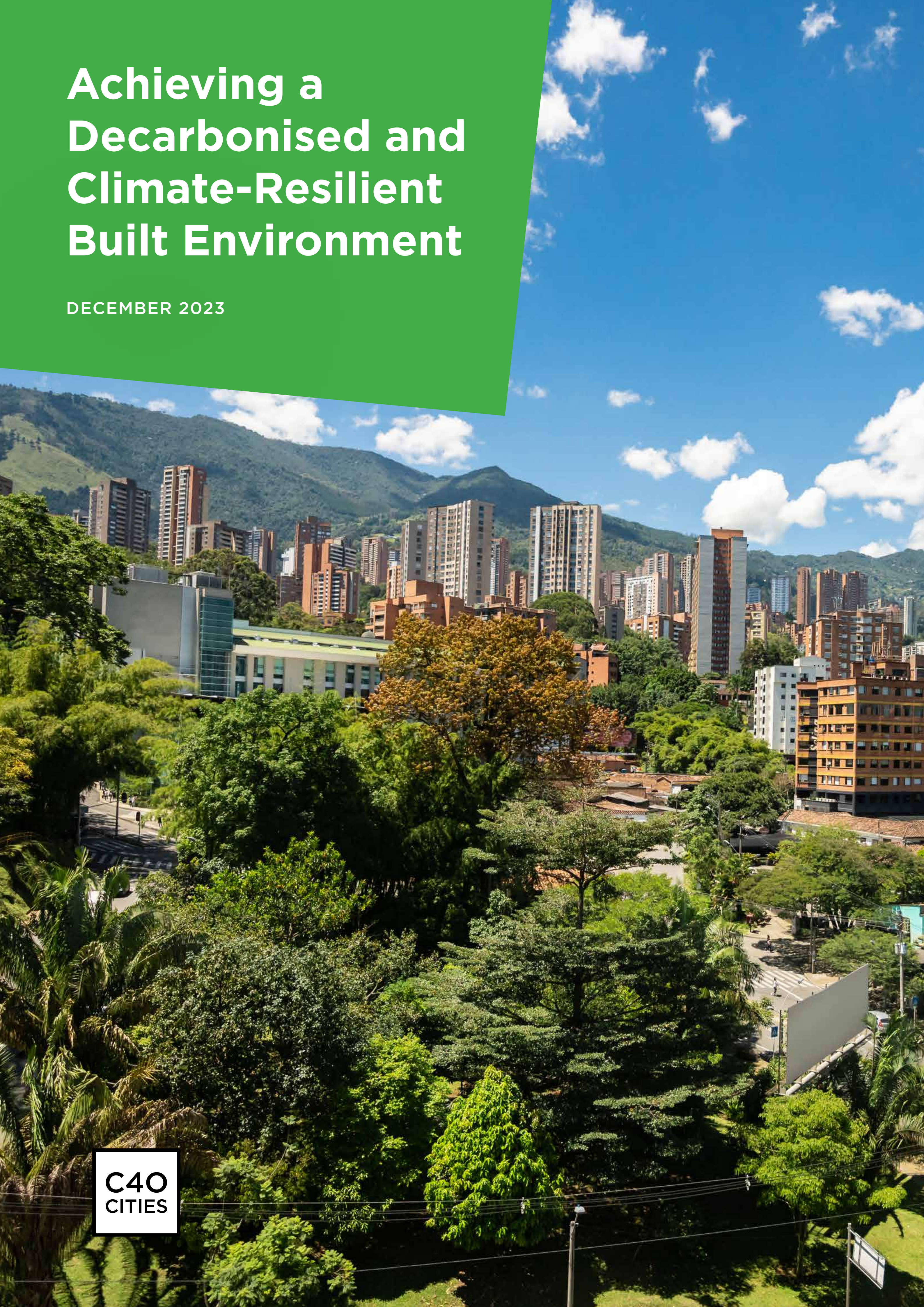
Achieving a Decarbonised and Climate-Resilient Built Environment

DECEMBER 2023



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The Clean Construction programme adopts a holistic approach to support cities demanding and driving a just transition towards a resilient, decarbonised, circular and equitable built environment.

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ABOUT C40 CITIES

C40 is a network of nearly 100 mayors of the world's leading cities who are working to deliver the urgent action needed right now to confront the climate crisis and create a future where everyone, everywhere can thrive. Mayors of C40 cities are committed to using a science-based and people-focused approach to help the world limit global heating to 1.5 degrees Celsius and build healthy, equitable, and resilient communities. Through a Global Green New Deal, mayors are working alongside a broad coalition of representatives from labour, business, the youth climate movement, and civil society to go further and faster than ever before. The current chair of C40 is Sadiq Khan, mayor of London, and three-term mayor of New York City Michael R. Bloomberg serves as president of the board. C40's work is made possible by our three strategic funders: Bloomberg Philanthropies, Children's Investment Fund Foundation (CIFF), and Realdania.

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Foreword

This foundational strategy paper outlines why and how we need to tackle the emissions and climate related impacts[a] of the built environment hand in hand. It advocates for an integrated approach to tackle both emissions and climate risks[b] in tandem, moving away from prevalent siloed thinking.

This paper is not intended to be a comprehensive analysis of the emissions or climate risks of the built environment, as several solid resources on these topics are already available. Instead, it provides an overview of the interdependence and interconnection of mitigation and adaptation issues in the built environment. Each section will examine one specific climate risk to illustrate this interconnectedness, yet we acknowledge many more links can be made to other climate risks. All sections of this paper are interrelated and should not be considered in isolation.

New York © Barry Winiker / Getty Images

[a] The effect of climate change on natural and human systems.

[b] The probability of harmful consequences or expected losses resulting from interactions between climate-related hazards and vulnerable conditions.

Context

The built environment – our homes, offices, schools, hospitals, streets, bridges, drainage systems, electrical lines, parks, open spaces and more – shapes our lives in numerous ways. It is where we sleep, eat, work, are educated, entertained, and cared for. However, the built environment significantly contributes to the climate crisis in two major ways: by generating greenhouse gas (GHG) emissions and increasing climate risks.

The construction sector is responsible for at least 23% of global CO_2 emissions,[1] consumes at least 30% of all globally extracted resources[2] and produces high pollution and waste streams.[3] If we include energy-related emissions, the built environment is responsible for approximately 40% of global GHG emissions.[4] Cities drive up demand for construction activities, from retrofit projects to new buildings. Over 2.5 billion more people are expected to live in urban areas by 2050.[5]

Climate risks are a growing concern. Over 85% of the world's population have experienced climate-related disruption events such as extreme heat, flooding, storms, drought, and increased spread of vector-borne diseases.[6]

Cities, people, buildings, and infrastructure will become even more exposed and vulnerable to climate hazards[c] as they become more frequent and severe globally.[7] By 2050, 1.6 billion residents in over 970 cities will be regularly exposed to average summertime temperature highs above 35°C (95°F). Up to 800 million people in more than 570 coastal cities will be at risk of coastal flooding and storm surges.[8]

This has financial and economic consequences too. In 2022, economic losses from natural disasters, many driven by the changing climate, were estimated at US$ 313 billion.[9] Besides physical damage and economic operational losses, extreme events can reduce a property's value by 5% to 20%.[10]

Buildings and infrastructure are not only vulnerable to the impacts of the climate crisis, they contribute and amplify it by worsening flash floods and the urban heat island effect for instance.[d] Rapidly built developments – both formal and informal – have frequently neglected natural protective systems by weakening, choking, or removing them. Rapid urbanisation has driven and intensified climate risks through changes such as land-use patterns, resource scarcity and socio-economic inequality.[11] The built environment sector is also responsible for 30% of biodiversity loss globally.[12]

[c] Potential events or physical conditions that can cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

Measures taken to reduce the built environment's GHG emissions can inadvertently increase climate stresses, and interventions solely focused on adaptation can generate even more emissions. This creates tensions and conflicts, and can feed misconceptions within the sector and the general public.[13] Siloed interventions need to be urgently replaced by integrated mitigation and adaptation approaches when tackling the unequal climate impacts of buildings, infrastructure and sites.[14]

Revolutionising the way we approach the built environment is crucial for cities to reduce their emissions, improve their resilience to ongoing and future climate stresses and shocks,[e] and safeguard people's health, lives and livelihoods. Cities are taking action to implement solutions in the built environment. However, more needs to be done to ensure that what is renovated or built now withstand escalating climate impacts, avoid malinvestment[f] and early obsolescence, and support thriving ecosystems for people and nature that sequester carbon – all while reducing their ecological and carbon footprint.

The paper provides an overview of the challenges posed by our built environment. It also offers tangible solutions and city policy examples to address its contribution to emissions and climate risks through the lens of three critical elements that shape our urban fabric:

location and site choices – where

design choices – how

materials choices – what

[d] An urban heat island means that an urban area or metropolitan area is significantly warmer than its surrounding rural areas due to human activities. From: Dodman, D., et al (2022). Cities, Settlements and Key Infrastructure. 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, Cambridge, UK and New York, NY, USA, pp. 907–1040. Available at: https://doi:10.1017/9781009325844.008-.

[e] Shocks are sudden, sharp events that threaten a city, e.g. earthquakes (Friedman, Y. & Lee, T. (2017). Cities Taking Action. 100 Resilient Cities. Available at: https://resilientcitiesnetwork.org/downloadable_resources/UR/Cities-Taking-Action.pdf

[f] Actions that can be undone or rendered less effective by the effects of climate change if they are not sufficiently resilient. C40 Cities. (2018). New tool will help cities understand interactions between mitigation and adaptation actions. Available at: https://www.c40.org/news/new-tool-will-help-cities-understand-interactions-between-mitigation-and-adaptation-actions/

Location and site choices

Copenhagen © Oleksandra Korobova / Getty Images

How do location and site choices contribute to increased emissions and climate risks?

Constructing in areas prone to climate hazards such as flooding, landslides, sea level rise, drought or earthquakes results in a heavy social and financial cost during extreme climate events. As the climate crisis escalates, areas previously considered low risk are now in higher danger. For example, rising temperatures are contributing to the intensification of tropical cyclones.[15] People are either being displaced, harmed, or killed. Homes, schools, roads, and critical infrastructure are being damaged or destroyed. On top of the human and financial losses, post-disaster reconstruction efforts are often completed hastily with cheap and carbon-intensive repairs, usually in the same location.[16]

Many people already living in coastal areas[17] are exposed to sea-level rise and increased risk of flooding.[18] The trend is rising, and the number and physical weight of buildings and infrastructure in turn increases risk of flooding.[19] This is in addition to the emissions generated during their construction and use. In many fast-growing cities located along coasts and rivers, low-income populations settle in the most unsafe areas, often near seashore and river beds, as the only places they can afford. These communities and their homes, usually self-built and unplanned, are highly vulnerable to climate risk and the first to be hit by flooding.[20]

Typical urban surfaces such as concrete and paving are not only high-carbon, they are also impermeable. Water quickly flows over them to collect in low lying areas, both within and downstream from cities, causing flooding.[21] Many cities have concreted, paved, converted, encroached and/or hidden their natural waterways and drainage underground to create more urban space. Lakes, wetlands, riverbeds and water-stream ecosystems host rich biodiversity and provide a natural flood control mechanism. Constructing over them blocks natural water flows and exacerbates flooding and drought risks. In the outskirts of Athens in 2017, flash flooding caused by poor infrastructure, illegal construction and paved or concreted streams resulted in the avoidable death of 20 people.[22]

Man-made grey infrastructure, such as dikes, floodgates, levees, embankments, seawalls, and drainage systems, are essential to protect areas from flooding when they complement rather than replace natural systems. However, over the past century cities have systematically over-relied on grey infrastructure at the expense of natural systems. These ageing assets are not only carbon intensive and heavily reliant on concrete, they are also costly to maintain, repair and replace.[23]

Underground drainage systems are often unable to cope with high water volumes, leading to flooding when they are overwhelmed. Outdated and poorly designed stormwater infrastructure are one of the main causes of urban flooding. Their design did not account for excess water caused by impermeable pavements and choking debris. This directly contributed to the 2021 urban flooding from Hurricane Ida in New York City, causing 44 deaths and an economic loss of US$ 7.5–9 billion.[24]

The 2015 floods in Chennai were caused by an intense and sustained rainfall episode on encroached lakes and wetlands and a drainage infrastructure failure. 400 lives were lost. The floods destroyed property and livelihoods, particularly of low-income and marginalised residents living alongside bodies of water. The impact on the environment and public health was high due to the overflow of sewage drains and spread of vector-borne, waterborne, and airborne diseases.[25]

Solutions

The ideal solution is to avoid new construction projects in hazard-prone or fragile regions. However, with high concentrations of people already residing in these areas, pragmatic solutions are needed. This includes stronger protection systems, managing displacement, new or tighter regulations on land use, planning and substantial investment in existing and new infrastructure.[26]

The first critical approach for cities is to put **effective and resilient safety measures** in place, such as early warning systems and evacuation and emergency plans. This should prioritise timely and effective support to marginalised groups and the population at highest risk. Rio de Janeiro has a flood alert system to minimise the impact of flood events in low-income communities, where they receive a warning signal and are strongly encouraged to move to pre-built shelters. This measure must be coupled with rapid, sturdy, low-carbon and resilient reconstruction strategies, utilising resources and knowledge from local communities.[27]

Conducting a **climate risk assessment** (CRA) can help to strengthen a city's resilience. CRAs should identify the likelihood of future climate hazards, locations that are highly exposed and any existing cause of social vulnerability[g] for communities and residents.[28] It should profile the population, infrastructure and assets that might be at risk, both at present and in future. It can then serve to develop an evidence-based strategy with necessary steps and actions to effectively build resilience to climate risks.[29] IIntentionally coupled with climate action plans and zoning policies, CRA's can reinforce emissions reduction plans for the built environment. For example, preventing new construction in high-risk areas would avoid or significantly reduce exposure[h] to climate hazards, while avoiding the high emissions generated by new construction activities.

Addressing the climate crisis, restoring nature, and preserving biodiversity are mutually supporting goals. **Nature positive**[i] **actions** repair and restore natural systems to support safe and healthy cities.[30] Implementing **nature-based solutions**[j] and/or **green-blue infrastructure**[k] provides benefits to both ecosystems and human health. During the initial planning phases, construction projects can include these solutions to preserve or regenerate existing natural habitat and ecosystems, such as coastal mangroves, wetlands or living shorelines. Riparian buffers


Riparian buffer © recep-bg / Getty Images

[g] The United Nations Office for Disaster Risk Reduction (UNDRR) defines vulnerability as 'the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.' Available at: https://www.undrr.org/terminology/vulnerability

[h] The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

[i] 'Nature positive' is a global goal to halt and reverse nature loss by 2030 and achieve full recovery by 2050.

[j] Nature-based solutions are 'actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature'', as defined by the IUCN.

[k] Green-blue infrastructure are interconnected networks of multifunctional green and blue space that link together and provide multiple benefits. These include conventional open spaces, such as parks, woodlands and playing fields, but also allotments, street trees, private gardens, green roofs and walls, and sustainable drainage systems.

***Bioswales* - United States** © Billy Hustace / Getty Images

Permeable pavement
Brussels © Michael Roberts / Getty Images

(vegetated stream buffers) and earth bunds (sloped embankments made from earth) use the natural topography and vegetation of the site to avoid top erosion to withhold water from river or stream banks. Other nature-based solutions or green-blue infrastructure solutions include bioswales (vegetated channels that slow down the flow of rainwater), permeable pavements, and rain gardens. These solutions increase the capacity of the built environment to manage excess water and risks from floods, high sea-level rise, and intense rainfalls. Adopting more green-blue infrastructure would reduce the embodied emissions[l] impact of grey infrastructure, sequester more carbon, and increase the area's resilience.

Nature-based solutions and green-blue infrastructure also provide numerous ecosystem services, such as capturing and storing carbon in trees, plants, and root systems; preventing erosion and consolidating riverbeds; reducing flood and heat risks; purifying water and air; enhancing biodiversity with native trees and shrubs; and conserving existing wetlands and mangroves. It is an excellent context-specific strategy to both mitigate and adapt to climate breakdown.[31]

Nature-based solutions and green-blue infrastructure also provide several co-benefits, such as providing recreational public spaces, community cohesiveness, wellbeing and health benefits, and creating more attractive places to live.[32] Care should be taken to distribute such solutions equitably in cities, prioritising areas that need it most and avoiding gentrification.[m]

While green-blue infrastructure reduces climate risk, it has limitations, especially in areas of high population density. For example, natural systems may be insufficient to cope with the increased intensity and frequency of urban floods. They may require larger amounts of land, often in short supply in cities, and suffer from negative misconceptions from the development sector and/or the general public.[33] A hybrid approach **combining grey and green-blue infrastructures** can provide a viable alternative.[34] For example, wetland restoration can be combined with engineered measures such as small levees for stronger coastal flood protection.[35]

[l] Emissions related to the extraction of raw materials, their manufacturing, assembly during construction, any maintenance or replacements, the disassembly and demolition, and any associated transport, waste, and end of life impacts. C40 Clean Construction Accelerator Technical Note. (2022). Available at: https://www.c40.org/wp-content/uploads/2023/10/C40-CCA-Technical-Note.pdf

[m] Construction and development in gentrifying areas can contribute to rising property values and changes in the socio-economic and cultural landscape of a neighbourhood and can be combated through intentional zoning regulations, affordable housing policies, and community engagement.

City action examples

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Ellinikon International Airport

Athens, Greece

Ellinikon International Airport and its surrounding waterfront, unused for almost two decades, is being transformed into a 600-acre coastal park. By adopting green infrastructure, the developers aim to rejuvenate the area, offering Athenians a park, playground, and cultural centre, while enhancing climate resilience. The green spaces will act as sponges to absorb excess water and increase cooling during extreme heat events. To reduce embodied emissions, on-site concrete slabs will be reused. Climate benefits are translated into economic ones, through reducing flood damage, as well as improving physical and mental health and social cohesion.[36]

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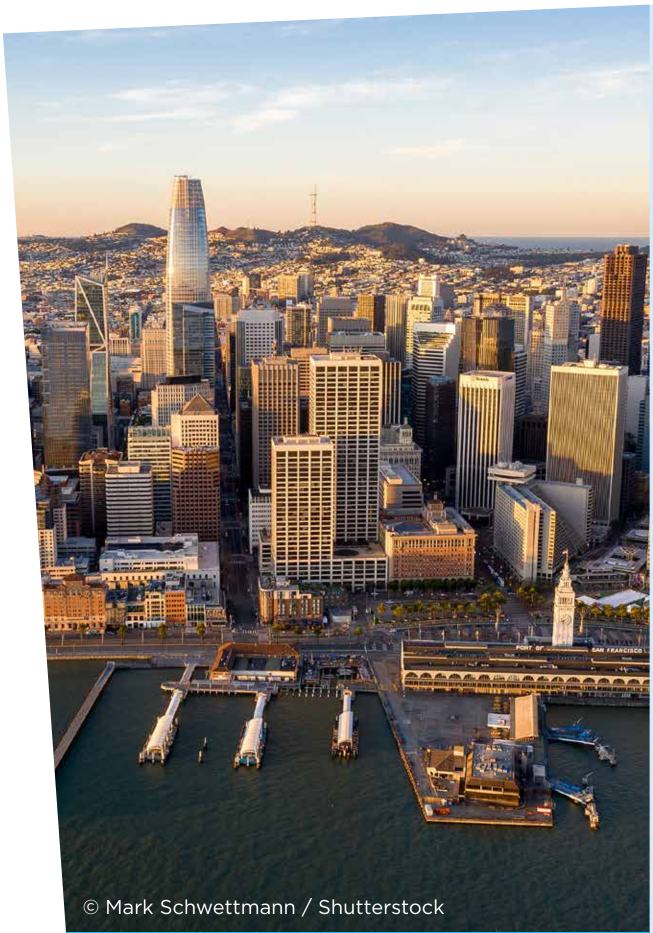
Coastal Management Line

Cape Town, South Africa

Cape Town's coastline is one of its most important socioeconomic and environmental assets, as well as being a major source of risk to the city. Cape Town's **Coastal Management Line** (CML) is a city-wide strategy created in 2007 to promote risk-averse coastal planning. The strategy proactively delineates at-risk coastal areas to restrict construction activity seaward of this line. It is a planning mechanism to protect existing structures, preserve the ecological function of the coastal zone, maintain equitable access to the waterfront, and prevent risk to coastal property from storm surges, dune migration, coastal erosion, and other current and future ocean-related hazards.[37]



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Waterfront Resilience Program

San Francisco, United States

The Port of **San Francisco Waterfront Resilience Program** (WRP) was created to reduce seismic, coastal, and inland flooding climate risks that support a safe, equitable, sustainable, and vibrant waterfront. Adaptation strategies have been developed to address climate risks for a 7.5 mile stretch, while supporting a resilient, sustainable, and equitable waterfront for the next 100 years. They are a combination of construction projects and policy changes that will guide decisions about where, when, and how high to build flood defences; how and when to adapt buildings and infrastructure to ensure continued operation of city services; and how to incorporate nature-based and ecological features. The programme will also include recommendations for policy changes that will best defend public and private land, preserve and grow housing and jobs, and create recreational opportunities, waterfront access, and improved bay habitat. The WRP has implemented a Living Seawall pilot project to assess its ability to support native species' growth. It is also exploring concrete alternatives for waterfront applications that maximise durability while reducing emissions.[38]

Additional city examples

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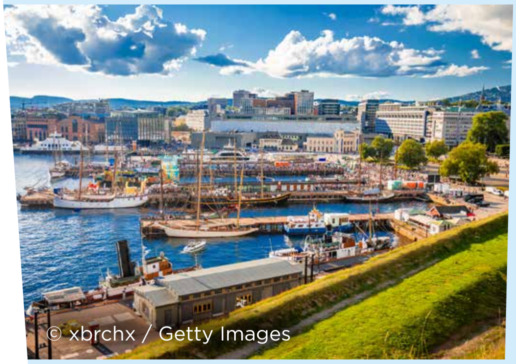
Copenhagen implemented the city-wide Cloudburst Management Plan to mitigate and adapt to extreme rainfall events using a hybrid green-grey infrastructure technique. This was achieved by retrofitting and expanding the existing stormwater system while avoiding demolition, and by implementing landscape-level green-blue solutions over selected locations where the risks are highest.

© Alexandre Morin-Laprise / Getty Images

Medellín established 30 green corridors or 'Corredores Verdes' between 2016 and 2019. This network of green spaces connects several natural areas by transforming pavements and verges of 18 roads and 12 waterways and restoring green and blue belts throughout the city. The project was adopted to fight rising temperatures, worsened by the long stretches of concrete and tarmac absorbing and radiating the sun's heat.[39] Planting trees and creating rain gardens also helped absorb heavy rains and reduce vulnerability to flood risks.[40] Co-benefits include carbon sequestration, green job creation, improved air quality and health and wellbeing of inhabitants, and increased urban biodiversity.[41]



© xbrchx / Getty Images

Oslo has undertaken a Climate Risk and Vulnerability Assessment which provides a brief summary of expected climate impacts and related challenges. It is intended as a knowledge base and an aid in municipal land-use planning to identify assets that are currently under a high-risk zone, and avoids building on areas which could have a potential future threa.

© mayichao / Getty Images

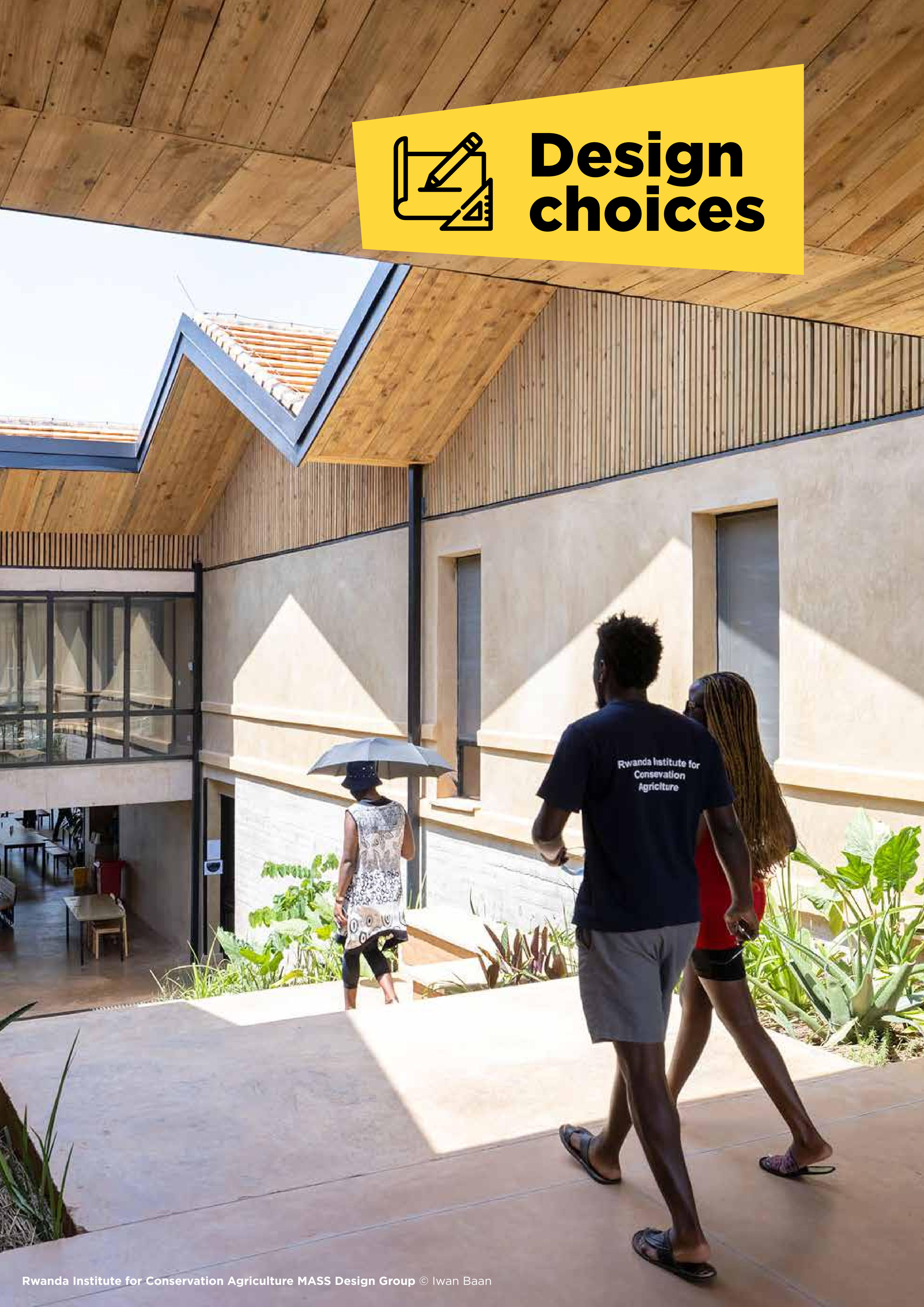
The **China Sponge City Initiative**[42] was launched to increase the flood resilience of Chinese cities. Nature-based solutions and green-blue infrastructure were developed to retain and release rainwater while reducing pollutants. The initiative used solutions such as rehabilitation and regeneration of drainage systems and urban water bodies, permeable pavements, restoration of wetlands, rain beds, rainwater storage tanks, green belts and sunken green spaces. These solutions counteract the vast stretches of concrete in the city to prevent waterlogging and reduce emissions.

Praça Doutor João Mendes e Largo Sete de Setembro © MATTERIA

Praça Doutor João Mendes e Largo Sete de Setembro, **São Paulo**, is one of the winning projects of the third edition of the C40 Reinventing Cities competition.[n] The project proposes revitalising a public square into a green and thriving space for residents and the local community by increasing accessibility for pedestrians and cyclists and boosting resilience with extensive vegetation, including over 80 new trees and 2,496 square metres of permeable area and bioswales. Sustainable materials, including the reuse of demolition materials, low-carbon cement and bio-based elements will also be used to construct bike lanes and pathways. The project is part of a wider effort to revitalise public spaces, encompassing four key areas within the city centre of São Paulo.

[n] A call for innovative urban projects to transform underutilised sites while driving carbon-neutral and resilient urban regeneration in cities across the globe.

Design choices



Rwanda Institute for Conservation Agriculture MASS Design Group © Iwan Baan

How do design choices contribute to increased emissions and climate risks?

Design applies to different scales, from the layout of a city to the detailed design of individual buildings, sites or structures. Design methods and strategies range from active or passive design principles, vernacular or traditional design styles, and modernist design methods.[43]

Modernist design and construction are the most prevalent in use today. It emerged in the early 20th century and centred on functionality. Heavily driven by technological innovation and industrialised methods, it moved away from traditional approaches, for example designing structures from bricks, stones, earth and wood. Modernist design marked a shift towards using the new and innovative materials of the time, specifically reinforced concrete, glass and steel, to cope with the urbanisation boom.[44] This helped build faster and taller structures, however its prevalence now poses a number of environmental concerns.

High-rise or tall buildings[o] were and are still seen as a solution to address land pressure, as well as creating iconic city skylines.[45] Yet this height means increased sun and wind exposure, as well as greater seismic pressures.[46]

To be structurally sound, tall buildings require larger quantities of carbon-intensive structural materials such as concrete and steel to support the vertical load and resist wind and seismic forces. This increases the building's embodied emissions.

In addition, tall buildings are not used optimally – commercial buildings often have high vacancy rates.[47] This trend worsened with the COVID-19 pandemic.[48]

The design of many modern structures typically does not account for local climate and weather patterns, relying instead on innovation and technology to overwrite environmental conditions. However, increasingly harsh conditions in the context of climate breakdown were not factored into modernist design decisions, putting many buildings and their occupants at risk.

Fully glazed skyscrapers often use excessive energy to maintain comfortable indoor temperatures for their occupants as heat is gained and lost faster through large glass windows than through insulated walls. Such design choices dramatically increase the energy needs of the building – its operational emissions[p] – especially in the context of a rapidly warming planet.[49]

Innovations in reflective glass attempt to eliminate the heat from the sun's rays entering high rise buildings by deflecting sunlight down towards other buildings and the pavement. These surfaces, typically made of asphalt and concrete, absorb the heat and release it again, causing the urban heat island effect.[50]

[o] The Council on Tall Buildings and Urban Habitat (CTBUH) defines tall building as a building that is above 117 m (approx 30 storeys) in height.

[p] Emissions associated with the energy used to operate the building or in the operation of infrastructure. C40 Clean Construction Accelerator Technical Note (2022). Available at: https://www.c40.org/wp-content/uploads/2023/10/C40-CCA-Technical-Note.pdf

The second half of the 20th century witnessed the global adoption of modern air-conditioned residential units as the default for those who could afford it. Initially introduced in the United States for industrial use, air conditioning "(...) came to be seen as essential, a symbol of modernity and comfort". It became the optimum solution to standardise the production of American homes and offices with the advantageous ability to cope with high temperatures – a feat of productive technical progress that went global.[51] However, air conditioning is fuelling the climate crisis due to its greedy energy demand. By releasing hot air directly outside, it also contributes to the urban heat island effect, further increasing cooling demands.[52] Low-income households that cannot afford air conditioning are disproportionately affected during periods of extreme heat.[53]

The modernist approach also adopts a linear economy of take–make–dispose. This generates excessive waste and uses more energy and raw materials than necessary. It also contributes to the intense consumption of finite resources, with the construction sector consuming at least 30% of all globally extracted resources.[54] This leads to resource scarcity and ecosystem depletion, which in turn accelerates climate risks.[q] This is explored further in the materials section.

Design choices directly contribute to the overuse and over-specification of high-carbon materials. In a sample set of UK buildings, steel beams were designed to withstand twice the load than was structurally required.[55] Also in the UK, up to 50% of materials are wasted during the construction stage in some projects.[56] This unnecessary material demand adds pressure on finite natural resources, interferes and depletes ecosystems, and contributes to climate risks and high emissions.

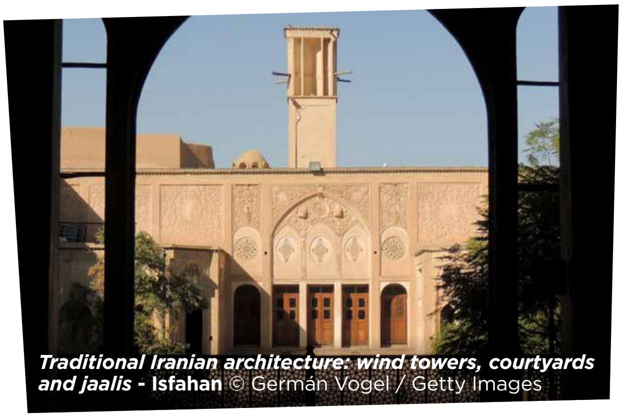
Design choices also influence the lifespan of our built environment. A building's life depends on its ability to withstand and adapt to varied and changing climate conditions, as well as its capacity to change functions depending on evolving users' needs. When design decisions have not accounted properly for future scenarios, assets can become stranded, vacant or hazardous. If not tackled, this can create negative social consequences such as increased crime rates.[57] The longer the buildings or assets remain unused, the more expensive repairs, renovation and retrofit solutions become.[58] Knocking down a building before the end of its useful life and building new is the usual answer to meet changing needs. This is the most carbon-, pollution- and waste-intensive option, often justified by economic models that prioritise profits over social and environmental benefits.[59]

[q] The destruction of ecosystems undermines nature's ability to regulate greenhouse gas (GHG) emissions and protect against extreme weather, thus accelerating climate change and increasing vulnerability to it.

Solutions

A resilient and decarbonised design approach prioritises local, low-carbon, circular and regenerative construction methods and materials. It factors in the location of the asset to embed and optimise its natural characteristics. It is adaptable and extends the asset's lifespan, while being fit for current and future purposes, including withstanding climate impacts safely and equitably.

Passive design strategies[r] harness natural forces, such as sunlight and wind, to better adapt to local climatic conditions and minimise the use of mechanical systems for climate control. They reduce energy demands of buildings without compromising indoor comfort. Passive techniques cope with extreme temperatures, particularly heat, with natural ventilation, tree canopy, narrow street layout, northerly building orientation, semi-permanent shading devices, roof and window protections, and high-albedo[s] roofing.[60] Compared to conventional energy-intensive heating, ventilation, and air conditioning (HVAC) systems, passive design strategies increase the adaptability and resilience of the building during extreme heat or cold events. Passive strategies require less maintenance than mechanical systems, resulting in cost savings. Other benefits include reduced materials use and improved comfort and productivity of occupants.[61]



***Traditional Iranian architecture: wind towers, courtyards and jaalis* - Isfahan** © Germán Vogel / Getty Images

Traditional or vernacular architecture[t] elies on passive design strategies adapted to the local context.[62] Wind towers[u], courtyards[v], roof terraces, and jaalis[w] (stone lattices) are examples of traditional architectural elements used in many parts of North Africa, West Asia and South West for effective sun protection and thermal control. Vernacular architecture can also play a prominent cultural role in communities,[63] for example courtyards or terraces act as communal spaces to promote social interaction and strengthen community bonds.

Combining traditional architecture with modern technological innovations[64] can reinforce their effectiveness. Prioritising passive strategies first can minimise the number of additional mechanical systems, which are more carbon intensive. Active building design,[65] such as solar panels, wind turbines, building automation and heat recovery systems, can achieve significant energy savings.[66] Reflective surfaces, such as white roofs[67] and solar PV, act as heat sinks to effectively cool buildings.

[r] Passive techniques utilise the natural environment to provide heating, cooling, ventilation, and lighting to a building without the need of purchased energy.

[s] High-albedo roofs such as green roofs, white roofs, terracotta tiles, reflect the sunlight and reduce heat transfer from the roofs to the interior of the building.

[t] 'Vernacular architecture refers to the traditional, indigenous, or native architecture of a particular place or region, often developed over time through a process of trial and error, rather than being designed by professional architects. It is typically functional, reflecting the needs, resources, and cultural values of the people who use it. Vernacular architecture is often characterised by a close relationship to the natural environment and the use of locally available materials and construction techniques. It can include a wide range of structures, such as houses, barns, sheds, temples, and other buildings that are adapted to the local climate, landscape, and way of life.' Urban Design Lab. (2023). https://urbandesignlab.in/vernacular-architecture-meaning-examples/

[u] Wind towers harness the cool breezes and redirect them downwards into the building through a shaft or tower.

[v] Courtyards allow natural light to enter rooms.

[w] Jaalis prevent glare and heat gain while facilitating ventilation and having visual connection with the outside.

The Confederation of Indian Industry Sohrabji Godrej Green Business Center (CII-Godrej GBC)

Hyderabad, India

© Swastik Banerjee

The CII-Godrej GBC combines traditional architectural elements such as wind towers and courtyards with passive cooling techniques such as northerly building orientation and cross-ventilation, complemented by a mechanical energy efficient system.[68] The 20,000 square foot green building contributes to 50% savings in overall energy consumption, a 35% reduction in potable water consumption and reduced embodied emissions through the use of 80% recycled materials.[69]

Eastgate Building,

Harare, Zimbabwe

© Carlos Takudzwa Kankhungwa / iStock Photo

The Eastgate Building uses passive cooling techniques inspired by termite colonies. It uses a system of tunnels and vents to regulate temperature. The Eastgate Building has hollow floors, central vents, external shading devices, air shafts and other passive design elements that lower the indoor temperature. The design incorporates low carbon indigenous masonry techniques, such as bricks and reconstructed stone, along with steel and glass. The building does not use a conventional air conditioning system at all. Overall, its engineers have found that it utilises 90% less energy that it would if it were built using conventional design principles.[70]

Cities have a significant stock of existing buildings and assets that require maintenance or design alterations to cope with changing environmental conditions and user needs. For example, more than 40% of residential buildings in Europe were constructed before the 1960s, when performance standards for building regulations were not very high.[71] Around 17-22% of buildings are expected to be renovated by 2033.[72]

Timely repair, maintenance, renovation, refurbishments and/or retrofits of assets with low-carbon materials make structural systems more robust and resilient in the face of climate hazards and avoids emissions from construction and demolition (C&D) waste and premature demolition.

Building retrofitting
United Kingdom © dmbaker / Getty Images

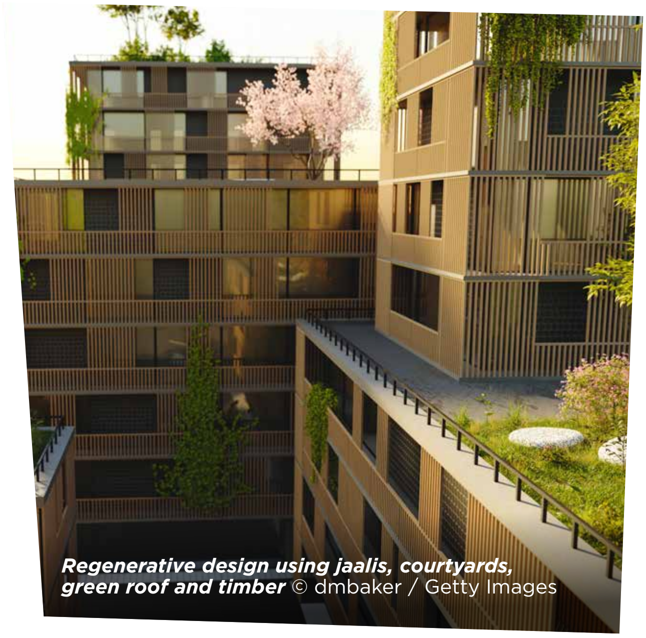
Adaptive reuse of existing structures or following a **design for adaptability**[73] approach for new assets allow components or systems to be replaced, removed or upgraded.[74] This intervention is designed to help buildings and infrastructure adapt to changing climate patterns and user needs.[x] For example, more structural flexibility makes it easier to add beneficial systems such as solar PV and green roofs in the future.[75] Adaptive reuse and design for adaptability increase longevity and reduce embodied emissions by demanding less virgin materials and generating less waste.

Adaptive reuse of heritage buildings and assets preserve the historical and sociocultural value of buildings while giving them new functions and uses.[76]

Design for adaptability can go hand-in-hand with **design for disassembly** (DfD) and other techniques such as **deconstruction, modular and prefabricated construction**. Design for disassembly enables the dismantling of components and materials once assets have reached the end of their useful life. This method recovers resources that would have been otherwise ruined by a wrecking ball and sent to landfill. The recovered elements can be reused, reducing the demand for raw material. Studies show that design-for-disassembly strategies result in significant life cycle impacts compared to conventional construction, and reduce GHG emissions between 10% and 50%.[77] **Material passports** and **buildings as materials banks** also optimise resources[78] and reduce embodied emissions. These measures ensure it is easier to repair damages from climate hazards[79] by documenting the materials present in a product or building.

[x] The term 'adaptability' usually refers to the capacity of buildings to change in response to varying needs. (skar, R., Bragança, L. & Gervásio, H. (2021). Adaptability of Buildings: A Critical Review on the Concept Evolution. Applied Science, 11 (10): 4483. Available at: https://doi.org/10.3390/app11104483).

Digital building technologies can support decarbonisation and resilience if they are geared to include climate information in their analysis. For example, Building Information Modelling (BIM) software models building and infrastructure projects during the planning, design, construction and operation phases to analyse trade-offs between different solutions. This helps to assess resource footprints such as energy, materials and water.[80] Integrating a life-cycle assessment (LCA) in the early design stage of projects for instance would support embodied emission reductions. BIM can also incorporate climate information such as solar radiation, wind patterns, temperature variations and precipitation levels, which then inform decisions about building orientation, insulation and energy efficient design.[81]


Regenerative design using jaalis, courtyards, green roof and timber © dmbaker / Getty Images

Digital twin is another tech-based solution where the physical building is mirrored as a 'twin' in a digital, dynamic format. This helps identify potential risks from extreme weather events for buildings or infrastructure and take preventive measures. This kind of automation increases efficiency, quality and safety and decreases the margins of error.[82] These digital tools are, however, not available or feasible in all parts of the world due to high cost and lack of technological knowledge and equipment. Fostering exchange of knowledge and supporting education and training of professionals should be a priority for the sector.

Regenerative design iis an approach that mimics restorative aspects found in nature to co-evolve with the surrounding natural environment. Regenerative design not only reverses degradation to nature, but can also replenish natural ecosystems.[83] It uses a variety of approaches including vernacular architecture, passive design, adaptive reuse, nature-based solutions and bio-based materials to create a positive impact on the human and natural systems that interact with them.[84] For example, well-designed green roofs and green walls[85] with carefully selected plant species can decrease the urban heat island effect, increase air quality, manage urban stormwater runoff and enhance biodiversity.[86]

To avoid siloed thinking and gain maximum benefits, design choices should integrate climate risk assessments and address existing social and environmental vulnerabilities in tandem with a **whole life-cycle (WLC) approach**[y] aaccounting for embodied and operational emissions across different stages of the asset's life-cycle.[87] Potential tensions between adaptation and mitigation solutions must also be considered. For example, passive cooling strategies such as wind towers and courtyards must be designed with bio-based or low-carbon materials to gain maximum dual benefits.

[y] Whole life-cycle emissions refer to all the emissions emitted throughout the life-cycle of a building or piece of infrastructure. C40 Clean Construction Accelerator Technical Note (2022). Available at: https://www.c40.org/wp-content/uploads/2023/10/C40-CCA-Technical-Note.pdf

City action examples


© James ONeil / Getty Images

Bioclimatic Urbanism Plan
Paris, France

Paris' Bioclimatic Urbanism Plan (2023) is an efficient urban planning tool to mainstream adaptation and mitigation actions that address both emissions and climate risks. The plan responds to rising temperatures by putting carbon thresholds on materials – the use of concrete is banned unless developers can demonstrate no other alternative. The plan prohibits building towers that are taller than 37 metres to reduce embodied emissions associated with tall buildings. It encourages green open space and specifically seeks to reduce impermeable surfaces in the city landscape. There is a wider set of actions that intelligently link decarbonising and climate resilience together, with a special focus on urban heat and flooding.


© Roberto Machado Noa / Getty Images

Toronto Green Standard 4
Toronto, Canada

The **Toronto Green Standard** (TGS) is a critical component of the City's **Net Zero by 2040 Climate Strategy**. TGS has been setting sustainable design and performance requirements for new private and city-owned developments since 2010. Version 4, which came into effect in 2022, takes into account a whole life-cycle emission perspective by setting caps on embodied and operational emissions. It requires the use of low-carbon sustainable material alternatives to the proposed structure and/or envelope. Using whole building energy modelling, energy demand is minimised through efficient building design, including optimised heating and insulation systems and the use of renewable energy. The standards also address the urban heat island effect and stormwater run-off through green roofs, high albedo pavement materials, permeable pavements and planting drought tolerant trees and shrubs.

Les Ateliers Cabot, Montréal © Sid Lee Architecture

Reinventing Cities winning project: Les Ateliers Cabot

Montréal, Canada

Les Ateliers Cabot, **Montréal**, is one of the winning projects from the second edition of the C40 **Reinventing Cities** competition. Les Ateliers Cabot transforms a former industrial site into an artistic, entrepreneurial and technological hub. The project prioritises existing assets, retaining and refurbishing 72% of the existing industrial buildings on the site. The project has reduced embodied carbon in the construction process by 64% by repurposing existing buildings, eliminating basements and using timber for new buildings.

Using a combination of adaptation measures, the project minimises the risk of overheating and flooding. This includes allocating 60% of space for greenery including a new urban forest and on-site natural retention basins.

Additional city examples

© Maremagnum / Getty Images

São Paulo's Environmental Quota (2016) mitigates floods on private allotments using nature-based solutions such as trees, green roofs, green walls, permeable flooring and draining reservoirs. Economic incentives such as a slight increase in the allowed built area per plot of land or tax relief for private enterprises are provided. This increases the city's resilience during storm surges and extreme rainfall, avoiding damage to people and property while also reducing emissions through nature-based solutions. When slight built area increases are granted, they should ideally also follow resilient, low-carbon design principles.

© Boy_Anupong / Getty Images

Melbourne is introducing stronger planning controls for developments that holistically combat the impacts of the climate crisis. The Sustainable Building Design – Planning Scheme Amendment C376 will reduce embodied emissions associated with design and materials, improve energy and water efficiency, reduce waste generation, as well encourage more greenery on roofs and walls through the city's Green Factor Tool.

© Jean-Baptiste Gurliat / Ville the Paris

The Oasis project in **Paris** is a city initiative that renovates school courtyards to increase the city's resilience to heatwaves and flooding. The renovated courtyards have increased vegetated areas and used light-coloured, low carbon materials that absorb rainwater and cool down the area. The design incorporates fun, child-friendly layouts and features.

Materials choices

Sydney © Andrew Merry / Getty Images

How do materials choices contribute to increased emissions and climate risks?

Aluminium, asphalt, concrete, steel, and glass are the most commonly used materials for the built environment globally. More than 70% of the world's population live in reinforced concrete buildings.[88] The extraction, production and assembly of these materials generate high upfront emissions, and these industries are projected to significantly grow[89] following the rising global urbanisation curve.[90] Concrete and steel respectively contribute 8%[91] and at least 7%[92] of global GHG emissions. TThe world now consumes more cement in one year than it did during the entire first half of the 20th century.[93] These materials also directly influence cities' climate vulnerability by contributing to the urban heat island effect and exacerbating urban flooding.

Commonly used plastic insulation, including expanded polystyrene (EPS) and extruded polystyrene (XPS), can achieve advantageous thermal conductivity, but they are criticised for their high flammability and high embodied carbon. They are made from unsustainable fossil fuel products and release hazardous waste at the end of their life.

Moreover, the increasing materials demand results in overexploitation of finite raw resources such as sand, limestone, iron ore, water, crude oil and gas. Three billion tons of raw resources are consumed each year.[94] Sand, a major component in producing cement, glass and asphalt, is currently being mined at a far greater rate than it can naturally replenish.[95] It is causing irreversible changes to riverine, deltas, coastal and marine ecosystems, such as river and coastal erosion, groundwater depletion and altered water flow patterns. This significantly contributes to habitat and biodiversity loss, as well as increases the vulnerability of nearby coastal communities to flooding and storm surges.[96]

Did you know?

After water, concrete is the most widely used substance on Earth.[97] It is cheap, versatile and all workers are trained to use it. Its global production is not slowing down: more than four billion tonnes of cement, concrete's main ingredient, are produced every year.[98] In comparison, eight billion tonnes of plastic has been produced over the last 60 years.[99] The environmental and cultural impacts of both materials are huge.

Concrete is made of cement, aggregates – sand or gravel – and water. Cement is the main cause of emissions. Mostly made from limestone, the rock is full of CO_2, which is released into the atmosphere when burned to produce lime. Concrete production is also a thirsty industry. It absorbs almost a tenth of all industrial water use, and strains drinking and irrigation supplies in drought and water-stressed regions where the industries operate.[100]

Concrete exacerbates various climate-related risks. Its impermeability prevents rainwater absorption and aggravates the speed and severity of flooding.[101] The prevalence of concrete and asphalt surfaces in cities contributes directly to the urban heat island effect.

Water-logging on concrete roads
China © undefined undefined / Getty Images

When combined with heat released by vehicle engines and air conditioning, paved areas can boost the temperature in cities by as much as 22°F (5°C), according to the US Environmental Protection Agency (EPA).[102] Rising temperatures disproportionately impact marginalised communities. Formerly 'redlined'[z] neighbourhoods in the US are 5°F (~3°C) warmer on average than non-redlined neighbourhoods,[103] due to fewer trees and more concrete. Warmer areas also increase the energy demand for cooling systems for those who can afford it and have health impacts for those who cannot.

"Concrete is how we try to tame nature. Our slabs protect us from the elements. They keep the rain from our heads, the cold from our bones and the mud from our feet. But they also entomb vast tracts of fertile soil, constipate rivers, choke habitats and – acting as a rock-hard second skin – desensitise us from what is happening outside our urban fortresses."[104]

- Jonathan Watts, global environment editor, The Guardian

[z] In the US, redlining was the institutional practice of denying financial services such as loans, mortgages, insurances to residents based on race. Legal Information Institute, Cornell Law School. Redlining. Available at: https://www.law.cornell.edu/wex/redlining

Materials also have a direct and indirect impact on workers and users' health. Spray foam insulation for instance releases volatile organic compounds (VOCs) during and after installation. It can cause pulmonary and respiratory health issues for users and construction workers if not properly managed.[105] Exposure to asbestos, used predominantly in the 20th century for insulation and fireproofing, causes cancers and other lung diseases.[106] Construction workers are on the frontlines of dealing with this toxic material, which poses a severe health risk during renovation and demolition.[107]

Although not a climate risk[108], earthquakes and seismic risks are a critical factor in determining design and materials choices. However, numerous contracting layers, low profit margins and fast delivery time can result in substandard materials and construction methods that do not comply with building codes and regulations.[109] Buildings and infrastructure constructed from low quality concrete or faulty design is considered to be one of the principal causes of fatalities in low- and middle-income countries.[110]

Despite regular earthquakes, building codes globally continue to rely solely on reinforced concrete designs for quake-resistant structures, contributing to high vulnerability and high emissions.[111] Most building codes exclude vernacular materials and techniques, often as a colonial or western legacy categorising them as primitive.[112] Adobe and non-engineered construction typically account for 70 to 80% of residential construction in developing countries and are often not formalised into building codes.[113] Rather, in some regions, policies act as deterrents, where the use of traditional adobe construction in urban settlements are banned.[114] In Turkey, the 1967 earthquake damaged residential buildings constructed of wood and stone, yet they were still standing after the disaste.[115] In 2023 the Turkey-Syria earthquake destroyed thousands of buildings made from concrete, steel and brick.[116] This was attributed to poor quality concrete and construction techniques, poor workmanship[117] and disregard for the region's traditional building culture.[118]

Solutions

Shifting to local and sustainably sourced bio-based materials is one of the most efficient ways to reduce the demand for carbon intensive materials.[119] Sustainably sourced and harvested bio-based materials contribute to highly resilient and low-carbon building and infrastructure.[120] For instance, sustainably sourced mass timber,[121] engineered bamboo,[122] well-designed straw bale[123] and rammed earth[124] structures are all low-carbon options

Straw bale structure
© anandoart / Getty Images

Rammed earth structure
Ouarzazate © Chris Griffiths / Getty Images

that are proven to withstand earthquakes. Mass timber also performs well when exposed to strong wind.[125] Bamboo structures on stilts[126] are designed to avoid flooding and withstand heavy storms.[127] Rammed earth[128] and straw bales[129] have outstanding thermal performance, meaning they perform well in extreme cold and can be considered viable alternatives to conventional high-carbon insulation materials.

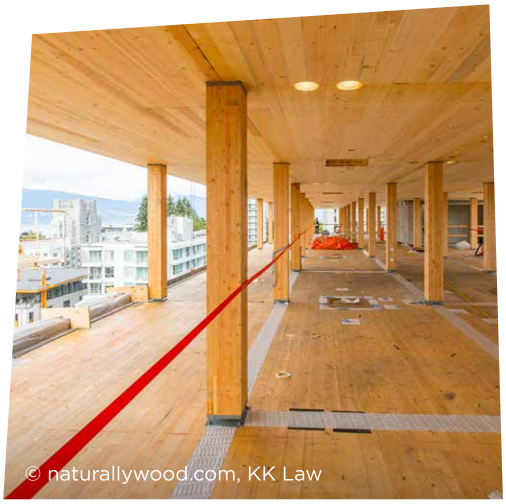
Regionally abundant low-carbon materials such as stone and earth are another strong solution. Used for thousands of years for its stability and durability, stone is making a resurgence in structure and wall cladding. It provides excellent thermal comfort to cope with high temperatures.[130] Well-designed stone masonry is also known to be earthquake resistant.[131]

Did you know?

Mass timber or engineered timber is made from several layers of wooden board stacked and glued together. This provides dimensional stability, strength and rigidity, making it a viable structural alternative to materials like concrete, masonry and steel.

Mass timber performs well when exposed to seismic forces[132] and windstorms as it is lightweight and can withstand very high loads and resist lateral forces. Mass timber can move like a tree in a windstorm, enduring no structural damage.[133] Fire performance and fire safety need to be carefully considered and handled by engineers, fire experts, insurers and regulators jointly. Fire risks require adequate, recognised and neutral competency to establish or restore trust, especially when it comes to addressing regulatory barriers.[134] A number of studies show positive results on fire and timber structural integrity[135] and highlight the importance of safety engineering[136] and local fire safety regulations.[137] However this remains a much-debated issue.

Besides aesthetic advantages, the indoor use of timber holds significant benefits in terms of health and wellbeing.[138] A hygroscopic material,


© naturallywood.com, KK Law

timber absorbs or expels moisture, maintaining a comfortable humidity level indoors. Mass timber fits well with biophilic design philosophy, leading to lower stress levels, improved physical and mental wellbeing and increased productivity.[139]

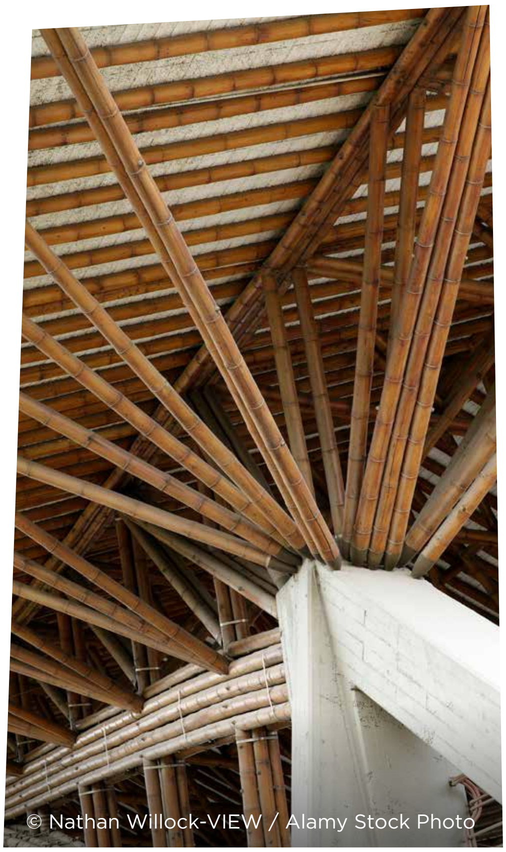
Timber must be treated against insect and fungal attacks for enhanced durability.[140] Scaling-up of mass timber products must go hand in hand with careful management of forest and agricultural lands to avoid mass-scale deforestation and depleted resources for future generations. Sustainable forestry practices such as afforestation and reforestation efforts will be crucial for a sustainable transition, particularly in emerging economies.[141] Circular timber practices will also be vital, for example combining its use with design for disassembly.

Did you know?

Engineered or structural bamboo is made from raw bamboo, which is treated with heat and pressure then glued together to form structural parts. Bamboo products are typically laminated with a resin to make them fire-resistant.[142]

Bamboo is a rapidly growing renewable material, with the ability to be harvested and replenished in just 3 to 5 years. Bamboo forests can produce 37% more oxygen than traditional forests, having immense carbon sequestration potential. Its root system stays intact throughout growth and harvest, preventing erosion of the topsoil.[143] Bamboo can and should be properly treated and dried prior to use to protect it from insects, fungus, rot, and fire.[144]

Engineered bamboo has outstanding structural abilities. Its compressive strength is on par with concrete and its tensile strength is higher than steel. These properties make it a fundamental material for quake-proof structural engineering.[145]



© Nathan Willock-VIEW / Alamy Stock Photo

Like timber, bamboo must be sourced from sustainably managed bamboo forests and harvested locally where possible.

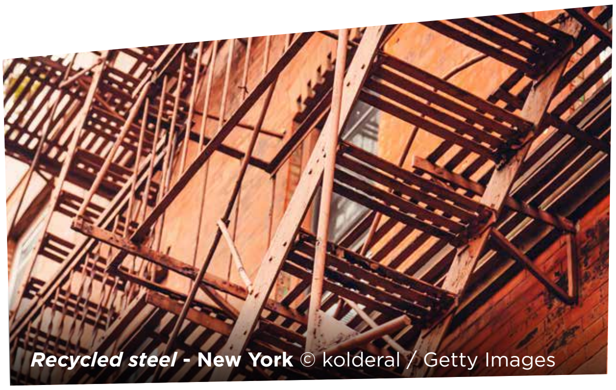
OctaGreen emergency shelters,
Pakistan

Yasmeen Lari, Pakistan's award-winning and first female architect, is on a mission with her team to support and train local communities in the flood-ravaged regions of Sindh and Balochistan to build their own low-cost and disaster-resistant homes as part of a post-disaster recovery rethink.

Known as the Lari Octa Green (LOG), these emergency shelters boast an octagonal shape made of bamboo panels lined with date palm matting and topped with a conical roof. The more permanent structures are coated in mud for insulation. These shelters use the vernacular architectural style and promote a zero-carbon, resilient approach to construction.

These can be built by six or seven people and cost around US$ 114 each. They can be easily turned into permanent homes or dismantled and transferred when displaced families move back to their home villages, avoiding demolition.[146]

Even though this case is set in rural parts of Pakistan, similar principles can be applied in cities with similar context.



***Recycled steel* - New York** © kolderal / Getty Images

Hybrid approach: Mass timber building on stone foundation set in cement mortar © BuildX Studio

Low-carbon versions of high-emitting materials such as recycled steel and low carbon concrete should be considered when available, especially in cities where bio-based materials are not an option. If combined with clever design, they can help increase resilience. For instance, permeable low carbon asphalt can increase flood resistance.[147]

In most cases, a **hybrid approach to materials choices** combines bio-based, reused and/or recycled materials with reduced quantities of low carbon versions of high-emitting materials. Each material should be selected depending on its specific properties and suitability. For instance, low carbon concrete structural foundations for a mass timber building can protect from water damage, as timber is not suitable for all applications.

Base Bahay,
Manila

© Spring Rain Global

Base Bahay is a Filipino organisation that researches, pilots and mainstreams alternative building technologies. It developed the Cement Bamboo Frame Technology (CBFT), which combines a load-bearing bamboo frame with metal connections and mortar cement plaster.

Base Bahay took inspiration from Bahay Kubo, a traditional Filipino house made of wood and bamboo and raised on stilts. This pliable, lightweight structure facilitates easy reconstruction and repairs following earthquakes, typhoons, or floods. Base Bahay is pioneering the use of bamboo to create affordable, low-carbon homes that are resilient to climate hazards.

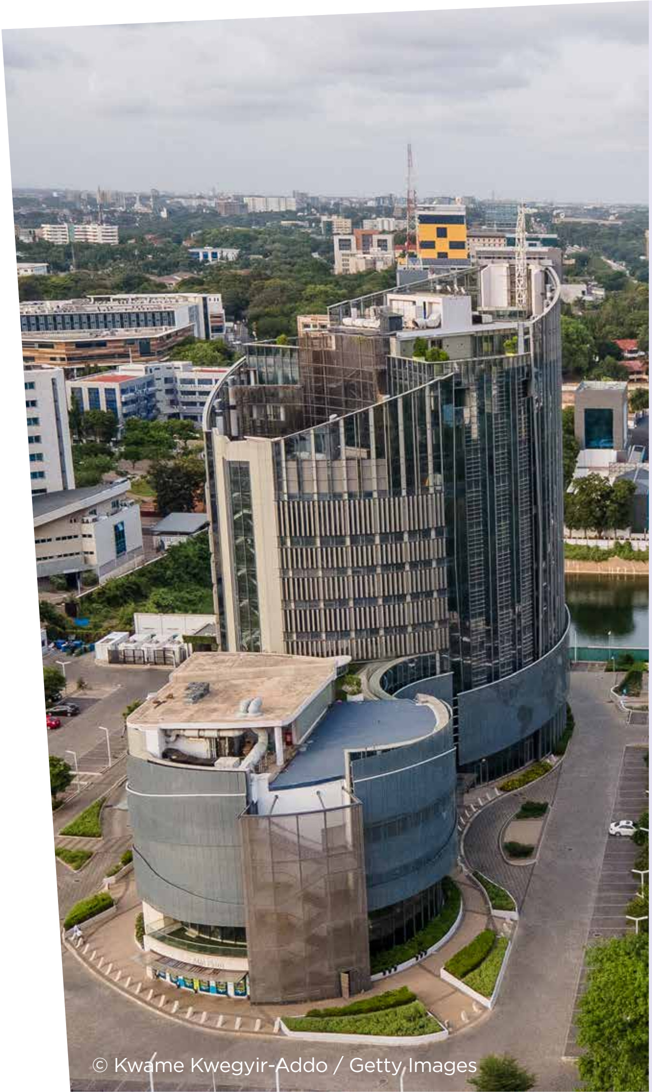
Base Bahay has helped establish bamboo settlements across Metro Manila, including an affordable housing project made up of 25 homes in the north region of Quezon City. These structures save 15–20% in costs and reduce emissions by 74%. The programme combines vernacular and modern architecture. In 2020, the Base Innovation Centre opened, serving as a research and training hub for CBFT and other alternative building technologies to promote its use.[148]

Hybrid materials are a growing innovation trend to reduce embodied carbon, especially from conventional Portland cement. Timbercrete[149] uses sawdust to replace cement and ferrock[150] uses recycled materials such as waste steel dust and silica from ground-up glass.

The uptake of these solutions requires adequate research and testing to guarantee quality control and safety of residents.[151]

Timbercrete © Glenn / Flickr

City action examples



Ghana Building Code,
Accra, Ghana

The **Ghana** Building Code (2018) establishes minimum requirements for buildings in the country using prescriptive and performance-related provisions. The building code helps standardise structural efficiency, durability and materiality to increase climate and social resilience, reduce emissions and improve public and environmental health and safety.[152]

The code sets requirements against shoddy and substandard building practices and requires developers and building owners to comply with regulations when retrofitting buildings. It is modified from existing international standards to suit local conditions by formalising the use of vernacular design and materials. It also encourages material selection that provides resilience from fire, earthquakes, and flooding.[153] The code incorporates locally made materials such as bamboo and rattan.[154]

The Ghanaian government is partnering with private sector and research institutions to develop best practices, for example promoting the use of new materials. The code is also projected to increase the demand of skilled labour in the building and construction industry by providing over 100,000 new good, green jobs.[155]

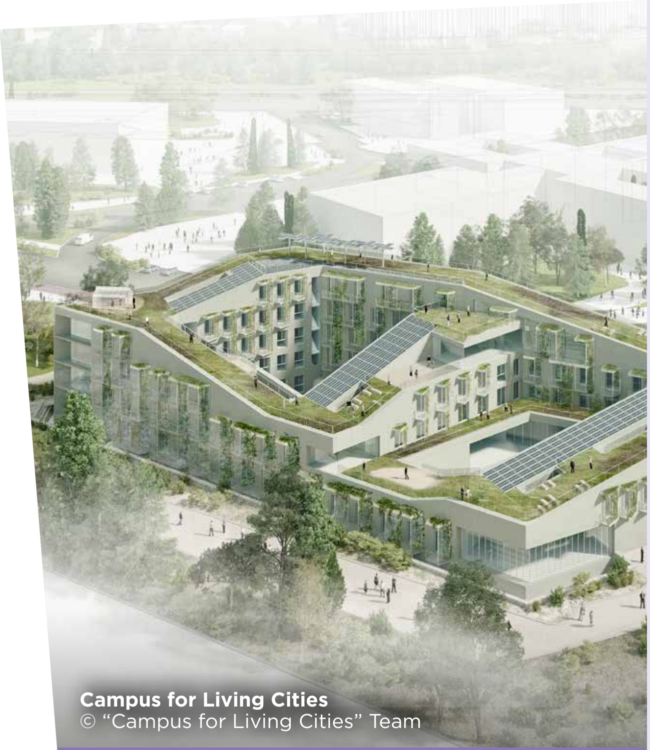
The Collective for Climate © The Collective for Climate

Reinventing Cities winning project: The Collective for Climate, Paris, France

The Collective for Climate, **Paris**, is one of the winning projects from the first edition of the C40 Reinventing Cities competition.

he project is the first zero-carbon neighbourhood in Paris and spans over 35 hectares. 80% of the superstructure will be built with French Cross-Laminated Timber (CLT) and stone. All façades are entirely made of locally bio-sourced materials such as terracotta, bricks and hemp.[156] The project used adaptive and bioclimatic design strategies such as bio-solar roofs, semi-permeable surfaces, rainwater harvesting and dedicated green vegetative spaces to tackle extreme heat, flooding, drought and water scarcity.[157]

By combining relevant mitigation and adaptation measures, the project reduces embodied and operational emissions by 85% while adapting to climate stresses and shocks such as extreme heat, drought and flooding.



Campus for Living Cities
© "Campus for Living Cities" Team

Reinventing Cities winning project: Campus for Living Cities,
Madrid, Spain

Campus for Living Cities, **Madrid**, is one of the winning projects from the first edition of the C40 Reinventing Cities competition.

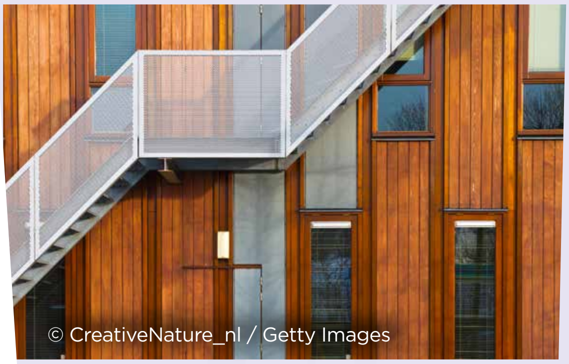
The project includes the extensive use of wood and bio-sourced materials and is set to be the largest cross-laminated timber structure in Spain. It also includes lightweight wooden insulated panels. The project will reduce building emissions by 87% compared to business-as-usual.

Through bioclimatic and regenerative design, the project achieves a 56% decrease in building water usage through greywater recycling, along with a 90% reduction in irrigation via native plant species. The project also integrates nature-based solutions such as permeable paving, infiltration trenches, underground and rooftop reservoirs. Biodiversity is enhanced by green roofs and micro-habitats, having a cooling effect to protect residents from increased and prolonged heat waves.

Additional city examples


© Didier Marti / Getty Images

New York City is partnering with a research institute to develop and test ground glass pozzolan, made from recycled post-consumer glass, to reduce embodied emissions in coastal infrastructure projects. This material has the potential to replace up to 50% of cement in concrete, dramatically reducing its emissions. The initiative on ground glass pozzolan will explore its use in marine application, with a view to incorporate it into large coastal infrastructure projects for increased resilience against sea-level rise.


© CreativeNature_nl / Getty Images

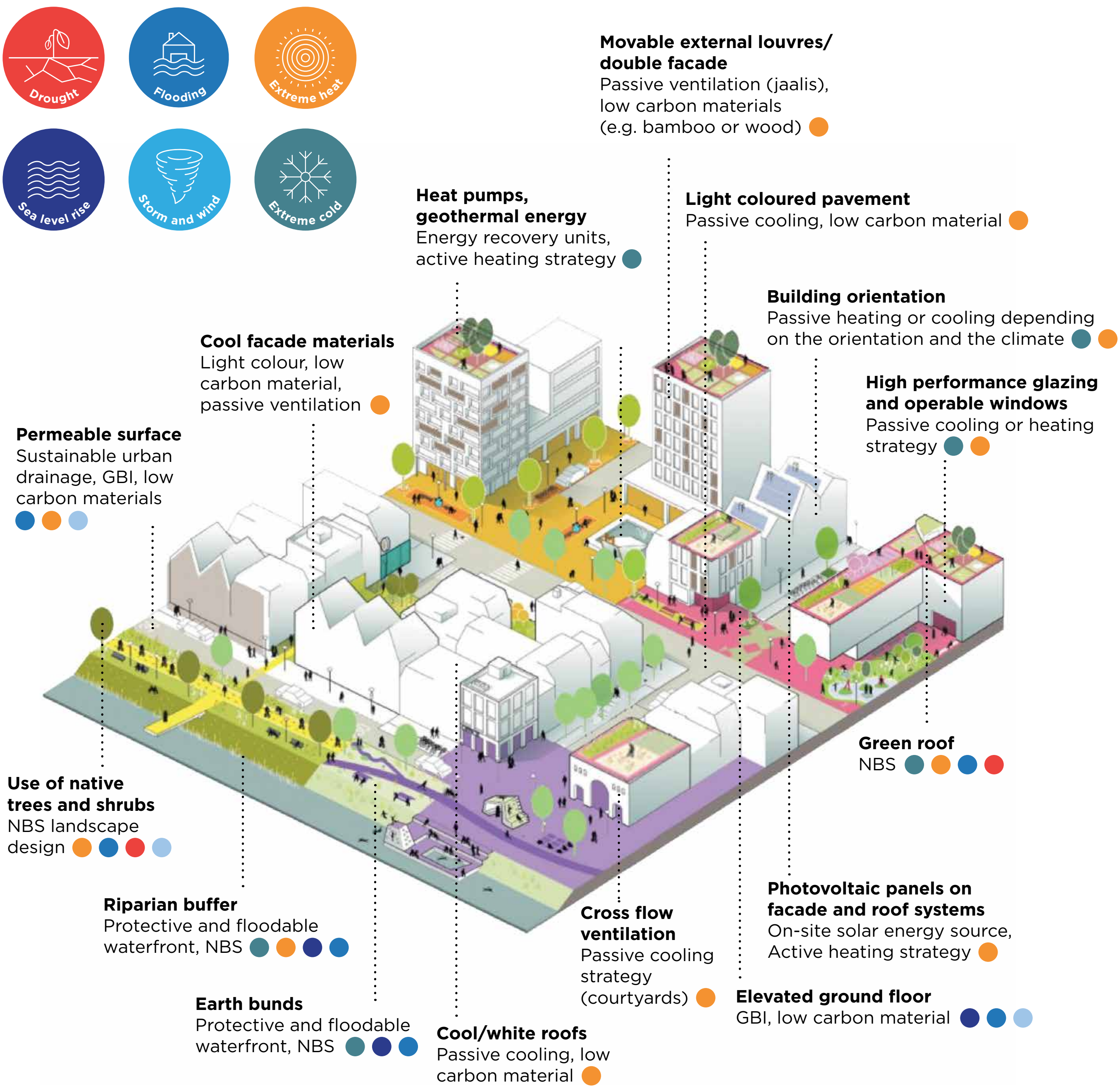
Amsterdam Circular Economy Implementation Plan 2023–2026, (November 2023) shows how the city will revert current patterns of material use and reduce climate risks. The city will stimulate the use of circular and biobased construction materials, including insulation such as cellulose, flax and cattail. This will help increase their market availability and reduce the harmful effects of construction materials' production, in conjunction with the Amsterdam Metropolitan Area's Timber Construction Green Deal. This is expected to reduce approximately 220,000 tons of CO_2 annually. Other measures include extending the lifespan of buildings and infrastructural assets, ensuring all urban planning projects conform with circular design principles, circular construction, circular criteria in procurement for all municipal assets, renovations, maintenance and material reuse in public spaces.

The city recognises that by using fewer primary raw materials, huge sustainability gains can be made in terms of GHG emissions, climate and biodiversity. The city is promoting artificial turf made from biobased materials to keep the ground cooler and facilitate intelligent water storage.

Cityscape example for location and site, design and material choices

Solutions currently exist that can best tackle emissions and vulnerability jointly. The illustration below showcases some of the wide range of solutions that we've discussed within each section. It is important to note that location, design and material choices are intrinsically connected and suggested solutions should be assessed and implemented depending on each city's specific context.

Figure: **Cityscape example for location, design and material choices**



Recommendations for Policymakers

The built environment shapes our lives in numerous ways. It makes up our homes, offices, schools, hospitals, streets, bridges, drainage systems, electrical lines, parks, open spaces and more. It is designed primarily to protect and serve us, however this urban fabric also:

- contributes massively to GHG emissions, resource consumption, pollution and waste streams
- contributes to and amplifies climate risks, for example by worsening flash floods and the urban heat island effect
- is the first impacted by loss and damage, with unequal and often deadly impacts on communities and workers

Actions to build resilience must accompany the charge toward net zero. The long lifespan of buildings and infrastructure means we need to act now to avoid locking-in the emissions and climate risks generated by their construction and operation. It will only become more complex and costly to mitigate these as time goes on.

Cities and the sector as a whole need to adopt more integrated mitigation and adaptation actions when tackling the unequal climate impacts of buildings and infrastructure.

The recommendations listed here can support cities to meet their climate targets while ensuring the built environment effectively protects, provides for and connects all residents, even in the context of climate breakdown.

Please note that the following recommendations are not a comprehensive list, but a selection of key steps that cities can take to effectively adopt, activate and mainstream the solutions presented in this paper in an integrated way.

Depending on their powers, cities can:

1 **SYSTEMATISE AND IMPLEMENT CLIMATE RISK ASSESSMENTS (CRA) AND MODELLING SCENARIOS** TO LEAD BY EXAMPLE AND INFORM THEIR:

- early warning systems
- evacuation and emergency plans
- land use, zoning and planning policies
- public procurement requirements
- building codes or by-laws

> *These types of assessments support cities to make informed decisions, avoid malinvestment, loss and damage on people and assets, and avoid speedy high-emitting repairs and reconstruction that often follow.*

2 PRIORITISE NATURE-BASED SOLUTIONS AND BLUE-GREEN INFRASTRUCTURE THROUGH:

- land use, zoning and planning policies, for instance by mandating the use of green factor tools
- public procurement requirements
- building codes or by-laws
- the creation, preservation or regeneration of existing natural habitat and ecosystems, including the protection of bio-diverse areas in the city
- incentives such as tax reductions and speedy planning approvals for developers
- commitment to science-based targets and tangible actions through relevant C40 Accelerators
- awareness, education campaigns and official guidance on the application and benefits of nature-based solutions for residents and the wider sector

> ***Cities can use tools to model emissions impacts of projects, such as Pathfinder, Sasaki Carbon Conscious Resources or co-creation platforms such as Urban Living Lab for sustainable, future proof natural innovations that improve quality of life and boost the economy.[158] Where cities foresee stakeholder resistance, they can provide free licences to such tools, especially for SMEs and vulnerable businesses.***

> ***The C40 Urban Nature Accelerator offers a good example of cities committing to tangible actions for greener and more resilient urban areas with solutions from nature.***

3 EXTEND THE BUILT ENVIRONMENT LIFESPAN VIA:

- proactively mapping social and environmental vulnerabilities
- measures to maintain, repair and retrofit buildings and structures to ensure they are low carbon, energy efficient and resilient assets
- tracking vacant, underused, unused, derelict or stranded assets
- voluntary schemes, incentives and disincentives such as tax on vacant properties, to bring back assets to the market
- adopting mixed-use and adaptive land, zoning and planning policies, public procurement requirements and building codes or by-laws
- support or lead workforce training and skills development programmes for low-carbon, energy efficient and resilient renovation and retrofitting projects

> ***Care should be taken to embed equity and social justice at the earliest stage of decarbonised and regenerative choices to reap the maximum benefits of reducing emissions and climate risks while meeting people's needs, especially the most marginalised.***

[A] Novel in the way they are being used to achieve different co-benefits.

4 AUTHORISE, ADOPT AND REWARD VERNACULAR, PASSIVE AND BIOCLIMATIC OR REGENERATIVE DESIGN TECHNIQUES THROUGH:

- land use, zoning and planning policies
- public procurement requirements
- building codes or by-laws
- circular economy strategies and plans
- incentives for the sector to adopt these techniques, such as financial schemes, design criteria, bonus points and fast tracking planning approvals
- demonstration sites and pilots
- regular dialogue with communities and residents to raise awareness and foster ownership
- city-led or city-supported workforce training, skills development and apprenticeship programmes to increase trust, build capacity and create decent and good green job opportunities
- investment and support of R&D to demonstrate the validity of vernacular, passive and bioclimatic techniques, to dispel misconceptions around their use and enable evidence-based choices. Such investments can be balanced against the costs of loss and damage from present and future climate disasters[159]
- official guidance for practitioners, written after proper consultation

> ***Documenting and disseminating the numerous benefits of these techniques will support buy-in and agency from local communities and businesses.***

5 AUTHORISE AND MAINSTREAM LOW CARBON AND CIRCULAR CONSTRUCTION MATERIALS THAT REDUCE CLIMATE RISKS WITH:

- all the levers described in recommendation 4, facilitated by digital buildings and landscape technology where available
- explicit mentions and measures in adaptation and climate resilient strategies and plans
- required Life Cycle Assessments (LCAs) and Environmental Products Declarations (EPDs) when available in zoning, planning and procurement
- created and enforced carbon thresholds on high carbon industrialised materials, unless developers can demonstrate no other alternative can be used
- incentivising the adoption of circular, low-carbon, modular, offsite and prefabricated construction in private projects, for instance via bio-based materials requirements and pre-demolition audits

> ***Regular dialogues between communities, residents, workers and the building sector is critical to address cultural barriers and potential misconceptions from both the general public and the sector.***

6 ADOPT A WHOLE-LIFE CARBON (WLC) APPROACH:

- mandate WLC assessment[160] in municipal projects
- demand WLC assessment reporting in zoning and planning policies and in building codes or by-laws
- use the WLC data gathered to set informed targets and define baseline
- enforce whole life-cycle limits or caps in construction projects zoning and planning policies and in building codes or by-laws
- incentivise first then require materials and energy efficiency in renovation, retrofit and new projects through all levers available

> *Cities should support a holistic approach to decarbonised and resilient assets by adopting a WLC approach in tandem with the five recommendations above. This will address any unintended trade-offs between operations and embodied emissions, as well as tensions between mitigation and adaptation agendas, as detailed in the design section of the paper.*

> *A WLC approach is a key opportunity to embed equity and inclusion across the construction sector. This can include training, retraining or upskilling on-site construction workers to work on retrofits; deconstruction to salvage materials and components; or with mass timber. Tools such as C40's Equitable and Inclusive Infrastructure tool for zero carbon buildings projects can support cities to make evidence-based decisions and plans.*

Additional C40 resources

- Reducing climate change impacts on new buildings, C40 Cities
- Reducing climate change impacts on municipal buildings, C40 Cities
- Reducing climate change impacts on private buildings, C40 Cities
- Reducing climate change impacts on clean energy supply, C40 Cities
- Clean Construction Policy Explorer, C40 Cities
- How to adapt your city to extreme heat, C40 Cities
- How to adapt your city to sea level rise and coastal flooding, C40 Cities
- How to conduct a climate change risk assessment, C40 Cities
- Climate Change Risk Assessment Guidance and Screening Template, C40 Cities
- Water Safe Cities, C40 Cities
- Adaptation and Mitigation Interaction Assessment (AMIA) tool, C40 Cities
- Why your city should use nature-based solutions to manage climate risks, C40 Cities
- Nature-based solutions: How cities can use nature to manage climate risks, C40 Cities
- The Future We Don't Want, C40 Cities
- Net Zero Carbon Buildings Accelerator, C40 Cities
- Clean Construction Accelerator, C40 Cities
- Urban Nature Accelerator, C40 Cities
- Water Safe Cities Accelerator, C40 Cities

A number of valuable resources from partners and other organisations can be found in the references.

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