (Frediani et al., 2023). The combined contribution of housing investments and housing services represents at least between 13% and 16% of emerging markets' GDP (Acolin and Hoek-Smit, 2020). These figures reveal that housing is as important to the economy as manufacturing. Therefore, investing in the entire housing sector — new units, the existing built units and those that are self-built — can further accelerate local business development, promote jobs and livelihoods, and reduce future costs simultaneously.

1.3. Incremental housing initiatives that contribute to climate adaptation

Climate adaptation solutions are about addressing systemic gaps to build adaptive capacity that can break patterns of vulnerability. Adaptation strategies in informal settlements thus need to be deployed to decrease concentrated inequalities, support climate justice, and help entire communities build their resilience.

Incremental, self-built housing — a process by which families construct their homes and communities gradually, depending on the availability of resources — can allow individuals or communities to make more sustainable choices in house design, construction materials and methods. In less-developed countries, it constitutes a predominant method of residential development. This approach enables individuals to modify and expand their homes as their needs evolve. Incremental housing is often more adaptable to changing environmental conditions, enabling people to improve and renovate their homes as they can afford it and making it easier to incorporate climate-resilient features over time.

Currently, more climate financing is directed to “gray” or physical infrastructure than to “green” or natural infrastructure or social infrastructure. Why and how should climate adaptation action include investing in green housing in informal settlements? With 75% of infrastructure planned to be built by 2050, green housing should be affordable, support the local economy and have a sustainable life cycle that considers costs, maintenance and reuse of construction materials (Oomen, 2022). Using both nature-based and traditional engineering approaches can contribute to reducing climate risks and to building resilience at the neighborhood, city and global scales. As an engine of growth, greening the housing sector can support local business development, promote jobs and livelihoods, and reduce greenhouse gas emissions from the construction sector (Acolin and Hoek-Smit, 2020).

Green approaches to housing in informal settlements can help manage heat risk through insulation or changes in building orientation. Adaptation approaches also include raising structures that can help adapt to flood risks. The right combination of adaptation approaches contributes to well-being and ability to work. At the community level, carefully planned nature-based solutions, or NBS, such as public green spaces, improved urban drainage systems and storm water management, can deliver both health and development benefits. When these adaptations succeed, water, waste and sanitation can be improved to better manage climate risk and provide households and cities with better services. Many nature-based solutions entail bringing back plants and trees into cities, which also helps reduce the concentration of heat-trapping greenhouse gases in the atmosphere.

2. When incremental housing interventions meet climate adaptation: Selected examples

The examples in this section describe global initiatives developed by and for vulnerable communities living in what are sometimes referred to as “informal settlements.” These examples include strategies to help manage heat risk through insulation, building methods that adapt houses to hurricanes and flood risks, the creation of green spaces, and improvements to urban drainage systems and stormwater management that deliver both health and development benefits. Several of the interventions described can help households not only cope with the impacts of climate change but also reduce the concentration of greenhouse gases in the atmosphere.

Many of the examples described below focus on ecosystems and biodiversity, aligning with the concepts of green infrastructure and nature-based solutions that provide multiple benefits simultaneously through and for ecosystems. Nature-based solutions are defined as “Actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges (e.g., climate change, food and water security of natural disasters) effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016, p. xii).

NBS for housing support the need to take advantage of the ecosystems in which housing exists in order to bring about a range of direct and indirect co-benefits. In meeting local needs and aspirations, nature-based approaches will not be adequate in all contexts and may introduce new issues such as maintenance and economic burdens. Therefore, considering incremental and autonomous options is especially promising. This is where the potential of incremental self-built homes needs to be recognized. NBS can be incremental and part of a larger set of solutions in a wide spectrum of gray-to-green and hybrid approaches. In this context, “green solutions” refers to measures that can help reduce pressure on finite resources (e.g., water) by extracting less ("use less") or reusing them ("use again"). This also means using technologies that reduce pollution ("make cleaner").

Without delving into the intricacies of urban informality, for the purposes of this working paper, "informality" refers to the fact that houses are built on land without permits (usually delivered from governmental authorities), which means households are prone to evictions and other forms of displacement. Informal settlements are typically characterized by high density of the built environment, exposure to multiple climate-related hazards and other socio-environmental risks, lack of access to "formal" infrastructure and services (e.g., water and sanitation services provided by the municipality or the utility), poor political representation, and limited access to green spaces. While most examples presented below are in urban contexts, some are from peri-urban and rural areas. It is also of note that several of the examples come from vulnerable communities that do not live in contexts of informality but from which inspiration can be drawn for the context of informal settlements. All of these characteristics can represent barriers to implementing green housing solutions for climate adaptation, but such solutions can also represent opportunities to address these barriers directly or indirectly.

These compounding traits have implications in the way green strategies are designed, implemented and managed over the long term. For example, the fact that providing services — including housing — to populations living in informal settlements would fall outside the mandate of authorities means that maintaining these green strategies might be the responsibility of local residents. While the majority of the selected green strategies require relatively low maintenance, this is an important consideration. Who manages the strategies is therefore a key question, particularly for strategies that are implemented in "public" space or outside the house (e.g., rain gardens and bioswales). The list of solutions is neither exhaustive nor prescriptive, and context specificity must be recognized. Other solutions not described here also can be acknowledged, including hardware solutions, such as green walls, and software solutions, such as community insurance systems. Each of the green solutions listed in this section comes with one or several examples of implementation that come with particular socio-environmental conditions. While some of these examples have been well-monitored and documented, others are either ongoing or need to be studied further, especially regarding their performance in the provision of ecosystem services. They have been integrated into this report for illustrative purposes, and their emerging challenges and issues are also discussed.

2.1. Solar home systems

Decentralized energy solutions through solar home systems can generate electricity from solar power and reduce reliance on a centralized electric grid. Unlike traditional grid connections, which are costly and typically out of reach for households in informal or isolated settlements, microgrid and off-grid systems can provide cheaper and more efficient solutions. Solar home systems have proved successful in supplying direct and resilient access to energy to communities while being reliable in the face of extreme events such as storms, droughts or heavy rainfalls that overload power systems. Solar photovoltaics, or PV, have been recognized as a well-suited technology for home use that provides clean energy. Such technologies also tend to reduce the risks of electric shocks and fires, notably because they typically have direct current, or DC, loads (as opposed to alternating currents, or AC) and require less wiring. Solar PV can power essential appliances, lighting and even small-scale appliances.

The uptake of solar home systems has been steadily gaining pace around the world, particularly in East Africa and Southeast Asia, where a range of off-grid solar products and services have been actively included in electrification plans (Bisaga and Parikh, 2018). For example, Kenya, Tanzania and Rwanda are following the successful example of Bangladesh, where over 4 million systems have been installed as part of the government's off-grid electrification scheme (ibid). Another example is Puerto Rico, where grid-tied community microgrids have provided reliable solutions in the face of tropical cyclones (**Appendix 2A**). When Hurricane Maria hit the island in 2017 and plunged most of its population into darkness, the mountain town of Adjuntas, equipped with solar microgrids with a 187-kilowatt capacity of solar and about 1.1 megawatts of storage managed by the community-based organization Casa Pueblo, continued to have access to electricity. Referred to as an "energy oasis," this community let people come to power medical devices and charge their phones while the rest of the island was experiencing what became the longest blackout in America's history (Mignoni, 2018).

In some cases, solar home systems can be developed in informal settlements where multiple households share one large roof, which can be even more beneficial than in free-standing structures, with the condition that the roof is sufficiently shadow-free. Networks of stand-alone solar PV and battery units can also be scaled up to a micro-grid (Soltowski et al., 2019). However, solar systems, particularly because of their battery components, involve significant upfront costs, which requires financial support. Moreover, various technical and financial challenges must also be considered; for example, unstable rooftops can present a challenge when mounting panels. Some systems are also not sufficient or suitable for certain appliances, such as water heaters.

2.2. Insulated roof panels

The growing prevalence of heatwaves and cold extremes requires communities to build their homes with better approaches to insulation. Improving insulation helps manage thermal conditions by blocking heat from entering homes in summer and holding heat indoors during winter months. This can significantly reduce energy demand and minimize energy costs to households. Meanwhile, the use of recycled and locally sourced insulation materials has helped reduce the carbon footprint of the construction sector while supporting circular economic practices (Bonamente and Cotana, 2015). Modular structures are also well-adapted to the context of informal settlements, where plot configurations are small and irregular. These structures also enable material to be reused.

In Ahmedabad, India, the startup ReMaterials developed ModRoof modular systems of lightweight roof panels made from cardboard waste combined with coconut husk for natural binding and coated with a waterproof layer (Appendix 2B). 90% of each system is recyclable at the end of its life, at 25% to 30% of resale value (Oomen, 2022). ModRoof is designed to be an alternative to asbestos cement sheets frequently used in low-income communities (Vellingiri et al., 2020). Their structure provides insulation that helps keep heat out and reduces the indoor temperature by as much as 16 to 18 degrees Fahrenheit (equivalent to 8 degrees Celsius) (Oomen, 2022; Tewari and Singh, 2021). This has helped improve habitability and the health of residents in increasingly hot climates. Mahila Housing Trust, a women-led trust, has helped spring awareness of this solution in settlements by initiating co-operative credit schemes to make ModRoofs accessible to residents and cover the costs (between US$1,100 and US$1,400). As of 2022, ReMaterials had installed 150,000 square feet of ModRoof (Chandraby, 2020).

2.3. Solar-reflective paint

Using solar-reflective white paint on the outer surfaces of buildings, including roofs, is another simple way to help households reduce indoor temperatures and thereby reduce energy consumption and better manage heat stress. Solar-reflective paint is typically made with specialized pigments that have more solar reflectance and higher thermal emittance — key factors that determine its effectiveness in reducing heat gain.

A study conducted in an informal settlement of Ahmedabad in India showed how this technique, also supported by the Mahila Housing Trust, has helped households resist heat (Appendix 2C) (Chandraby, 2020). Tests have revealed that the mean ambient temperature of tin roofs coated with solar-reflective paint was 33.5 degrees Celsius, plus or minus 1.12 degrees. This was 1 degree lower than the uncoated tin roof, which had a mean temperature of 34.6 ± 0.87°C (Vellingiri et al., 2020).

While this is a simple and accessible solution, its effectiveness is also limited. The paint may require periodic reapplication, particularly in areas with extreme weather conditions of high pollution, which is a challenge in communities with limited resources. While the paint is usually made of sustainable components, some might still contain volatile organic compounds, which are harmful carbon-containing substances. These issues mean that asbestos might still be perceived as a viable alternative for households despite its impact on human health. Yet solar-reflective white paint can be applied in conjunction with other cooling approaches, including insulated roof panels.

2.4. Green roofs

Green roofs are passive design features of vegetation surfaces applied to a waterproofing layer of a roof buildup, and are generally constructed in rainy climates (Attia, 2014). Green roofs can provide many different benefits, notably to help houses adapt to extreme temperatures. Intensive green roofs (i.e., covering a relatively small surface but constructed with deeper substrates) can help protect buildings from extreme temperatures by providing insulation — thus regulating indoor temperatures — while reducing the impacts of the urban heat island effect — thus reducing outdoor temperatures. Green roofs have been associated with up to 55% of cooling energy reduction in climate zones with hot summers (He et al., 2023). For example, in the informal settlement of Arará in Rio de Janeiro, Brazil, recorded temperatures of green roofs were on average 40% lower than those observed in the surrounding regular roofs (Oppla, 2021) (**Appendix 2D**). In the United States, green roofs have showed their potential to mitigate the impacts of heavy rainfall events by reducing stormwater runoff rates from roofs by up to 65% (GSA, 2021).

Maintenance challenges in informal settlements can be significant where resources are limited. The design process requires knowledge of the types of landscaping features and plant species that are adapted to the context of implementation. Once implemented, green roofs require regular upkeep, such as weeding and, in arid climates, irrigation. Structural integrity and waterproofing must be maintained to prevent leaks and damage. These challenges can be overcome with community education and training and access to resources for maintenance, all of which can be facilitated with supportive institutions such as local governments, NGOs and community-based organizations.

Green roofs are not easy solutions to implement in any context, notably because they need to be adapted to the climate in which they are implemented. They tend to perform poorly in water-scarce climate zones, as drought periods kill vegetation unless it is sustained through artificial irrigation, which therefore hampers their efficiency potential. However, some cases have proved effective, especially where circular systems were put in place, but also where their multifunctional aspect was optimized. In Middle Eastern countries such as Egypt, roof farming has been presented as a successful alternative in the informal settlements of the Greater Cairo Region. Besides reducing heat stress, this technique has shown promising results by helping to grow food locally and supporting local economies (Farag, 2017).

2.5. Elevated houses

Integrating foundations that elevate houses built near water (e.g., in coastal areas) reduces the risks of damage to entire structures by providing them with protection against sea-level rise and flood events. Approaches to elevating houses in informal settlements include stilts or poles (e.g., in South and Southeast Asia), though these tend to be less sustainable, notably because of limits in elevation (Prosun, 2011). Amphibious foundations and buoyant foundations differ in the way they allow adaptation by making houses float as water levels rise, then settling back onto their conventional foundation when the water recedes. They can be made of various types of materials, such as expanded polystyrene, air chambers to enhance buoyancy, and concrete (which can be made of natural materials itself) (Rao et al., 2022). As opposed to many other rising techniques, these can reduce damage to ecosystems and better coexist with natural habitats.

In Jamaica, a partnership between the Buoyant Foundation and the NGO CARIBSAVE has implemented initiatives informed by the amphibious housing approach in communities affected by floods (Ahmed, 2020)(**Appendix 2E**). The application of amphibious house retrofitting has been facilitated by the fact that houses in this area are often made of a single-story structure and wood frames, which requires less buoyancy to achieve flotation than masonry unit wall structures (Turner and English, 2015). Challenges include that such interventions can be expensive (US$1,500 or more in the context of the Buoyant Foundation project). They also do not protect houses under extreme weather conditions, such as coastal storms associated with high-speed waves. And even though retrofitting techniques facilitate the implementation of this approach, the process of lifting structures may affect the structural integrity of a house, especially if the house was not initially designed with elevation purposes in mind. Elevated structures may also pose challenges for residents with limited mobility.

2.6. Bamboo-based house structures

Bamboo has been used as a construction material since early times, though brick, concrete and steel have been preferred for safety and low maintenance. While greener and accessible options are being developed in masonry for the context of informal settlements (see for example TwistBlocks in Kenya; **Appendix 2G**), research shows that bamboo is increasingly being reconsidered as an ideal material to build with in many countries worldwide because of its desirable physical and mechanical properties (Cantos et al., 2019). It is an important resource for building houses because of its capacity to resist typhoons and other hazards. In zones affected by earthquakes, bamboo-reinforced houses have proved to better resist seismic forces. This was demonstrated during the earthquake that hit Ecuador in 2016 and led to the creation of an Ecuadorian bamboo building code (Witte, 2019). Bamboo is also recognized for its environmental credentials compared with industrialized materials because of its renewability and availability. A bamboo plantation can grow as much as 25 centimeters per day and can be harvested every three to five years (Gutu, 2013).

In the Philippines, bamboo is plentiful and yet not commonly considered a building material. The government of the Philippines has yet to implement mandatory regulations requiring the use of resilient and sustainable materials such as bamboo to build houses, although some incentives do exist (e.g., The Green Building Code). The not-for-profit organization Base Bahay Foundation Inc., or BASE Bahay, has developed "Cement-Bamboo Frame Technology" using locally grown bamboo (**Appendix 2F**). This technology aligns with other nonconventional approaches to build resilient and ecologically friendly homes. The prefabrication process conducted by BASE Bahay treats the bamboo to make it more resilient and upgrades its quality.

Major cultural, technical and economic roadblocks still need to be addressed to increase and improve the use of bamboo in construction (Archila et al., 2018). One challenge faced by the bamboo industry relates to perceptions of its impermanence, as it can decay rapidly with improper construction techniques that lead to minimal protection from rotting, fungal attack or termites (Witte, 2019). However, when sufficiently treated, bamboo can last over 100 years (ibid). The bamboo industry also faces market challenges due to logistical bottlenecks for structurally mature culms. For example, Guadua bamboo in Ecuador takes a long time to grow. It can take several years for culms to appear after planting. It reaches its full height at six months and gains structural maturity over a span of five years or more. Farmers are often paid based on culm diameter, leaving little incentive to wait for culms to mature. The result is a market filled with inferior "green" culms, bamboos that have not reached their full structural potential. Such issues are not uncommon in relation to engineered bio-based materials. To address this and support the sustainable scaling of bamboo supply, UNEP proposes the adoption of better regulations and other measures to ensure the transparency of the bamboo supply chain (UNEP, 2023).

2.7. Rainwater harvesting systems

Rainwater harvesting systems capture and store rainwater, usually from roofs, for domestic use. By providing a decentralized water source, rainwater harvesting systems help reduce reliance on freshwater supply systems that do not reach communities or can be particularly under pressure during drought periods. Collecting rainwater at home can save significant amounts of potable water and reduce the need for importing water, which can be costly and time-consuming. This approach can also reduce stormwater runoff from properties by diverting excess water. The elimination of runoff can reduce contamination of surface water with pesticides, sediment, metals and fertilizers.

Rainwater harvesting systems require installing a tank or cistern, which can come with upfront expenditures, and training to install and maintain the systems, notably to keep the tanks clean. Yet the longer-term economic benefits can be significant for households. The amount of water collected through rainwater harvesting systems depends on three factors: the roof area, local rainfall and storage capacity. In Semarang, Indonesia, a study highlighted how a household was able to save up to 20.5% of its total monthly cost of clean water through rainwater harvesting (Mukaromah, 2020) (**Appendix 2H**). Rainwater harvesting can also help save energy by reducing the use of water systems that require power (e.g., pumps used to pressurize water systems and water filtration and purification systems operated with electricity) (Chiu et al., 2009). In regions with moderate rainfall (20 inches/51 centimeters per year), a household with a large roof could collect up to 60,000 liters of water per year.

In the Middle East, where populations suffer considerably from water stress, rooftop rainwater harvesting is often considered a nonconventional but still reliable way to capture and store water. Experiences from Jordan and Lebanon show that such systems can reduce pressure on freshwater resources that struggle to meet demand –- in terms of both quantity and quality –- notably in relation to influxes of displaced populations, but also because of historical issues with water management. A study conducted in Jordan showed that up to 19.7% of potable water could be saved through rainwater harvesting (Abdulla and Al-Shareef, 2009). UN-HABITAT is one of the numerous actors supporting vulnerable communities in Jordan and Lebanon and has been implementing an Adaptation Fund project that includes rooftop rainwater harvesting in those communities (Appendix 2I). If appropriately scaled up, rainwater harvesting systems could support water provision beyond the household level and in schools and other public buildings such as mosques.

2.8. Waste-to-energy conversion with biogas technology

Biogas plants provide oxygen-free conditions that allow anaerobic digestion that turns organic waste into biogas and fertilizers. They help communities handle waste where waste management is limited. This is important where, for example, the lack of waste collection exposes communities to multiple risks during floods, when solid waste, sewage and gray water can spread and pose ecological and human health risks. Like other decentralized energy systems, energy production systems with biogas plants also help houses diversify energy sources and therefore reduce reliance on utility grids. Many small-scale biogas technology projects around the world have shown their great potential in managing waste while providing a sustainable form of energy production.

The waste used in biogas plants can be sewage sludge from community toilets, food scraps from local markets, and any feedstock that is available and meets the objectives of the biogas production. The biogas generated can be piped out of the digester for storage in gas storage tanks or containers. The stored biogas can be used to produce electricity and heat. Biogas has been used as a source of energy in informal settlements around the world (Agarwal et al., 2023). Small-scale biogas plants at the community level can produce several thousand kilowatt-hours of energy per year. Biogas can also be used for cooking and thereby replace traditional fuels like firewood and liquefied petroleum gas. During the digestion process, the solid residue left is a nutrient-rich digestate that can be used as fertilizer. This model also can significantly reduce carbon emissions (over 50% in some cases) through the rapid capture and valorization of waste from septic tanks and pit latrines, which create anaerobic conditions and typically produce a lot of methane (Johnson et al., 2022; Agarwal et al., 2023).

In Ghana, Safisana's circular model combines fecal sludge and organic waste treatment with the production of renewable energy, nutrients and water (Appendix 2J). Fecal sludge is collected from communities and organic waste from food markets, abattoirs and food processing industries at a recycling plant. The biogas is subsequently used to produce power to feed households and the national electricity grid. The residue from the digester is further used and composted into a nutrient-rich organic fertilizer. Biogas technologies require regular maintenance and monitoring (e.g., checking for gas leaks, maintaining temperature levels, etc.). These technologies require handling waste that, because of social acceptance implications, is one of the barriers that has limited their uptake in various contexts (Dumont et al., 2021). This model can be applied at different scales, but experience shows it has worked best when scaled up at neighborhood level (Kalina et al., 2022). If its governance aspects are well-deployed in partnership with different actors, it can benefit governments, utilities and food processing industries.

2.9. Rain gardens and bioswales

Rain gardens and bioswales are landscaped features designed to manage stormwater runoff. Rain gardens are depressed areas that function as bioretention systems infiltrating stormwater on site to prevent it from entering stormwater systems or other water bodies. Models have shown that rain gardens could capture and infiltrate a significant portion of rainfall, potentially reducing runoff by 30%-90% compared with impervious surfaces (Ishimatsu et al., 2017; Richards et al., 2015; Zhang et al., 2020). Factors influencing such performance range from soil properties to construction and design characteristics. Rain gardens can also act as natural filters and remove contaminants such as heavy metals, fertilizers and pesticides. Research shows that polyculture plantings (i.e., where more than one plant species is planted) can improve the performance of rain gardens in capturing runoff pollutants. This is particularly relevant in urban areas exposed to repeated flooding (Morash et al., 2019). In climates characterized by high discharges of heavy rainfall, rain gardens might not be sufficient to prevent flooding and could be constructed next to other drainage systems.

Similarly, bioswales are designed to slow down water flow to improve runoff management. However, unlike rain gardens, bioswales consist of redirecting runoff. Bioswales are usually designed to manage larger volumes of stormwater than rain gardens. Their design is typically linear, shallow and sloped. Bioswales usually follow the natural contours of a landscape. They are often integrated into wider drainage systems and built alongside streets — roadside ditches to capture and direct runoff over long distances. Bioswales can also filter and treat stormwater. Experience has shown that bioswale projects are less likely to succeed if done in isolation (e.g., Bioswale Research Project in Dieplsloot township in South Africa; de Groen et al., 2020).

Both rain gardens and bioswales require regular maintenance work. The most frequent maintenance is the disposal of garbage (e.g., plastic bags, cans, etc.), which can block channels and reduce the performance of these systems. This can constitute an important limitation in neighborhoods where solid waste management is a challenge.

The construction of rain gardens and bioswales can be expensive for individual households. Costs must cover plants and other landscaping components, such as sand and soil, rock and gravel, mulch and edging. Local governments and NGOs around the world have tried to address this by providing financial incentives. In Canada, the nonprofit organization EcoSuperior has developed a rebate program to support households in areas exposed to flooding (Appendix 2K). The program has attracted an increasing number of households over the past three years. Yet an important question remains on how the rebate model could be applied elsewhere to support the uptake of such solutions in other socioeconomic contexts.

2.10. Permeable pavements

Informal settlements often lack adequate stormwater drainage systems, leading to flooding, waterlogging and unsanitary conditions during heavy rains. Permeable pavements, made from materials such as pervious concrete or interlocking pavers, allow rainwater to infiltrate the ground, reducing the risk of flooding (typically between 50% and 70%) (Zhu et al., 2019). They also help conserve scarce water resources by allowing rainwater to recharge the groundwater and trapping certain pollutants. Moreover, these pavements are relatively cost-effective and can be installed without advanced engineering skills, making them suitable for low-resource contexts. The approach followed by the company Terraforce with its “terracrete” pavers illustrates this well. In Langrug settlement in Franschhoek near Cape Town, South Africa, the company has laid permeable, interlocking, concrete terracrete blocks over a 1,000-cubic-meter surface to drain and filter water (Mseleku, 2021)(Appendix 2L). This is part of a wider water management system that also uses gray water disposal points linked to underground pipes feeding miniature wetlands and tree gardens, which filters pollutants before reaching the municipal sewer system.

Despite their benefits, permeable pavements also come with limitations. Several technical considerations need to be taken into account when implementing permeable pavements in informal settlements. The choice of permeable pavement material, construction techniques and maintenance are critical factors. Local soil conditions should be assessed to ensure proper infiltration and drainage. Routine maintenance, including debris removal and occasional vacuuming, is essential to prevent clogging and maintain the pavement’s permeability. Furthermore, these pavements may not be suitable for high-traffic areas, as they have reduced load-bearing capacities compared with traditional asphalt or concrete pavements.

In areas with high groundwater contamination, permeable pavements may not be suitable because of infiltrated water mobilizing pollutants. Moreover, the initial cost of installation can be higher than traditional pavements, which might pose a financial challenge for informal settlements. Inadequate maintenance can lead to reduced permeability over time, diminishing their effectiveness. Nevertheless, with proper planning, community engagement and tailored solutions, permeable pavements can play a vital role in improving living conditions and resilience in informal settlements, addressing the unique challenges these communities face.

2.11. Tree planting

Where forests are degrading, populations lose access to important ecosystem services that range from providing a cooling effect to capturing pollutants, reducing the impacts of winds, reducing flood risks and helping manage water resources more widely. Urbanization often goes hand in hand with losses in canopy cover. Remaining trees in cities and towns are therefore valuable assets for climate adaptation, even at the very local scale. Studies have shown that a single tree along a city street or in a backyard can provide measurable cooling benefits, for example by providing shade (Vo and Hu, 2021). Temperatures in urban areas with trees can decrease by several degrees compared with areas with fewer trees. Urban street trees can provide many resources to the inhabitants of cities. In New York City, 88% of the tree species present –- including 9 out of 10 of the most common species –- are forageable for medicine, food and other livelihood aspects (Hurley and Emery, 2018).

Forest dynamics, species composition, soil dynamics, and the costs of planting and managing designed spaces are important variables in urban forest outcomes and must inform urban planting practices for successful planning and management (Oldfield et al., 2013). Specific regulations might also prevent tree planting, or landowners might not allow it. Individuals do not necessarily have the incentives to plant and maintain trees either because of the potential maintenance costs they require. The most promising environmental and health impacts of urban trees are those that can be realized with well-stewarded tree planting and tailored local interventions at site to municipal scales (Pataki et al., 2021). Collectively, individual tree planting efforts by households can contribute to reversing biodiversity loss and meeting broader climate adaptation goals by reducing the overall temperature in the settlement, enhancing resilience against extreme weather events, and combatting urban environmental challenges such as flooding, high temperatures and air pollution.

In Sierra Leone's capital, Freetown, 70% of forest loss has reinforced the impacts of climate hazards (Appendix 2M). In 2017, floods and landslides sweeping through the city led to the loss of nearly 1,000 lives. Since then, the city has taken considerable climate actions. Among them, the "Freetown the Treetown" campaign has contributed to reversing deforestation and increasing canopy cover by planting 1 million trees by 2024. Through efforts to deploy participatory approaches, the Freetown City Council, which is leading the initiative, has developed a stewardship program (the "pay-to-grow" scheme) to support households willing to adopt and plant trees in their backyards. Individual households willing to join the initiative have been able to receive financial compensation. The initiative functions with tokens sold on private and carbon markets. To ensure the long-term success of the initiative on both the social engagement and ecological sides, an online platform was developed to track the survival rates of trees. The city is currently on course to meet its target, and the survival rate of trees already planted is currently between 95% and 99% (2023a, 2021).

3. Accompanying approaches that support the implementation of solutions

The design, implementation and management of green solutions for housing in the context of informal and vulnerable settlements presents a multifaceted challenge that necessitates a deep understanding of the underlying conditions that shape communities. It is important to stress that the interventions for housing in the context of informal settlements listed in the previous section do not constitute a "sustainability fix'' on their own and need to be approached based on their context of implementation. Non-infrastructural approaches must accompany the implementation of these technical solutions as facilitating mechanisms that guarantee ecologically sustainable and socially just outcomes. Integrated approaches are essential to avoid short-term benefits turning into long-term problems. They must prevent the introduction of new patterns of vulnerability and support transformative change while contributing to long-term resilience-building.

Hybrid approaches can best address social and environmental needs in informal and vulnerable contexts.

Hybrid strategies mean that "green" techniques often need to be accompanied with "gray" techniques, allowing the adoption of greener strategies to be incremental. Integrated approaches can help reconcile potential tensions between urgent needs (e.g., access to basic services such as water, sanitation, energy, etc.) and longer-term needs (e.g., reduction of households' carbon footprint). Hybrid green-gray infrastructure systems can help navigate constraints of space in informal settlements while meeting multiple needs and aspirations in communities. Upgrading strategies that integrate green solutions also call for multisectoral approaches, for example with partnerships among the construction, housing, water and sanitation, and energy sectors (Mulligan et al., 2020).

Green solutions are most relevant when they consider the provision of ecosystem services at multiple scales.

Some of these techniques consist of deploying direct interventions onto housing structures (e.g., green roofs), and others are meant to be applied in the environment around houses (e.g., rain gardens). This is to align with the concept of green infrastructure and one of its core pillars, which revolves around the idea of connectivity (Diep et al., 2019). This recognizes that elements flow within and across dynamic ecosystems in order to contribute to the ecological health of wider ecosystems. The list of proposed techniques aims to suggest arrays of solutions that can be implemented in combination with each other in order to support multiple aspects of the housing environment and eventually create change at the community level, the neighborhood level and beyond.

Securing land tenure rights is also part of climate adaptation action.

The context of urban informality means that many barriers stand between residents of a settlement and the home interventions they want to make. Ultimately, securing land tenure constitutes one of the best ways to support housing and climate adaptation in informal settlements. Once land tenure is secured, residents with those rights are most likely to invest in their homes and communities, including by adopting green housing practices. They are more willing to make long-term improvements and investments in their properties, knowing that the risks of eviction and loss of assets will be lower. Furthermore, securing land tenure can facilitate access to financial resources such as loans and grants, which are crucial for implementing green housing solutions. Financial institutions are more likely to provide loans to property owners with formalized land rights, enabling them to invest in green infrastructure and upgrades. Local governments can work with informal settlement residents to formalize land rights through tenure regularization programs. This involves recognizing and documenting land ownership or occupancy through titles, leases or other legal instruments.

Managed resettlement as part of adaptation strategies must come with fair negotiations and compensations.

Authorities tend to resist providing residents of informal settlements with land tenure rights in areas that are exposed to climate hazards, are ecologically sensitive, or are considered in need of ecological protection. At the same time, these are the areas where many people are forced to live because of overpriced housing markets. Informal settlements around the world have also commonly been located on sites considered essential to creating barriers against hazards. For example, floodplains are essential buffer zones against floods, but they become contentious places where the right to affordable and safe housing clashes with flood risk mitigation. Informal settlements can both accommodate space for housing and maintain the provision of ecosystem services. Yet, where fair assessments of conditions indicate that risks are too high, only then should “managed resettlement” or “managed retreats” approaches be considered (Doberstein, 2019; Roquet et al., 2017). Conventional acquisition tools such as voluntary buyouts, land swaps, community conservation land trusts and leasebacks may not work in informal settlements where title deeds are not granted. Managed retreats can help provide fair compensation and access to safer housing solutions, as they require negotiation processes for different parties to agree on decisions such as the location where residents will move after the retreat, and the financial compensation that will be provided to them for resettling.

Community engagement is a key underlying requirement.

Participatory approaches are invaluable in this context. Involving the community in the design and implementation of greening techniques not only ensures that the solutions are culturally and contextually appropriate but also fosters a sense of ownership and responsibility, leading to more sustainable and resilient housing in informal settlements. These participatory approaches not only address the underlying conditions but also contribute to building community resilience and social cohesion, further enhancing the value of green housing strategies in the context of climate adaptation. Considering the historical lack of political power and participation marginalized communities have faced, participatory structures allow for empowered engagement in decision-making processes. Such approaches also help address potential tensions, like maintenance responsibilities crucial to the sustainability of green home solutions.

Collaboration and partnerships make the adoption of green home solutions more attractive and sustainable.

Collaborations and multi-actor partnerships can help considerably to address the multifaceted challenges of informal settlements, including efforts to improve access to tenure and basic services. Partnerships across public and private spheres; across governmental levels and sectors; and with civil society that includes young people, Indigenous populations and other marginalized individuals will facilitate the adoption, implementation and management of green home solutions. This is essential for knowledge management and data while creating a space for exchange and learning.

4. Considering trade-offs and knowledge gaps

Greening interventions alone do not inherently lead to win-win solutions in informal settlements. It is important to highlight that interventions implemented in informal settlements require special attention to unintended consequences and tradeoffs between existing vulnerabilities. Examples abound of well-intended initiatives that introduce new risks, such as added stigmatization of residents of informal settlements. This section calls attention to the fact that when interventions do not consider local voices and dynamics, they can easily result in maladaptation and in the creation or reinforcement of vulnerability.

4.1. Disrupted livelihoods

Climate-focused interventions may not align with the conditions of local populations and can disrupt livelihoods and increase risks, especially if residents are not consulted during planning and implementation processes. Green interventions around the world have shown that ecosystem conservation programs could deprive communities who live in proximity to them from important sources of livelihoods. For example, mangrove protection policies can affect communities where households rely on firewood from mangroves to cook, and watershed restoration programs can prevent farmers from pursuing agricultural activities. This is why it is important to adopt integrated approaches that consider trade-offs, identify ways to manage the emergence of ecosystem disservices, and propose alternative solutions for affected groups (Adegun, 2017).

4.2. Economic burdens

While green housing strategies should offer cost-effective solutions, they may still introduce or exacerbate economic burdens if they are not adequately supported by inclusive governance structures. For example, if the costs of installing solar home systems or maintaining green roofs are too high for residents, economically marginalized households may either be left without access to these benefits or suffer from additional economic costs. There are ways to avoid making households bear all capital and maintenance costs that can be fully or partly covered by governmental or nongovernmental entities.

4.3. Involving private actors

The mainstreaming of green home solutions might be prevented by market barriers because they represent financial risks preventing lenders from funding business models (e.g., solar home systems, biogas technologies). Through institutional models such as public-private partnerships, shortcomings of both the public and private sectors may help or hinder the outcome. Evidence of such partnerships facilitating the inclusion of multiple actors is mixed (Dodman et al., 2022). The evaluation of private-led housing projects has shown that the prioritization of profit may have detrimental impacts on the resilience of communities. However, the involvement of the private sector is also necessary, notably because private companies continue to be major producers of greenhouse gas emissions, land conversion and resource extraction, and climate action cannot occur without addressing these issues (Acolin and Hoek-Smit, 2020; Greenwalt et al., 2023).

4.4. Gentrification

Countless contexts of urban informality around the world have seen the introduction of green interventions lead to increases in real estate values and decreased access to affordable housing (Dodman et al., 2022). Such consequences have resulted in what has been qualified as ecological gentrification. Most importantly, it is crucial to reiterate that displacement, relocation or evictions in the name of climate adaptation do not constitute acceptable solutions as they increase socio-ecological vulnerability (Anguelovski et al., 2016; Henrique and Tschakert, 2019).

4.5. Key lessons

To successfully introduce housing-specific techniques for climate adaptation, it is crucial to address the underlying conditions that hinder their implementation. Without addressing these fundamental issues, any efforts to green informal settlements may fall short of their intended goals.

The examples of technical interventions and supporting approaches to simultaneously tackle housing improvements and climate adaptation in informal settlements all come with multiple benefits and challenges from which key lessons can be drawn:

- **Considering the economic costs of implementation increases the prospects of success.** Examples show that a range of options can be deployed by governments, CBOs and NGOs to financially support households to cover upfront costs for implementation. These options range from providing subsidies (e.g., to manufacturers, vendors and end users of solar home panels, bamboo structures and building blocks) to supporting community trusts and cooperative credit schemes (e.g., Mahila Housing Trust’s credit schemes for insulated roof panels and solar-reflective paint). NGOs can also act as intermediaries between financing institutions and communities and even help scale up interventions (e.g., by purchasing bulk material).
- **Some techniques may require specific support or technical guidance to be effective.** In the case of interventions like bamboo-based house structures, reusable building blocks and biogas plants, small and medium enterprises, or SMEs, are best-placed to provide such support. In the case of integrated waste-to-energy conversion systems (e.g., Safisana’s), more effective outcomes are ensured when multiple households are aggregated and operate at larger scales. To best support these, SME operators require an enabling regulatory and supporting market environment for access to financial schemes and to best create partnerships. As seen with the case of Arará in Rio de Janeiro, direct partnerships between researchers and community residents can also be instrumental in filling knowledge gaps.
- **Operations and maintenance requirements must not be overlooked.** The Freetown City Council's campaign illustrates successful deployment of a stewardship program that helps monitor the progress of a large-scale tree planting initiative. The program provides financial support to households willing to adopt and plant trees, and accompanies them in monitoring their growth. Nevertheless, sustaining the long-term management of interventions remains a recurring challenge, and monitoring comes with costs and time investments that represent a burden to many households.
- **Local urban plans and building codes can facilitate the adoption of adaptation strategies.** Households in informal settlements are legally constrained in terms of interventions to their homes and neighborhoods. Yet, where urban plans and building codes are adopted in ways that allows the implementation of adaptation strategies (e.g., rainwater harvesting, rain gardens and permeable pavements), co-benefits at multiple scale can emerge.

5. Policy implications and recommendations

5.1. U.N. agencies and multilateral financing entities

Mobilize financial resources that support housing strategies for climate adaptation.

Donor countries, U.N. agencies and multilateral actors must mobilize or allocate funds for climate adaptation to support green housing strategies for informal settlements. This includes increasing funding foreign assistance flows for the implementation of programs as well as capacity building, data production, knowledge exchanges on successful practices, and investments in learning from current local practices and innovations. Existing funds, including the Green Climate Fund and the Adaptation Fund, also need to more specifically support informal settlements.

Facilitate access to green housing finance for adaptation projects by local governments and community-based organizations.

Financing entities need to make green financing more easily accessible to actors on the ground through various mechanisms, such as concessions to governments, low-interest loans and microfinance options to SMEs, pay-as-you-go systems to households, community investment funds and community trusts. There is a particular need for more direct ways to ensure that funds reach the most vulnerable locally led initiatives (e.g., by supporting the establishment and management of community-led financing schemes). This is particularly important for solutions (e.g., solar home systems) that are more effective and sustainable if implemented as a result of group actions.

Advocate for targeted support to green housing solutions in informal settlements.

The international development community should encourage actions that prioritize the specific needs of informal and vulnerable settlements across climate resilience, urban development and housing policies and programs. U.N. agencies and multilateral entities have a unique platform to help recognize and support ongoing adaptation initiatives that are locally led, including autonomous investments made by local communities, to adapt to climate change. Supporting local efforts can often lead to more sustainable and just outcomes than deploying new top-down interventions that can create conflicts on the ground.

5.2. Governmental entities

Adopt policies and regulations that facilitate integrating adaptation solutions from households and settlements.

Authorities need to develop, extend or adjust land-use, zoning policies and building codes to facilitate the integration of adaptation efforts by households and organized communities. Such standards can be set with experts from the scientific community, including guidelines by UN-HABITAT, GlobalABC and the Sphere Humanitarian Standards. This is particularly important for interventions such as solar panels, green roofs, rainwater harvesting systems, rain gardens and bioswales that can be deployed in both private and public spaces. Regulations in place must be more flexible and create incentives to encourage climate-minded retrofitting and incremental construction. Policies and regulations need to encourage the long-term monitoring and evaluation of implemented solutions, including those that are incremental, to ensure continued adaptation to changing threats, hence preventing maladaptation.

Provide financial incentives to households, community-based organizations, and small and medium enterprises to adopt greener adaptation solutions.

Governance at all levels should promote financial incentives to facilitate the adoption of greener solutions at the household and community levels, particularly those that require high upfront costs and offer greater reductions to climate vulnerability. For example, providing tax breaks or rebates on concessional loans to facilitate the installation of insulated roof panels by households, extending subsidies to manufacturers to drive down the prices of infrastructure and materials, or offering subsidies to service providers to facilitate conversions and technical support. Other incentives can be offered directly to community-based organizations to build their capacity to implement solar home panels, green roofs or rainwater harvesting systems.

5.3. Housing actors

Community-based organizations can champion and support the adoption of green housing solutions for climate adaptation by their members

With the right support, CBOs have a unique opportunity to encourage their members to adopt initiatives and accompany them through the design, construction, implementation and operation. For example, community-based organizations can purchase rainwater tanks or cisterns in bulk. For this, CBOs can establish community funds and co-op credit schemes to guarantee the effective implementation of adaptation initiatives. They can also initiate the development of solutions such as rain gardens and biogas plants, and then encourage residents to get involved in their management. CBOs can use available data, research and knowledge to identify likely climate impacts in specific settlements and integrate appropriate technologies that will adapt to higher temperatures, increased flooding, drought, and other climate impacts. In general, CBOs can act as knowledge brokers gathering information from local practices and helping finance institutions make informed decisions to prioritize investments. This role may also involve developing locally accountable ways of assessing the success of adaptation measures at the community level (making sure measures deemed successful are understood, practiced and sustained).

Small and medium enterprises should prioritize ecological and ethical responsibility while ensuring safety and respect of regulations.

Small and medium enterprises need to ensure that safety measures are respected and that materials with limited carbon footprint are used for the deployment of housing and settlement solutions. This includes ensuring that solar home panels are adequately installed and maintained, that green roofs are appropriately installed so that they do not collapse, and that bamboo material is adequately processed to make sure it resists extreme conditions. Where possible, SMEs should be encouraged by other housing actors, donor agencies and governments to use local materials to minimize their ecological footprint and mobilize local labor to support local economies.

Nongovernmental organizations can be advocates of the effective climate adaptation of informal settlements.

The NGOs acting as housing practitioners, stakeholders and influencers should use their voice to advocate for an enabling environment for adaptation through housing for people living in informal settlements. This must be accompanied by policy and regulatory environments conducive of upgrading and ultimately supporting transformative change in informal settlements. This includes efforts toward the legal recognition of informal settlements and helping residents increase their tenure security, which will ensure the protection of their housing investments. Where this is not possible, they can help negotiate relocation (including in the context of managed retreats) so that community members can use their political voice and receive appropriate compensation.

Acknowledgments

This report was commissioned by Habitat for Humanity under the supervision of Maria Carrizosa, Amanda Entrikin and Rebecca Ochong. The author would like to thank the following contributors for their inputs: Puja Sawhney, Brenda Perez, Anja Van Der Watt, Carly Kraybill, Dana Choi, Jacob Simwero, Grace Ananda, Saurabh Rao, Iwona Bisaga, Veronica Olivotto, Georges Mikhael, Erich Wolff and Bart Orr.

Appendix 1: Summary of adaptation techniques at the housing level and their characteristics

Solar home systems

Description	Decentralized energy solutions designed to capture solar power and store it in batteries or use it directly to power lights, appliances and other electrical devices.
Adapt to what?	Events that overload centralized power systems and create risks of power outages (e.g., storms, droughts, heavy rainfalls).
Environmental benefits	• Access to renewable energy. • No emission of greenhouse gases.
Further co-benefits	• Provision of an energy source independent from centralized electric grids. • More efficient energy consumption. Cost savings. • If grid-tied, households can earn credits for excess electricity.
Examples of evidence of success	A home solar PV plant system with a 1kWh unit and a 2-3 kWh battery in a location with good sunlight can produce 3-4 kWh of electricity per day (see NREL calculator).
Common challenges to households	• Important upfront costs for batteries and panels. • Need to be installed on stable roofs, where panels are not blocked by shadow. • Might be insufficient for all households' needs.
Examples of implementation	Casa Pueblo's microgrid in Adjuntas, Puerto Rico.

Insulated roof panels

Description	Panels installed on roofs to block heat from entering homes in summer and hold heat indoors during cold seasons.
Adapt to what?	Extreme temperatures.
Environmental benefits	• Reduced energy demand. • Use of natural materials (e.g., coconut husk). • The modular aspect of panels makes them reusable.
Further co-benefits	• Modular structures mean they can be adapted to different types of plot configurations. • Lightweight. • Safer alternative to asbestos.
Examples of evidence of success	Tests conducted with ModRoof's panels showed indoor temperature was reduced by 8 degrees Celsius (Tewari and Singh, 2021).
Common challenges to households	Upfront costs (ModRoof systems cost between US$1,100 and US$1,400).
Examples of implementation	ModRoof's ReMaterials panels and Mahila Housing Trust co-operative credit scheme in Ahmedabad, India.

Solar reflective paint

Description	Use of solar-reflective white paint on the outer surfaces of buildings to help reduce indoor temperatures.
Adapt to what?	Heat stress.
Environmental benefits	Helps reduce energy consumption.
Further co-benefits	• Low-cost. • Easily applicable.
Examples of evidence of success	A test conducted in an informal settlement showed that a painted roof was 1 degree Celsius cooler than uncoated tin roofs (Vellingiri et al., 2020).
Common challenges to households	• Limited effectiveness. • Requires reapplication on a regular basis. • Some paints contain VOCs, which can be harmful.
Examples of implementation	Mahila Housing Trust in Ahmedabad, India.

Green roofs

Description	Passive design features of vegetation surfaces applied to a waterproofing layer of a roof build-up.
Adapt to what?	• Heat stress. Urban heat islands. • Flood risks.
Environmental benefits	Increased biodiversity.
Further co-benefits	• Provision of spaces for recreation and education. • Supporting food production.
Examples of evidence of success	Up to 55% of cooling energy reduction in climate zones with hot summers (He et al., 2023). They can also reduce runoff rates from roofs by up to 65% (GSA).
Common challenges to households	• Require adequate design for houses that cannot stand heavy layers. • Require maintenance. • Resistance is poor in water-scarce climate zones.
Examples of implementation	Teto Verde Favela, Arará settlement in Rio de Janeiro, Brazil.

Elevated houses

Description	Adding foundations to a house using a retrofitting approach that allows the house to elevate as water levels rise, thereby protecting its structural integrity.
Adapt to what?	Floods and sea-level rise.
Environmental benefits	• Reduce pollution during flood events. • The use of amphibious foundations can allow habitat preservation. • Certain techniques use environmentally friendly materials.
Further co-benefits	Less disruptive to residents' everyday lives, as residents can remain in their house during hazards.
Examples of evidence of success	Floods have less impact on amphibious retrofits than houses with permanent static elevation. In the U.S., cost comparisons show that amphibious retrofits cost 33% to 50% less than permanent static elevation (English et al., 2016).
Common challenges to households	• Upfront costs. • Largely limited to house structures that already allow elevation. • Not adequate to hazards such as hurricanes. • Limited solution over time.
Examples of implementation	Buoyant Foundation and CARIBSAVE's amphibious housing project in Jamaica.

Bamboo-based house structures

Description	Use of bamboo as a structural element in building frames to make them disaster-resistant and more ecological.
Adapt to what?	• Storm events (e.g., hurricanes, typhoons, etc.). • Fires.
Environmental benefits	• Use of renewable, durable and biodegradable material. • Reduced carbon footprint.
Further co-benefits	• Resistance to seismic forces. • Lower costs than "conventional houses."
Examples of evidence of success	More than 300 houses built in the Philippines by BASE Bahay with Habitat for Humanity using cement-bamboo frame technology have all withstood Category 5 typhoon Odette/Ray.
Common challenges to households	Bamboo material that is not fully grown and/or adequately treated can be prone to failure, rotting, fungal attack or termites.
Examples of implementation	BASE Bahay's Cement-Bamboo Frame Technology in the Philippines.

Rainwater harvesting systems

Description	Systems made with a tank or cistern that captures rainwater (usually from roofs) and enables households to store it.
Adapt to what?	Droughts and other forms of water stress.
Environmental benefits	• Reduced reliance on freshwater resources. • Water conservation.
Further co-benefits	• Provision of an independent and additional source of water. • Cost savings.
Examples of evidence of success	In regions with moderate rainfall, households with large roofs (~1,000 square feet) could collect on average up to 60,000 liters of water per year.
Common challenges to households	• Technical support to install systems. • High maintenance. • Regulations and permits are sometimes required.
Examples of implementation	• ACCCRN in Semarang, Indonesia. • UN-HABITAT in Jordan and Lebanon

Waste-to-energy conversion with biogas technology

Description	Converting waste into energy with biogas technologies through anaerobic digestion processes.
Adapt to what?	• Events putting pressure on energy systems. • Flood risks.
Environmental benefits	• Reduced carbon emissions through the capture and valorization of human waste. • Renewable source of energy (e.g., for cooking). • Can be part of circular models (e.g., water-energy-food nexus).
Further co-benefits	• Alternative form of energy. • Provision of byproducts such as fertilizers that can be used for food production purposes.
Examples of evidence of success	• Small-scale biogas plants at community level can produce several thousand kWh of energy per year. • Reduced carbon emissions can be as high as 50% (Johnson et al., 2022).
Common challenges to households	• Technical skills are required. • This solution is more effective if integrated into wider, large-scale systems (e.g., of waste collection at community level). • Waste handling has safety and social acceptance implications.
Examples of implementation	Safisana in Ashaiman, Ghana.

Rain gardens and bioswales

Description	Rain gardens are bioretention systems that infiltrate stormwater on-site. Bioswales slow down the flow of water before redirecting it to drainage systems.
Adapt to what?	Flood risks.
Environmental benefits	• Water treatment. • Groundwater replenishment. • Water conservation. • Increase in biodiversity.
Further co-benefits	Provide spaces for recreational and aesthetic purposes.
Examples of evidence of success	Rain gardens could reduce runoff by 30% to 90% compared with impervious surfaces (Richards et al., 2015; Ishimatsu et al., 2016; Zhang et al., 2020).
Common challenges to households	• Require design and construction skills. • Specific materials are needed (e.g., layers of soil, sand, organic mulch). • High maintenance. • Implementation in shared spaces might require permits.
Examples of implementation	EcoSuperior rebate program in Thunder Bay, Canada.

Permeable pavements

Description	Pavements made from materials like pervious concrete or interlocking pavers, which allow water to infiltrate the ground.
Adapt to what?	Flood risks.
Environmental benefits	• Reduction of pollutants. • Groundwater recharge.
Further co-benefits	• Cost effective. • Relatively easy to implement. • Can align with the development of pathways and driveways.
Examples of evidence of success	Permeable pavements can reduce surface runoff by more than 50% while reducing flood peaks (Zhu et al., 2019).
Common challenges to households	• Require routine maintenance. • Not suitable to all types of soils.
Examples of implementation	Terraforce in Franschloek, South Africa.

Tree planting strategies

Description	Planting of trees at scale to reverse biodiversity loss and increase resilience to climate hazards.
Adapt to what?	• Flooding. • Extreme temperatures. • Landslides. • Erosion. • Drought.
Environmental benefits	• Carbon sequestration. • Conservation and restoration of forests (including with native species).
Further co-benefits	• Creation of green jobs along the value chain. • Stewardship. • Increased awareness, particularly where done through participatory approaches.
Examples of evidence of success	Freetown has planted 700,000 trees (2023) with a survival rate above 95%. Full ecosystem services from trees planted during the initial years of the campaign will come once they are more established.
Common challenges to households	• Permission to plant trees around houses. • Maintenance costs are often disregarded.
Examples of implementation	“Freetown the Treetown” campaign in Freetown, Sierra Leone.

Appendix 2: Project examples

A. "Energy oasis" powered by solar home systems — Casa Pueblo, Adjuntas, Puerto Rico

- **Type of adaptation measure:** Adaptation to hazards putting pressure on energy systems (e.g., hurricanes, storms).
- **Environmental benefits:** Use of renewable energy; energy-efficiency.
- **Further co-benefits:** Independent from the "main" grids, reliable, scalable and cost-effective.
- **Challenges:** Costs; resilience of the structure itself (including the roofs on which panels are mounted); battery components can have a limited life**.**

In 2017, Hurricane Maria hit the island's central power system and plunged the population into darkness. But electricity supply continued in the mountain town Adjuntas, where the nonprofit and community center Casa Pueblo had installed solar home systems. Referred to as an "energy oasis," the community let people come to power medical devices and charge their phones while the rest of the island was experiencing a long-lasting blackout (over six months for some parts of the island). The system of microgrids has thereby proved resilient to shocks. It is important to note, however, that such systems are only as resilient as the roofs on which they are mounted. Some systems blew away during the storms. Maintenance and repairs are also important factors influencing the success of such approaches. Batteries need to be replaced every five to 10 years, depending on the type. Unless households are eligible to access support programs, they usually must bear the maintenance and repair costs.

More information: *Massol-González et al. (n.d.); Mignoni (2018).*

B. Co-operative credit scheme for insulated roof panels — Mahila Housing Trust and ReMaterials, Ahmedabad, India

- **Type of adaptation measure:** Adaptation to extreme temperatures.
- **Environmental benefits:** Made from cardboard waste and natural binders, reusable.
- **Further co-benefits:** Lightweight, provides insulation, healthier than commonly used asbestos sheet.
- **Challenges:** Costs of panels; maintenance and repairs.

ReMaterials developed modular systems of lightweight panels made from cardboard waste combined with natural binders (coconut husk) and coated with a waterproof layer. Their structure provides insulation that helps keep heat out and significantly reduces the indoor temperature by as much as 16 to 18 degrees Fahrenheit (8 degrees Celsius), improving habitability and health in increasingly hot climates. ModRoof is designed to be an alternative to the asbestos cement sheets frequently used among low-income communities. The company has already installed 150,000 square feet of its product. As 90% of ModRoof is recyclable at the end of its life, with a 25% to 30% resale value, it supports circular economic practices in construction. Households have been supported by a co-operative credit scheme managed by a group of women called the Mahila Housing Trust, or MHT, which provides loans of US$1,100 to US$1,400 to families. By facilitating the connection between households and vendors, the initiative has supported the purchase of 30,000 products while receiving commissions to support livelihoods.

More information: *Chandraby (2020); Oomen (2022); Tewari and Singh (2021).*

C. Solar-reflective paint — Mahila Housing Trust, Ahmedabad, India

- **Type of adaptation measure:** Adaptation to heatwaves.
- **Environmental benefits:** Reduced energy consumption.
- **Further co-benefits:** Low-cost technique.
- **Challenges:** Limited efficiency.

In informal settlements of Ahmedabad, the use of solar reflecting paint on houses has helped households resist heat. The use of solar-reflective white paint on walls or roofs is a simple solution that keeps the heat from penetrating buildings and lowers indoor temperatures. The initiative is supported by Mahila Housing Trust (similarly to ModRoof insulated roof panels), which has helped reduce the mean ambient temperature of solar reflective paint-coated tin roofs. A study showed that roofs with the paint had a surrounding temperature of 33.5 degrees Celsius, plus or minus 1.12 degrees. This was 1 degree lower than the uncoated tin roof, which had a mean temperature of 34.6 degrees Celsius, plus or minus 0.87 degrees. Mahila Housing Trust has also painted 13 traffic booths in Ahmedabad. As a result of its advocacy work, the municipal authorities have also agreed to provide the trust with land to make a bus station with a white cool roof.

More information: *Vandana (2023); Vellingiri et al., (2020).*

D. Cooling houses with green roofs — Teto Verde Favela and UFRJ, Parque Arará, Brazil

- **Type of adaptation measure:** Adaptation to extreme temperatures.
- **Environmental benefits:** Energy efficiency, reduction of stormwater runoff, supporting biodiversity.
- **Further co-benefits:** Reduction of stormwater runoff.
- **Challenges:** Heavy weight, financial costs, maintenance requirements.

Rio de Janeiro is a city with more than 1,000 informal settlements known as "favelas." Many homes in favelas suffer from extreme heat, which leads to health issues that range from dehydration to heat strokes. House roofs in Rio's favelas are commonly made of asbestos tiles or corrugated steel sheets, which conduct extreme heat. In the Parque Arará favela, however, households have installed green roofs to control and mitigate the heat island effect. The development of specific techniques and materials has been required to help house structures support the weight of green roofs. A civil engineering researcher from the Federal Rural University of Rio de Janeiro has helped the founder of the nonprofit Teto Verde Favela design lightweight green roofs with nonwoven geotextile made of polyester from recycled drink bottles. The selected plants are adapted to solar exposure and high wind and require low maintenance. While further long-term monitoring will be required to assess detailed performance, the tested green roof appears to have demonstrated lower temperatures than those around nearby houses. Costs could also be reduced because of the materials used (US$1 per square foot compared with US$11 for conventional green roofs). While the municipal government of Rio has incentivized the installation of green roofs, there is a need for more legal and financial incentives supporting their implementation.

More information: *Langlois (2023); Silva (2016).*

E. Elevated houses — Buoyant Foundation's amphibious houses, Jamaica

- **Type of adaptation measure:** Adaptation to floods, sea-level rise.
- **Environmental benefits:** Preservation of aquatic and marine habitats.
- **Further co-benefits:** Amphibious designs can be more cost-effective than static elevation designs; minimized disruptions to residents' everyday lives during floods.
- **Challenges**: High upfront economic costs; not sustainable over the long term.

Amphibious foundations are structures that make houses built near water more resilient to floods and other climate risks such as sea-level rise. They allow elevated houses to adapt to changing water levels — floating when water levels rise and going back to their original structure when water levels drop. Amphibious housing approaches have been implemented in North America, Europe and Asia. The Buoyant Foundation has partnered with the NGO CARIBSAVE to apply the approach to vulnerable communities in Jamaica. Among several factors, wood-framed structures in the communities where amphibious housing designs were implemented facilitated the retrofitting (as opposed to those with concrete masonry unit structures on concrete slabs), notably because light weight required less buoyancy material. Nevertheless, the costs of amphibious housing retrofitting remain high (the Buoyancy Foundation technique costs US$1,500 or more), meaning such interventions can be limited in some contexts. Other limitations include that this is not adapted to coastal areas with high-intensity waves.

More information: *Turner and English (2015); English and Turner (2016); Ahmed (2020).*

F. Resilient house structures reinforced with bamboo — Base Bahay Foundation's Cement-Bamboo Frame Technology, Philippines

- **Type of adaptation measure:** Adaptation to storms, seismic risks, fires.
- **Environmental benefits:** Reduced footprint; long lasting; renewable material.
- **Further co-benefits:** Low cost.

- **Challenges**: Poor resistance to shocks and durability (e.g., attracts insects and fungus) if not fully mature or not treated properly.

Bamboo is considered a promising resource because of its environmental credentials in comparison with industrialized materials, along with its capacity to resist winds and other shocks and stresses. Despite being a plentiful material in the Philippines, bamboo is not commonly considered as a building material given the challenges faced by the construction sector with pests. BASE Bahay has developed a strategy to build housing structures referred to as "Cement-Bamboo Frame Technology." The prefabrication process conducted by BASE Bahay treats the bamboo to make it more resilient and upgrades the quality. While the Philippines government has not yet implemented mandatory regulations requiring sustainable practices such as BASE Bahay's, some incentives do exist. BASE Bahay reports that almost 1,000 of its inhabited houses have survived numerous extreme events, including 322 built with Habitat for Humanity that withstood Category 5 Typhoon Odette (also known as Rai) in 2021.

More information: *Base Bahay, Inc (n.d.); E4C (2022); TCIS (2023).*

G. Reusable concrete building blocks — Start Somewhere's TwistBlocks, Nairobi, Kenya

- **Type of adaptation measure:** Adaptation to fire, seismic risks.
- **Environmental benefits:** Reusable.
- **Further co-benefits:** Low-cost, modular.

The production facility TwistBlocks, based in Nairobi, Kenya, developed a precast hollow concrete block technology that is affordable and resists fire and seismic risks. Because TwistBlocks require no mortar, walls can be dismantled to accommodate additional rooms, and the bricks can be reused for the new construction. The design was made in response to the small, irregular plot sizes of settlements like Kibera (Kenya's largest informal settlement), which makes the optimization of floor plans and construction quality challenging. TwistBlocks compare favorably pricewise with typical construction materials for informal settlements and are also more durable.

More information: *Oomen (2022).*

H. Communitywide rainwater harvesting — ACCCRN's systems, Semarang, Indonesia

- **Type of adaptation measure:** Adaptation to droughts and other climate events putting pressure on freshwater resources.
- **Environmental benefits:** Reduced consumption of freshwater resources.
- **Further co-benefits:** Reduced reliance on municipal/utility water sources.

The Asian Cities Climate Change Resilience Network, or ACCCRN, project in Semarang implemented a comprehensive rainwater harvesting initiative with a strong focus on climate adaptation in informal settlements. These systems included the installation of rooftop rainwater collection and storage infrastructure. ACCCRN worked closely with the local community to educate residents on the benefits of rainwater harvesting, offer training on system maintenance, and involve residents in decision-making processes. Rainwater harvesting systems provided a sustainable and decentralized source of clean water for residents, reducing their reliance on municipal water sources. This is especially crucial in areas with unreliable or contaminated water supplies. The project's strong focus on community engagement empowered residents to actively participate in climate adaptation efforts. They gained knowledge and skills related to rainwater harvesting and disaster preparedness. However, addressing challenges such as initial investment, maintenance, scale-up and policy alignment have been needed to ensure the long-term success and sustainability of such initiatives.

More information: *Dewi et al. (2023); Mukaromah (2020).*

I. Rooftop rainwater harvesting for displaced populations and host communities — UN-HABITAT, Jordan and Lebanon

- **Type of adaptation measure:** Adaptation to droughts and other climate and non-climate events putting pressure on freshwater resources.
- **Environmental benefits:** Reduced pressure on freshwater sources (groundwater).

- **Further co-benefits:** Provide renewable nonconventional options, including for refugee populations.

As part of a long-term strategy for water management in the Mashreq region and funded under the Adaptation Fund (with a total amount of nearly US$14 million), UN-HABITAT has aimed to scale up rooftop rainwater harvesting in several governorates, including Irbid and Mafraq in Jordan and Zahle in Lebanon. Both rural and urban populations in the Middle East suffer from a lack of access to water that results from a combination of water management issues, including climatic conditions, conflicts, and influxes of refugee populations — notably populations who have migrated from Syria since 2011 and settled in and outside of refugee camps in both countries. All these factors have increased the gap between supply and demand on already fragile water resources. UN-HABITAT's approach has consisted of upscaling existing rainwater harvesting practices so that they expand beyond the household level and serve children in schools and people in public spaces such as mosques. This aims to reduce pressure on water sources such as groundwater while increasing water supply options. According to UN-HABITAT, the whole project, which also includes other strategies such as gray water reuse, could benefit 120,000 people.

More information: *UN-HABITAT (2021).*

J. Recycling waste to produce biogas for households — Safisana's waste conversion model, Ghana

- **Type of adaptation measure:** Adaptation to floods.
- **Environmental benefits:** Waste recycling, biogas production.
- **Further co-benefits:** Sanitation services in areas deprived of sanitation access; health benefits; contributing to food security; mitigation approach

Safisana reuses waste as a resource to produce biogas and organic fertilizer. Its circular model combines fecal sludge and organic waste treatment with the production of renewable energy, nutrients and water. Fecal sludge is collected from communities and organic waste from food markets, abattoirs and food processing industries at a recycling plant. Through a natural process of anaerobic digestion and fermentation, organic and fecal sludge is transformed into biogas. This renewable energy is subsequently used to produce power to feed households and the national electricity grid. The residue from the digester is further used and composted into a nutrient-rich organic fertilizer. This model also benefits governments, utilities and food processing industries.

More information: *Safisana (2023).*

K. Rain garden rebate programs — EcoSuperior in Thunder Bay, Canada

- **Type of adaptation measure:** Adaptation to heavy rainfall events.
- **Environmental benefits:** Recharge groundwater; remove pollutants; increase biodiversity.
- **Further co-benefits:** Reduce pressure on "conventional" drainage systems; education.
- **Challenges**: Performance relates to climate conditions; maintenance.

EcoSuperior is a nonprofit organization active in the city of Thunder Bay, offering environmental programs and services. The organization has developed a rain garden program to help residents capture and filter rainwater and thereby reduce pressure on storm drains that conduct water to local streams. A variety of rain garden designs has been implemented, ranging from small- to large-scale gardens. However, upfront costs (varying between US$500 and US$1,000) have represented an important barrier. To address this, the program has included a rain garden rebate model that aims to provide incentives for households to install rain gardens on their property and reduce upfront costs. Supported by the local government, the program offers rebates of US$500-US$625 for plants (under the condition that 50% are wildflowers or native plant species), soil amendments (sand, compost, low-clay topsoil), gravel or rock, mulch and edging, and other landscaping supplies that must be preapproved.

More information: *EcoSuperior (2021).*

L. Permeable pavements — Terraforce's terracrete pavers, Franschhoek, South Africa

- **Type of adaptation measure:** Adaptation to floods.
- **Environmental benefits:** Groundwater recharge.
- **Further co-benefits:** Help develop pathways and driveways; can potentially help cool surfaces.
- **Challenges:** Not fit for all types of soils; not adequate for heavily trafficked areas.

In the Langrug settlement of Franschhoek near Cape Town, pavers were used to help manage stormwater runoff and recharge groundwater. Terraforce laid permeable, interlocking terracrete blocks over a 1,000-cubic-meter surface to help drain and filter water in the settlement. This initiative is part of a wider water management system that also uses gray water disposal points linked to underground pipes feeding miniature wetlands and tree gardens, which filters pollutants before reaching the municipal sewer system. Though permeable pavements need careful consideration of their context of implementation (e.g., soil conditions and vehicle traffic), they represent a cost-effective solution for communities that seek to create or expand pathways and driveways while minimizing flood risks.

More information: *Mseleku (2021).*

M. Citywide tree planting campaigns — Freetown, Sierra Leone

- **Type of adaptation measure:** Adaptation to floods risks, landslides and erosion.
- **Environmental benefits:** Increased canopy cover and support of biodiversity.
- **Further co-benefits:** Stewardship and stronger human-nature relationships.
- **Challenges:** Tree survival.

As part of wider urban adaptation strategies, the "Freetown the Treetown" campaign has consisted of planting 1 million trees in the capital of Sierra Leone by 2024. The initiative is led by the Freetown City Council with support from national and international financing entities such as the World Bank. Informal settlements represent 35% of the campaign's targeted areas, recognizing the need to reverse low vegetation covers in these areas, notably to combat soil erosion and prevent landslides. The campaign has deployed a stewardship system that financially and technically supports households willing to adopt, plant and monitor trees in their backyards. As of 2023, 700,000 trees have been planted. The campaign has also directly or indirectly led to the creation of green jobs along the value chain, including community growers and tree nurseries.

More information: *FCC (2023a); FCC (2023b).*

References

Abdulla, F.A., and Al-Shareef, A.W., 2009. "Roof Rainwater Harvesting Systems for Household Water Supply in Jordan." *Desalination* 243, 195–207. https://doi.org/10.1016/j.desal.2008.05.013

Acolin, A., and Hoek-Smit, M., 2020. *Cornerstone of Recovery: How Housing Can Help Emerging Market Economies Rebound from COVID-19*. Habitat for Humanity International. https://www.habitat.org/sites/default/files/documents/Cornerstone-of-Recovery-English.pdf

Adegun, O.B., 2017. "Green Infrastructure in Relation to Informal Urban Settlements." *Journal of Architecture and Urbanism*. 41, 22–33. https://doi.org/10.3846/20297955.2017.1296791

Agarwal, R.; Khanna, A.; Mukerji, N.; and Abrao, M., 2023. "Managing the Climate Impact of Human Waste: A Study to Understand the Impact of Methane Emissions from Fecal Sludge and Potential Abatement Approaches," *USAID Urban Resilience by Building and Applying New Evidence in Water, Sanitation, and Hygiene (URBAN WASH).* USAID, Washington, D.C.

Ahmed, I., 2020. "To 'Float' or 'Not': Cases of Amphibious Housing and Their Impacts on Vulnerable Communities of Jamaica," in: Chowdhooree, I., and Ghani, S.M. (Eds.), *External Interventions for Disaster Risk Reduction: Impacts on Local Communities, Advances in 21st Century Human Settlements.* Springer, Singapore, pp. 273–296. https://doi.org/10.1007/978-981-15-4948-9_15

Anguelovski, I.; Shi, L.; Chu, E.; Gallagher, D.; Goh, K.; Lamb, Z.; Reeve, K.; and Teicher, H., 2016. "Equity Impacts of Urban Land Use Planning for Climate Adaptation: Critical Perspectives from the Global North and South." *Journal of Planning Education and Research* 36, 333–348. https://doi.org/10.1177/0739456X16645166

Archila, H.; Kaminski, S.; Trujillo, D.; Zea Escamilla, E.; and Harries, K.A., 2018. "Bamboo Reinforced Concrete: A Critical Review." *Materials and Structures* 51, 102. https://doi.org/10.1617/s11527-018-1228-6

Base Bahay, Inc, n.d. *Cement-Bamboo Frame Technology: Technical Manual.*

Bisaga, I., and Parikh, P., 2018. "To Climb or Not to Climb? Investigating Energy Use Behaviour Among Solar Home System Adopters Through Energy Ladder and Social Practice Lens." *Energy Research and Social Science*. 44, 293–303. https://doi.org/10.1016/j.erss.2018.05.019

Bonamente, E., and Cotana, F., 2015. "Carbon and Energy Footprints of Prefabricated Industrial Buildings: A Systematic Life Cycle Assessment Analysis." *Energies* 8, 12685–12701. https://doi.org/10.3390/en81112333

Buchner, B.; Naran, B.; Fernandes, P.; Padmanabhi, R.; Rosane, P.; Solomon, M.; Stout, S.; Strinati, C.; Tolentino, R.; Wakaba, G.; Zhu, Y.; Meattle, C.; and Guzmán, S., 2021. "Global Landscape of Climate Finance." Climate Policy Initiative.

Cantos, G.L.; Lopez, L.F.; Jesus, R.M. de; Salzer, C.; Garciano, L.E.O.; Cantos, G.L.; Lopez, L.F.; Jesus, R.M. de; Salzer, C.; and Garciano, L.E.O., 2019. "Investigation of an Alternative Testing Protocol to Determine the Shear Strength of Bamboo Parallel to the Grain." *Maderas-Cienc Tecnol* 21, 559–564. https://doi.org/10.4067/S0718-221X2019005000411

Chandraby, K., 2020. "India: Women Act to Make Slums Climate-Resilient, One House at a Time" | UNW WRD Knowledge Hub [WWW Document]. UN-Women. https://wrd.unwomen.org/explore/insights/india-women-act-make-slums-climate-resilient-one-house-time (accessed Nov. 7, 2023).

Chiu, Y.-R.; Liaw, C.-H.; and Chen, L.-C., 2009. "Optimizing Rainwater Harvesting Systems as an Innovative Approach to Saving Energy in Hilly Communities. *Renewable Energy* 34, 492–498.

Cohen-Shacham, E.; Janzen, C.; Maginnis, S.; and Walters, G., 2016. *Nature-Based Solutions to Address Global Societal Challenges*. IUCN. https://doi.org/10.2305/IUCN.CH.2016.13.en

De Groen, M.; Dollie, A.; Lerotholi, N.; and Dunsmore, S., 2020. "Research on the Use of Sustainable Drainage Systems in Gauteng" (No. GT/GDARD/094/2018). *Agriculture and Rural Development*, Gauteng Province.

Dewi, S.P.; Kurniati, R.; and Ristianti, N.S., 2023. "Revealing Community Capacity for Applying Rain Water Harvesting in Semarang Coastal Areas. *Local Environment* 28, 1410–1427. https://doi.org/10.1080/13549839.2023.2221891

Diep, L.; Dodman, D.; and Parikh, P., 2019. "Green Infrastructure in Informal Settlements Through a Multiple Level Perspective." *Water Alternatives* 12, 554–570.

Doberstein, B., 2019. "Alternatives to Long Distance Resettlement for Urban Informal Settlements Affected by Disaster and Climate Change." *KnE Social Sciences* 136–150. https://doi.org/10.18502/kss.v3i21.4964

Dodman, D.; Hayward, B.; Pelling, M.; Castan Broto, V.; Chow, W.; Chu, E.; Dawson, R.; Khirfan, L.; McPhearson, T.; Prakash, A.; Zheng, Y.; and Ziervogel, G., 2022. "Cities, Settlements and Key Infrastructure," in: Pörtner, H.-O.; Roberts, D.C.; Tignor, M.; Poloczanska, E.S.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; Okem, A.; and Rama, B. (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040. https://doi.org/10.1017/9781009325844.008

Dumont, K.B.; Hildebrandt, D.; and Sempuga, B.C., 2021. "The 'Yuck Factor' of Biogas Technology: Naturalness Concerns, Social Acceptance and Community Dynamics in South Africa." *Energy Research and Social Science*. 71, 101846. https://doi.org/10.1016/j.erss.2020.101846

E4C, 2022. *A landscape Analysis of Sustainable, Green, and Circular Housing Solutions in the Philippines.* Engineering for Change, New York City.

EcoSuperior, 2021. *Rain Garden Rebate Program.*

English, E.; Klink, N.; and Turner, S., 2016. "Thriving with Water: Developments in Amphibious Architecture in North America." *E3S Web of Conferences* 7, 13009. https://doi.org/10.1051/e3sconf/20160713009

Farag, F., 2017. "A Socio-economic Approach to Urban Rooftop Farming in the Greater Cairo Region" [WWW document]. *Deutsche Gesellschaft für Internationale Zusammenarbeit* GIZ GmbH. URL https://panorama.solutions/en/solution/socio-economic-approach-urban-rooftop-farming-greater-cairo-region (accessed Nov. 4, 2023).

FCC, 2023a. *Freetown's First Climate Action Strategy 2022-2030.* Freetown City Council, C40, Urban Shift, Freetown.

FCC, 2023b. *Urban Forestry: Solutions for a Changing Climate*.

FCC, 2021. *#FreetownTheTreetownCampaign Progress Report: Phase 1 Results (2020) and Phase 2 (2021-22) Planning and Impact Investment Strategy: Transforming Climate Risk into Resilience in the City of Freetown, Sierra Leone*.

Frediani, A.A.; Ciciña, C.; and Roche, J.M., 2023. *Improving Housing in Informal Settlements: Assessing the Impacts in Human Development*, Home Equals. Habitat for Humanity International, Washington, D.C.

GlobalABC, 2021. *Buildings and Climate Change Adaptation & OID: A Call for Action.* Global Alliance for Buildings and Construction, Paris.

Global Commission on Adaptation, 2019. *Adapt Now: A Global Call for Leadership on Climate Resilience.* Global Commission on Adaptation, Rotterdam.

Greenwalt, J.; Bütow, C.; Carillo Silva, D.; Francisco, A.; Klooster, J.; and Dudley, R., 2023. *Nature-Based Solutions to Build Climate Resilience in Informal Areas.* United Nations Human Settlements Programme, Nairobi.

GSA, 2021. *Green Roofs* [WWW document]. U.S. General Services Administration. https://www.gsa.gov/governmentwide-initiatives/federal-highperformance-green-buildings/resource-library/integrative-strategies/green-roofs (accessed Nov. 4, 2023).

Gutu, T., 2013. *A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization 2.*

Henrique, K.P., and Tschakert, P., 2019. "Contested Grounds: Adaptation to Flooding and the Politics of (In)visibility in São Paulo's Eastern Periphery." *Geoforum* 104, 181–192. https://doi.org/10.1016/j.geoforum.2019.04.026

Hurley, P.T., and Emery, M.R., 2018. "Locating Provisioning Ecosystem Services in Urban Forests: Forageable Woody Species in New York City, USA." *Landscape and Urban Planning.* 170, 266–275. https://doi.org/10.1016/j.landurbplan.2017.09.025

Ishimatsu, K.; Ito, K.; Mitani, Y.; Tanaka, Y.; Sugahara, T.; and Naka, Y., 2017. "Use of Rain Gardens for Stormwater Management in Urban Design and Planning." *Landscape and Ecological Engineering.* 13, 205–212. https://doi.org/10.1007/s11355-016-0309-3

IPCC, 2023: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

Kalina, M.; Ogwang, J.Ò.; and Tilley, E., 2022. "From Potential to Practice: Rethinking Africa's Biogas Revolution." *Humanities and Social Sciences Communications*. 9, 374. https://doi.org/10.1057/s41599-022-01396-x

Langlois, J., 2023. "In Brazil's Favelas, Green Roofs Might Help Relieve the Heat" [WWW document]. *Undark Magazine*. https://undark.org/2023/05/22/in-brazils-favelas-green-roofs-might-help-relieve-the-heat/ (accessed Nov. 5, 2023).

Massol-González, A.; Johnnidis, A.A.; and Massol-Deyá, A., n.d. *The Evolution of Casa Pueblo, Puerto Rico*.

Mignoni, E., 2018. "Puerto Rico's Solar-Powered Energy Oasis" [WWW document]. *Yale Climate Connections*. http://yaleclimateconnections.org/2018/04/puerto-ricos-solar-powered-energy-oasis/ (accessed Nov. 4, 20233).

Morash, J.; Wright, A.; LeBleu, C.; Meder, A.; Kessler, R.; Brantley, E.; and Howe, J., 2019. "Increasing Sustainability of Residential Areas Using Rain Gardens to Improve Pollutant Capture, Biodiversity and Ecosystem Resilience." *Sustainability* 11, 3269. https://doi.org/10.3390/su11123269

Mseleku, E.S., 2021. *Guidelines for Integrated Flood Control Design in the Informal Settlements of Cape Town Municipality: A Case Study of Kosovo, Philippi District (Degree Project in the Built Environment).* KTH Royal Institute of Technology, Stockholm.

Mukaromah, H., 2020. "Rainwater Harvesting as an Alternative Water Source in Semarang, Indonesia: The Problems and Benefits." IOP Conference Series: Earth and Environmental Science 447, 012059. https://doi.org/10.1088/1755-1315/447/1/012059

Mulligan, J.; Bukachi, V.; Clause, J.C.; Jewell, R.; Kirimi, F.; and Odbert, C., 2020. "Hybrid Infrastructures, Hybrid Governance: New Evidence from Nairobi (Kenya) on Green-Blue-Grey Infrastructure in Informal Settlements." *Anthropocene* 29, 100227. https://doi.org/10.1016/j.ancene.2019.100227

Oldfield, E.E.; Warren, R.J.; Felson, A.J.; and Bradford, M.A., 2013. "FORUM: Challenges and Future Directions in Urban Afforestation." *Journal of Applied Ecology.* 50, 1169–1177. https://doi.org/10.1111/1365-2664.12124

Oomen, J., 2022. "Net-Zero Homes: How Circular Economy Solutions to the Housing Crisis in Low-Income Countries Are Key to Achieving Global Climate Targets." Terwilliger Center for Innovation in Shelter, Habitat for Humanity International, Atlanta.

Oppla, 2021. "Green Roofs in the Slums of Rio de Janeiro, Brazil" [WWW document]. Oppla. https://oppla.eu/casestudy/23397 (accessed Nov. 4, 2023).

Parmesan, C.; Anshari, G.; Buotte, P.; Campbell, D.; Castellanos, E.; Cowie, A.; Rivera, F.M.; Gonzalez, P.; Gunn, E.G.; Harris, R.; Hicke, J;, Kerr, R.B;, Laco, R.; Lempert, R.; Mackey, B.; Martinetto, P.; Matthews, R.; McPhearson, T.; Morecroft, M.; Mukherji, A.; Nabuurs, G.; Neufekdt, H.; Pedace, R.; Postigo, J.; Price, J.; Pulhin, J.; Rogelj, J.; Shmidt, D.; Schoeman, D.; Singh, D.; Smith, P.K.; Stevens, N.; Strutz, S.E.; Sukumar, R.; Talukdar, G.T.; Tirado, M.C.; and Trisos, C., 2022. "IPCC AR6 WGII Cross-Chapter Box NATURAL | Nature-Based Solutions for Climate Change. Mitigation and Adaptation," in: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, pp. 303–209.

Pataki, D.E.; Alberti, M.; Cadenasso, M.L.; Felson, A.J.; McDonnell, M.J.; Pincetl, S.; Pouyat, R.V.; Setälä, H.; and Whitlow, T.H., 2021. "The Benefits and Limits of Urban Tree Planting for Environmental and Human Health." *Frontiers in Ecology and Evolution*. 9.

Prosun, P., 2011. *The LIFT House: An Amphibious Strategy for Sustainable and Affordable Housing for the Urban Poor in Flood-prone Bangladesh.* University of Waterloo, Waterloo.

Rao, M.; Patil, A.; Gaikwad, M.; Bagul, A.; and Deosarkar, Prof. M.U., 2022. "A Review on Flood Mitigation Measures Amphibious Housing." *International Journal for Research in Applied Science and Engineering Technology* 10, 1909–1914. https://doi.org/10.22214/ijraset.2022.42704

Richards, P.J.; Farrell, C.; Tom, M.; Williams, N.S.G.; and Fletcher, T.D., 2015. "Vegetable Raingardens Can Produce Food and Reduce Stormwater Runoff." *Urban Forestry & Urban Greening*. 14, 646–654. https://doi.org/10.1016/j.ufug.2015.06.007

Roquet, V.; Bornholdt, L.; Sirker, K.; and Lukic, J., 2017. "Relocation of Informal Urban Settlements: Examples from India and Mauritania." *Directions in Development — Environment and Sustainable Development*. https://doi.org/10.1596/978-1-4648-0980-4_ch3

Safisana, 2023. "Poor Sanitation Is a Major Contributor to Climate Crisis."

Silva, B.R., 2016. "Telhados verdes em clima tropical: uma nova técnica e seu potencial de atenuação térmica." UFRJ, Rio de Janeiro.

Soltowski, B.; Campos-Gaona, D.; Strachan, S.; and Anaya-Lara, O., 2019. "Bottom-Up Electrification Introducing New Smart Grids Architecture — Concept Based on Feasibility Studies Conducted in Rwanda." *Energies* 12, 2439. https://doi.org/10.3390/en12122439

TCIS, 2023. *Green Housing Solutions in the Philippines: Making Sustainable, Circular Housing More Accessible and Affordable for Low-Income Households.* Terwilliger Center for Innovation in Shelter, Habitat for Humanity International, Cebu City.

Tewari, P., and Singh, R.V.P., 2021. *Thermal Comfort: Prescription for Cooling Dominated Indian Residential Buildings.* The Energy and Resources Institute (TERI), New Delhi.

Turner, S., and English, E., 2015. *Amphibious Housing for Vulnerable Communities in Jamaica.*

UNEP, 2023. *Building Materials and the Climate: Constructing a New Future.* Nairobi.

UNEP, 2022. "Too Little, Too Slow: Climate Adaptation Failure Puts World at Risk" (Online Annexes), *Adaptation Gap Report.* United Nations Environment Programme, Nairobi.

UN-HABITAT, 2023. *Rescuing SDG 11 for a Resilient Urban Planet.* United Nations Human Settlements Programme, Nairobi.

UN-HABITAT, 2021. *Increasing the Resilience of Both Displaced Persons and Host Communities to Climate Change-Related Water Challenges.* United Nations Human Settlements Programme, Nairobi.

Vandana, K., 2023. "India: White Roofs Cooling Women's Homes in Slums" [WWW document]. PreventionWeb. https://www.preventionweb.net/news/white-roofs-cooling-womens-homes-indian-slums (accessed Nov. 7, 2023).

Vellingiri, S.; Dutta, P.; Singh, S.; Sathish, L.; Pingle, S.; and Brahmbhatt, B., 2020. "Combating Climate Change-Induced Heat Stress: Assessing Cool Roofs and Its Impact on the Indoor Ambient Temperature of the Households in the Urban Slums of Ahmedabad." *Indian Journal of Occupational and Environmental Medicine.* 24, 25–29. https://doi.org/10.4103/ijoem.IJOEM_120_19

Witte, D., 2019. "Structural Bamboo Building Codes: Catalysts for Industry, Research, and Construction Technology." *Technology/Architecture + Design*.

Wolff, E.; Rauf, H.A.; and Hamel, P., 2023. "Nature-Based Solutions in Informal Settlements: A Systematic Review of Projects in Southeast Asian and Pacific Countries." *Environmental Science & Policy* 145, 275–285. https://doi.org/10.1016/j.envsci.2023.04.014

Zhang, L.; Oyake, Y.; Morimoto, Y.; Niwa, H.; and Shibata, S., 2020. "Flood Mitigation Function of Rain Gardens for Management of Urban Storm Runoff in Japan." *Landscape and Ecological Engineering*. 16, 223–232. https://doi.org/10.1007/s11355-020-00409-8

Zhu, H.; Yu, M.; Zhu, J.; Lu, H.; and Cao, R., 2019. "Simulation Study on Effect of Permeable Pavement on Reducing Flood Risk of Urban Runoff." *International Journal of Transportation Science and Technology*. Advances in Permeable Pavement for Stormwater Runoff Management 8, 373–382. https://doi.org/10.1016/j.ijtst.2018.12.001

every hand

makes a difference

Habitat for Humanity®

285 Peachtree Center Ave. NE, Suite 2700, Atlanta, GA 30303-1220 USA
322 W. Lamar St., Americus, GA 31709-3543 USA
(800) 422-4828 fax (229) 928-8811 publicinfo@habitat.org habitat.org

23-88776/PDF-DOC/GRA/11-2023/ARS