RESILIENT CITY

LANDSCAPE ARCHITECTURE FOR CLIMATE CHANGE

Elke Mertens

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BIRKHÄUSER BASEL

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FOREWORD

Richard Stiles

Colonial histories record that it was in 1855 that the Scottish explorer David Livingstone "discovered" that massive wonder of nature which he named Victoria Falls. Today, from our somewhat more enlightened perspective, we ask ourselves how it could be that the local native population had for centuries completely failed to notice this spectacle and that they required a foreign explorer to point it out to them!

Such colonial hubris comes to mind when one reflects on the recent rise to prominence of green infrastructure as a potential new savior of our cities and landscapes in the face of today's combined climate and biodiversity crises. The first use of the term "green infrastructure" can be traced back to a 1994 report on land conservation to the governor of Florida,[1] yet what is now being referred to as urban green infrastructure is surely nothing more than the very parks and squares that William Pitt "the Elder," British prime minister during the middle of the 18th century, was already referring to as "the lungs of London."

The fact that the life-enhancing qualities of urban green spaces have long been understood is further reinforced by examples such as the work of the prolific writer on gardens and horticulturalist, John Claudius Loudon, who was instrumental in proposing urban green space planning concepts for London with his *Hints for Breathing Places for the Metropolis,* published in 1829. Understanding parks and green spaces as "lungs" and "breathing spaces" viewed them very much from the perspective of green infrastructure, as did the call for "green rings around cities" in a German publication in 1874 by Adelheid Ponińska, Countess of Dohna-Schlodien, or the promotion of "sanitary greenspace for cities" in the 1915 dissertation of the Berlin city planner, Martin Wagner.

So if green infrastructure, like the Victoria Falls, is not such a new phenomenon after all, but perhaps just a new way of looking at something we have known about all along, then perhaps it is not "foreign" explorers that we need to bring it to our attention, but rather the "local knowledge" of those "natives" who knew it was there all along. As this excellent book wastes no time in reminding us, those "natives" are in fact landscape architects, for whom the planning and design of urban greenspace has long been a major concern. *Resilient City* invites us to view the urban environment from a fresh perspective, drawing attention to the critical relationship between three factors: climate change, green infrastructure, and resilience.

1
Karen Firehock (2010): A Short History of the Term Green Infrastructure and Selected Literature, January 2010, www.gicinc.org/PDFs/GI%20History.pdf

With the help of eleven city portraits of metropolises located across a wide spectrum of climate zones in the Americas, from Vancouver in Canada to Montevideo in Uruguay, it illustrates the ways in which landscape architecture is seeking to use different forms of green infrastructure to promote resilience to the impacts of climate change. In each case, a general introduction to the conditions in the city together with the challenges posed by the changing urban climate are followed by in-depth examples of landscape policies, plans, and projects which are being developed to strengthen the future resilience of the cities concerned. What these examples also highlight is the fact that, while the amelioration of climate change impacts is a vital function of urban green infrastructure, it is not its only function. As a rule, green infrastructure does not exist independently of traditional parks and urban greenspaces, and thus its role in promoting resilience has to happen alongside their many other time-honored functions, from being urban lungs and breathing spaces, to attractive places for recreation and relaxation, refuges for flora and fauna, as well as being important carriers of meanings and values for the people of the city.

As *Resilient City* convincingly demonstrates, navigating this, at first sight unfamiliar territory of urban green infrastructure does not, after all, call for a new breed of colonial explorer; instead we can put our faith in the tried and tested knowledge and skills of our reliable "native" guides to this terrain, landscape architects.

URBAN GREEN INFRASTRUCTURE

Today, more than half the world's population live, work, and spend their time in cities. To lead productive and fulfilling lives, they need healthy environments that allow them to flourish and realize their potential. In this context, green areas and public spaces where people can spend free time, play, exercise, and relax are of vital importance for cities. As experts for the design, construction, and maintenance of outdoor spaces, landscape architects play an important role, and in times of climate change, it is their competence that is especially needed to address the increasingly challenging and important planning and design tasks facing cities.

Green open spaces such as parks and gardens not only provide recreational opportunities for city dwellers but also serve other functions, such as ecological compensation areas for sealed surfaces, fresh air corridors for ventilating the city, and retention, infiltration, and evaporation surfaces for maintaining the water balance. In addition, they are needed as buffers for increasingly recurrent extreme weather events, during either heavy rainfall and storm surges or heat and extended dry periods. These functions, which are vital in all cities, are often referred to as green infrastructure, or, where bodies of water are also involved, as green-blue infrastructure. Like gray infrastructure—the technical facilities and utilities for supply and disposal, and social infrastructure, such as schools, care facilities, hospitals, sports grounds, and cultural facilities—green spaces are equally a form of infrastructure that serves important needs. They are generally accessible to the public as places to meet and are usually provided and looked after by the public sector, even if the land does not always belong to the city.

Any form of infrastructure only functions effectively if well maintained and kept in optimal condition on an ongoing basis. Green infrastructure, when properly managed, even becomes more valuable over time as vegetation grows, because the effect it brings improves as plants mature compared with when they were just planted. A further important quality of infrastructure is flexibility—especially in the context of climate change. Many gray infrastructure assets, such as road and rail structures or canals, flood protection walls or dams, as well as larger buildings, are static and can adapt only slightly to changing conditions. Green infrastructure, on the other hand, has a high degree of spatial and temporal flexibility, and its functions can adapt more quickly to new environmental conditions, such as climate change. In addition, green infrastructure serves multiple

functions: alongside being spaces for urban recreation, they help keep cities cool, retain groundwater, and bind and convert CO_2. Unlike gray or social infrastructure, green-blue infrastructure has no standard solutions, and must respond to the specific conditions of each place and be regularly reviewed, adjusted, and redeveloped, especially with regard to climate resilience. Adapting green infrastructure to changing climatic conditions is therefore an iterative process of ongoing development and management. While landscape architecture has increasingly embraced the wider remit of green infrastructure, in practice it still often fails to fully utilize the spectrum of available sustainable opportunities, such as rainwater harvesting, green roofs and facades, natural shading using tree canopies, and urban gardening.

This book looks at eleven cities in North and South America and examples of some of their outstanding projects by landscape architects to show how cities are preparing for climate change and using landscape architecture to mitigate its effects. Each of the cities was visited in 2018 and 2019 as were many remarkable landscape architecture projects and other relevant climate initiatives, and the author met and talked to numerous landscape architects, city administrators, and research institutions. Finally, the projects and lessons learned were evaluated and presented in this book. The approaches and plans described can serve as models for other cities, and the projects likewise as pioneering examples of new landscape architecture that can make a significant contribution to climate adaptation. Together they illustrate the factors that need to be considered in the design and development of climate-resilient open spaces. Of particular importance is collaboration with other disciplines and it is here that landscape architects can play a leading role.

CITIES IN THE CONTEXT OF CLIMATE CHANGE

While cities have been identified as major contributors to pollution and the emission of greenhouse gases in the discourse on climate change, city dwellers are also among those most directly affected by its impacts. Cities, therefore, have a particular responsibility to effectively reduce the causes of climate change and, at the same time, must also ensure that their citizens and urban infrastructure are not harmed by its effects. Many cities are already experiencing the urban heat island effect and accompanying heat stress for its citizens. Clearly, people are less able to adapt to higher temperatures, and young children and the elderly are particularly vulnerable to extreme heat. Climate change is therefore already affecting urban climates and its impacts are likely to be more pronounced in future. Even though the scale of the challenge varies, every city in the world is faced with the task of limiting such impacts and must adopt effective measures based on its size, geographic location, climatic conditions, and social and economic situation, to mitigate the impacts of climate change on economic and political equality, environmental justice, food security, public health, and biodiversity. In particular, the creation of networks between cities can help share knowledge and experience, and contribute to developing concerted action towards more rapid climate resilience, which ultimately benefits urban populations around the world.

Of central importance for research on the causes and consequences of climate change around the world is the Intergovernmental Panel on Climate Change (IPCC). Founded in 1988 by the World Meteorological Organization and the United Nations Environment Programme (UNEP), it is based in Geneva and serves as a source of information on climate change for policymakers, industry, and the general public. All 193 United Nations Member States can participate in the IPCC. It is divided into three Working Groups: the first works on the scientific basis of climate change, the second on the impacts and options for adaptation and vulnerability due to climate change, and the third on mitigating climate change by reducing emissions. The IPCC compiles findings from global research and regularly publishes assessment reports, which undergo a thorough scientific peer review process and are thus highly reputable. Additionally, the IPCC provides a knowledge base for decision-makers and is an important advisor to the UN Framework Convention on Climate Change. The upcoming Sixth Assessment Report will be published in 2021/22. Among the IPCC Special Reports are those on *Global Warming of 1.5 °C* and on *Climate Change and Land*, published in 2018 and 2019, respectively. A working group report on the *Mitigation of Climate Change* was prepared as part of the Fifth Assessment Report in 2014.

The IPCC Reports attribute climate change to the emission of greenhouse gases into the atmosphere from anthropogenic sources. Of these, the most harmful gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and man-made fluorinated (F) gases (HFCs, PFCs, and SF_6), with CO_2 accounting for the largest share. The major source of CO_2 is the combustion of fossil fuels in the power conversion systems of electric power plants, aircraft and vehicle engines, cooking, space heating, and industrial manufacturing processes. While these emissions account for the largest share of greenhouse gases, a further third of emissions result from agriculture (mainly CH_4 and N_2O), deforestation (mainly CO_2), fossil fuel production (mainly CH_4), industrial processes (mainly CO_2, N_2O, and F-gases), as well as municipal waste and wastewater (mainly CH_4).

Among the most common impacts of climate change are increasing temperatures and heat stress, rising sea levels with more frequent storm surges and heavy rain events, and flooding. Climate change affects all major climate parameters—temperature, precipitation, wind speed and direction—and the exact impacts of these changes are still unclear. Similarly, it is hard to make accurate predictions about the ramifications that will affect a city, when, or to what extent. What is clear, however, is that if cities evolve sustainably to address climate change, this will benefit climate adaptation around the world.

Although societies and cities are changing greatly as part of the global megatrend of urbanization, it was not until its Fifth Assessment Report in 2014 that the IPCC included a chapter on "Human Settlements, Infrastructure, and Spatial Planning" as part of the Working Group Report on *Mitigation of Climate Change*. By 2050, the urban population is expected to grow by 2.5 to 3 billion and will account for 64 to 69 percent of the world's population. There will also be correspondingly more urban spaces and infrastructure than at present. How cities and urban areas develop in the coming decades will be crucial for global energy consumption and CO_2 emissions.

Already in 2014, cities were estimated to account for between 67 and 76 percent of global energy consumption, and 71 to 76 percent of global energy-related CO_2 emissions. In the context of the urban realm, the factors that contribute most to greenhouse gas emissions include density of development, land use mix, and transportation and accessibility, which strongly determine traffic flows and volumes. Since these aspects interact with each other, they should therefore be considered not as isolated but rather as interdependent factors.

While cities are responsible for a high proportion of global CO_2 emissions, they occupy only 2 to 3 percent of the Earth's land area. Although the growth of conurbations will increase this to 4 to 5 percent by 2050, the ratio will still be disproportionate. Considering that cities are think tanks with the economic, scientific, and political potential to steer climate-sensitive development, and at the same time are major contributors to global warming, they have both the opportunity and a special obligation to positively influence climate change. Their focus must be twofold: on reducing, and ideally avoiding the production of greenhouse gas emissions (mitigation), and on reducing the impact of the changes that are occurring (adaptation).

Since cities are dependent on their hinterland for food production, for parts of their infrastructure, and for recreation, it is also important to establish a climate-respecting connection between the city and its surroundings. As cities grow, they expand into areas formerly used for agriculture and forestry, resulting in land use conflicts. Agricultural land, which currently accounts for 37 percent of the world's land area, has increased over the last three decades, especially in the tropics. To feed the growing world population, even greater areas of agricultural land will be needed. Much of it is converted into large-scale farming of meat and of soybeans, the latter being mostly used as animal feed, and for the extraction of palm oil. This in turn results in a tragic loss of biodiversity and ecosystem capacity, including the sequestering of CO_2. In contrast to the growing consumption of land by cities and for agriculture, forests are dwindling. Currently, forests account for about 29 percent of the world's land area, of which about two-thirds is forested, and only 36 percent is primary forest. Despite large-scale afforestation in various regions around the world, forests are being razed at an alarming rate, contributing to a loss of biodiversity and ecosystem capacity, as well as higher land erosion due to the removal of land cover and lower soil fertility.

The 2019 IPCC *Special Report on Climate Change and Land* points out in its "Summary for Policymakers" that land use actions that help adapt to climate change and mitigate negative impacts also counter desertification and land degradation, and improve food security. It explicitly mentions the mitigation potential of better cropland and livestock management, of agroforestry and systemic improvements to the entire food system from production to consumption, including food loss and waste.

The IPCC proposes Climate-Resilient Development Pathways (CRDPs) that can be used to shape a society-wide desirable future that is both socially equitable and low in carbon dioxide emissions. These correlate to the United Nations Sustainable Development Goals (SDGs) and the statements of the Paris Climate Agreement, in which the implementation of rapid greenhouse gas reductions

must be based on equity and take place in the context of sustainable development and efforts to eradicate poverty. The CRDPs combine the near-term implementation of the Sustainable Development Goals with a long-term sustainable strategy for development and reducing emissions to net zero by the middle of the century. To achieve this, urban habitats must become more resilient and able to adapt flexibly. Aside from that, networks are needed to enable and promote exchange when elaborating CRDPs, but each city will still need to develop its own CRDPs.

The 2018 IPCC Special Report on *Global Warming of 1.5°C* stresses the importance of not exceeding the 1.5°C global warming goal agreed at the 2015 Paris Climate Summit, because any effort required to adapt to temperatures beyond that is much greater. It also underlines that adaptation measures must go further than merely responding to specific impacts of climate change, for example building a seawall as a barrier against tidal surges, and instead require profound, systemic change, such as new strategies for responding to storm surges and runoff from rainfall events. This kind of transformative adaptation also involves reshaping social and ecological systems. In this respect, the IPCC's goals to meet the 1.5°C limit overlap to a large extent with the United Nations SDGs, which were also adopted in 2015.

The 17 SDGs are part of the 2030 Agenda, the UN's global plan to promote sustainable peace and prosperity and to protect the planet. To this end, national development plans should address the problems of poverty and social inequality, paying particular attention to the most vulnerable populations so that no one is left out in the effort to achieve the Agenda's goals by 2030. Overall, the SDGs aim to eradicate extreme poverty and hunger; to secure health, education, peace, clean water, and clean energy for all; to promote inclusiveness and sustainability in consumption, cities, infrastructure, and economic growth; to reduce inequalities such as those between genders; to combat climate change; and to protect the oceans and terrestrial ecosystems. *Goal 13: Climate Action* explicitly identifies climate change, its negative impacts on economies and the lives of people, especially the poorest and most vulnerable. Other goals closely linked to climate change include *Goal 3: Good Health and Well-Being*, *Goal 7: Affordable and Clean Energy*, and *Goal 11: Sustainable Cities and Communities*. *Goal 17: Partnerships to achieve the Goals* stresses the need to build networks and many cities have already established very good global connections, for example through the C40 cities and 100 Resilient Cities Network.

At present, C40 brings together 97 of the world's largest cities taking climate action to achieve a healthier and more sustainable future. The mayors of these cities, which together are home to more than 700 million citizens and account for a quarter of the global economy, have pledged to steer development in their cities to meet the climate goals of the 2015 Paris Agreement, and also to substantially improve their city's air quality by combating pollution. Among the cities featured in this book, Toronto, Vancouver, New York City, Houston, Bogotá, Medellín, and Rio de Janeiro belong to the C40.

The 100 Resilient Cities Network (100RC) was established in 2013 by the U.S. Rockefeller Foundation to help cities build resilience to the challenges of the 21st century. Of the more than 1,000 cities that applied, 100 were selected. These received project-based financial support over six years, as well as funding for a resilience manager to steer the city's efforts to become more sustainable and resilient and to assist in developing a resilience strategy. In addition, membership also involved participating in intensive knowledge sharing and collaboration among the cities. The 100 Resilient Cities represent one-fifth of the world's urban population and more than 50 resilience strategies with over 1,800 provisions and initiatives have been written to date. Ultimately the network has led to over 150 collaborations between cities. Although the initiative came to a close on July 31, 2019, the Rockefeller Foundation continues to support the resilience managers to ensure the valuable work done to date can continue. Of the cities described in this book, Toronto, Vancouver, New York City, Houston (as the 101st member, supported by Shell), Medellín, Rio de Janeiro, and Montevideo are all members.

THE RESILIENCE OF CITIES

Climate change is without doubt a significant challenge for cities actively working towards more sustainable development. Therefore, any strategy must ensure that no group of residents is disadvantaged, that public services are safeguarded, and that at least a certain level of prosperity is distributed as evenly as possible. Public green and open spaces are usually sizeable areas in cities that are accessible to all residents as well as visitors. Due to their vegetation, they have a better microclimate than the more built-up neighborhoods around them, but parks and green spaces are often unequally distributed throughout a city. While private green spaces likewise have a positive climatic impact, they are in most cases not accessible to the general public and are often found on the outskirts of cities. Where neighborhoods have comparatively few green spaces but a large number of inhabitants, the pressure on public spaces is correspondingly high. Such spaces must be designed to a particularly high standard and regularly maintained to ensure they retain their character and continue to serve the needs of their neighborhood.

The consequences of climate change, such as extreme weather events, have drawn attention to the fact that open spaces can serve an important buffer function to protect surrounding built-up areas against flooding and landslides. Hence, open spaces in flood risk areas should be designed as water retention areas to limit the extent of flooding, and at the same time also be able to withstand extreme weather events without excessive damage or destruction. Similarly, residential areas built on sloping sites prone to erosion during heavy rain events can be protected from damage by the creation of stabilizing open spaces. In extreme cases where safe housing cannot be ensured in the long term, residents of areas with particularly unstable ground may need to relocate to other, safer urban locations. The impacts and threat of climate change have increasingly refocused attention on the interests of urban communities, such as the development of green-blue infrastructure or building measures aimed at improving the city's climate resilience. Because each city has its own structure, specific location, size, and pattern of development, it is important that it becomes aware of how its climate is changing now and in the future, and of the parallel developments that need to be reconciled with climate change. Needless to say, citizens must be involved in climate change adaptation decisions.

In general, most cities already have plans in place to reduce greenhouse gas emissions, and this is true for nearly all of the cities in North and South America featured in this book. In addition, most cities have developed climate change adaptation plans and, in some cases, also resilience strategies that identify expected impacts—based on data from climate monitoring, aerial or satellite imagery, model simulations, or more usually a combination of these—and elaborate proposals for mitigation action and adaptation strategies.

Only occasionally is green infrastructure explicitly outlined as a means of mitigating climate change impacts and improving resilience. By contrast, investments in technical infrastructure are mentioned very frequently. Community participation and involvement in adaptation is sometimes also mentioned as an important factor. The fact that green infrastructure and landscape architecture are rarely brought up is especially surprising given the widely documented climatic benefits of green spaces, and especially of trees and various other accompanying solutions for increasing urban resilience. In fact, green spaces, when robustly designed, can absorb large amounts of rainfall during severe precipitation events and pass it on in a controlled manner without incurring permanent damage. Plus, rain gardens are being integrated into the design of new parks and street spaces as temporary water reservoirs during heavy rains, and at the same time help raise awareness of water cycles and climate change in the population, and especially among children. Improved tree planting is a further area where landscape architecture can benefit cities: it significantly increases the lifespan of urban trees and their ecosystem capacity, and it is well known that plants, and especially trees, act as carbon sinks as they store CO_2 and through photosynthesis release oxygen into the air. In addition, adequate planting can lower the ambient temperature through moisture evaporation and by providing shade, so that urban environments heat up less dramatically. In essence, the more vegetation there is, the more effective its ability to sequester carbon and the better its cooling effect through shading and evaporation for the local microclimate. It is, of course, essential that plants have an adequate supply of water and any necessary nutrients so that they can grow appropriately, live to a mature age, and contribute effectively to mitigating climate change. As such, the IPCC's goal to limit global warming to no more than 1.5° C, as well as other sustainability aspects such as food security, healthy ecosystems and, to some extent, reducing poverty, must be seen in direct relation to green infrastructure.

Cities in general are considered particularly vulnerable to the effects of climate change due to their high population density, important economic relevance, and predominance of gray infrastructure. While extreme weather events themselves do not automatically pose a risk, their consequences, such as heat stress or flooding, do when they endanger people's lives or health, or cause damage to the fabric of the city. The risk therefore depends on the kind of weather events that may be expected and the degree of vulnerability where they occur. It is, therefore, particularly important to conduct a risk assessment of the damage that may arise as a consequence of climate change, as a basis for identifying appropriate measures to take, especially in the most vulnerable parts of a city.

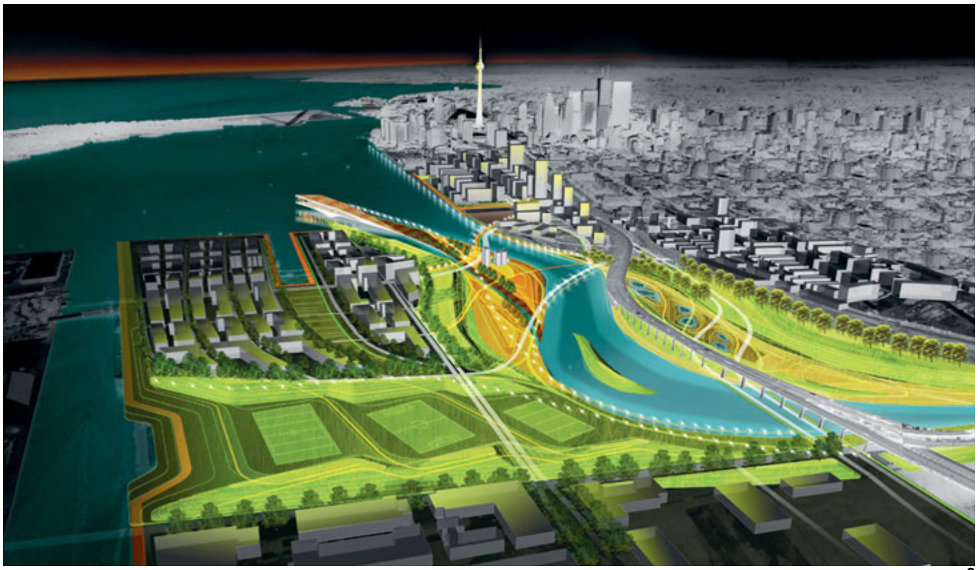
Making cities more resilient means equipping them so that extreme climatic and weather events do not have a lasting impact on the inhabitants and infrastructure of a city, but that urban functions can be resumed or at least rapidly restored without permanent impairment. Ideally, solutions should act at multiple levels and combine various measures, leading to a broader transformation of cities. Landscape architects are absolutely imperative for this process, yet it is also increasingly clear that in order to improve the resilience of cities to climate change, landscape architecture must in this context reexamine its priorities. Site-specific adaptations to climate change must be a central consideration of designs for open spaces; collaborations with planners and professionals from other disciplines must be strengthened; and landscape architects should ideally lead planning processes to coordinate the climate resilience of the various design aspects.

TOR ONTO

TORONTO

"Diversity Our Strength" is the motto of the city of Toronto, Canada's largest metropolis with almost 3 million inhabitants. Together with the Greater Toronto Area, the population figure doubles to 6.2 million. Situated on Lake Ontario, it is part of the so-called Golden Horseshoe, a densely populated, economically prosperous region that encircles the western end of the lake. The region has experienced significant growth in recent decades, and indeed nearly a quarter of Canada's population live there. Both socially and architecturally progressive, Toronto boasts modern buildings in the downtown and more recent waterfront areas, as well as extensive districts of terraces and houses, a multicultural community, and vibrant neighborhoods. The city's residents come from many different ethnic backgrounds and nearly half were born abroad. After Miami, Toronto has the second-highest proportion of foreign-born residents in North America—but unlike Miami, Toronto's immigrant population is not dominated by just a few ethnic groups; instead, it comprises a broad range of diverse minorities seen in few other cities of the world. The city's diversity motto therefore attests to its social and cultural self-image.

Toronto owes its byname *City of Ravines* to a distinct topographical feature that formed after the last ice age: the ravines and rivers flowing through the city area towards Lake Ontario. These densely forested areas, which make up 20 percent of the urban territory, serve several vital ecological functions, the most important of which is to collect water from the adjacent urban areas during rainfall and drain it into Lake Ontario. To this day, all urban planning considerations and initiatives are subject to the ravines' crucial role in channeling the flow of water in the city.



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1 (previous page)
Downtown Toronto on Lake Ontario.

2
Design for the mouth of the Don River into Lake Ontario. New retention areas at the mouth of the river help regulate the flow rate of swelling waters after heavy rainfall. The new hydrological and green infrastructure proposed as part of this competition entry creates new ecosystems, recreational spaces, and a residential environment with cultural offerings.

Toronto's climate is cold and temperate. The mean annual temperature is 8.7 °C, with the lowest monthly average in February, -4.4 °C, and the highest in July, at 21.9 °C. The highest daytime temperatures of the year are usually measured in August, reaching around 25 °C. While the mean total precipitation is 845 millimeters per year, monthly rainfall ranges from 50 to 85 millimeters across the year.

Temperatures differ significantly between the seasons. In winter, they can dip temporarily to -10 °C, and seem even colder due to the winds blowing in from the lake. From November to April, precipitation falls mainly as snow; relative humidity in winter is 80 percent, sunshine duration is two hours. In spring and summer, the sun shines on average up to seven hours a day.

EFFECTS OF CLIMATE CHANGE

Toronto is among the "100 Resilient Cities" selected as part of the Rockefeller Foundation's competition in 2013. Within the framework of this program, the city developed both a *Resilience Strategy* and a *Climate Action Strategy*, called *TransformTO*. In 2015, these plans were further supplemented by a *Climate Change and Health Strategy*.

The *Resilience Strategy*, a quite comprehensive document, outlines the specific expected impacts of climate change on the city: Toronto expects to become hotter, wetter, and stormier. This implies significant changes for the individual climate parameters: from 1976 to 2005, an average of 12.2 hot days with temperatures above 30 °C were recorded per year; from 2021 to 2050, 30.7 such days are expected, and in the period from 2051 to 2080, this number is again expected to rise, to 54.9 days. While the average mean precipitation between 1976 and 2005 was 786 millimeters, it is projected to increase to 817 millimeters by 2050 and 854 millimeters by 2080. Prior to 2005, heavy precipitation days—where more than 20 millimeters of rain or snow fall in a single day—occurred on average 6.6 days per year; by 2050 this is expected to rise to 6.9 days, and by 2080 to 7.8 days annually.

In 2017, the City Council unanimously approved *TransformTO*, Toronto's strategy paper for tackling climate change. Setting out long-term goals for the transformation of the city, it includes reducing greenhouse gas emissions, promoting public health, economic growth, as well as improving social equity. In this vein, targets for reducing greenhouse gas emissions are a 30 percent reduction by 2020, 65 percent by 2030, and zero energy consumption by 2050 or sooner. The paper also identifies buildings, transportation, and waste management as the main sources of greenhouse gas emissions.

The *Climate Change and Health Strategy* provides an overview of the anticipated negative impacts on the health of the city's population. These include an increased incidence of heat-/cold-related illness and premature death, a rise in direct and indirect injuries and disease resulting from severe weather (including water-borne and vector-borne diseases), disruptions to food supply (including

food insecurity and food-borne illnesses), and degraded air quality, increasing cardiovascular and respiratory illnesses.

Weather events that cause large-scale damage are typically strong motivators for raising awareness of climate change among a city's population. For Toronto, Hurricane Hazel on October 15, 1954, was such a landmark event: 121.4 millimeters of precipitation fell during that hurricane, causing significant damage that many older residents still recall today. Even though climate change is not expected to cause stronger and more frequent storms for the Toronto region, the example does show that such natural disasters remain anchored in the collective memory of a population for a long time. Tapping into this memory can help raise awareness of the frequency of other weather extremes that Toronto is expected to experience.

COMPLETE STREETS AND GREEN STREETS

To prepare for the consequences of climate change, the City of Toronto has developed two street renewal programs specifically designed to contribute to environmental quality, as well as to the social and economic development of streets. The two programs categorize streets into so-called *Complete Streets* and *Green Streets* and aim to combine their positive aspects with a view to improving Toronto's streetscapes.

The Toronto metropolitan area encompasses some 5,600 kilometers of streets and paved surfaces, typically contributing to climate change by heating up in summer and discharging surface runoff directly into the sewer system. Road surfaces account for about a quarter of the area of the city of Toronto. Only in New York do streets comprise a larger share of the total urban area, as comparisons with cities in Europe, North America, and Oceania have shown.

The *Complete Streets* program focuses on streets that are designed for all users: people who walk, cycle, use public transportation, or drive, as well as people of varying ages and degrees of ability. They also consider other uses like sidewalk cafés, so-called street furniture (e.g., benches, kiosks, and planters), street trees, utilities, and stormwater management. While *Complete Streets* aims to create street spaces that can accommodate multiple functions and seeks to improve their quality for all users, the *Green Streets* program, developed a few years later, focuses more on the ecological effectiveness of streets through the incorporation of green infrastructure. Accordingly, Green Streets are roads or streets that feature natural and human-made elements such as trees, green walls, and low-impact stormwater infrastructure providing ecological and hydrological functions and processes. Unlike traditional streets where rainwater is discharged directly into sewers and drains along with any pollution that collects on sealed surfaces, "green" streets capture rainwater and make it available to plants. In this context, the soil acts as a natural filter to clean the water before it soaks into the ground or makes its way into local waterways. Urban vegetation can therefore benefit from rainwater for longer, helping it grow better, and more water is available for evapotranspiration, in turn reducing the heat island effect.

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Permeable infiltration areas can help replenish groundwater levels by taking up stormwater, especially after heavy rain events, while improving air quality and increasing humidity levels. As examples of possible approaches, the program cites the walkable green roof on Toronto City Hall, the greening of streets and parking lots, and roadside greenery that can retain and cleanse water in its soil.

The *Green Streets* program compiles technical guidance for planners, project developers, and local government to assist in planning sustainable stormwater management solutions. In doing so, it details a selection of appropriate green infrastructure measures that can be incorporated into street redesign or reconstruction. Particular emphasis is placed on the design of systems for soils and substrates that can absorb large amounts of precipitation to assist in meeting runoff requirements. Not only must green streets be attractive and functional, they must also fit in with their urban surroundings. By prioritizing *Green Streets* over traditional, less multifunctional streets, the aim is for their diverse forms of green infrastructure to promote effective stormwater management at the point where it occurs.

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Example of a “complete street” at West Donlands, where the Athletes’ Village was built for the XVII Pan American Games in 2015.

STREET TREES

Planting, maintaining, and caring for trees along streets is already a particularly important aspect in Toronto, as it is in most cities. Climate change has made it even more challenging.

Of Toronto's roughly 10.2 million trees, 60 percent are privately owned. The remaining 4.1 million trees grow on public land. Six percent of all trees in Toronto, or about 600,000, are street trees, and only 1.5 percent of all trees, 150,000 specimens in absolute numbers, have a trunk diameter over 30 centimeters, measured at chest height.

Trees, and especially street trees, play an important role in mitigating the negative effects of climate change in cities: evapotranspiration through the leaves of trees helps cool urban areas where heat builds up through buildings and sealed roadways. At the same time shade from the trees cools the ground, reducing heat build-up from exposure to the sun. Trees counteract the warming of their immediate surroundings and create a more pleasant microclimate for people outdoors. In addition, they also sequester CO_2 and bind pollutants.

But trees, and again especially those street trees in urban centers, are also particularly vulnerable to the impacts of climate change. They must adapt to the higher temperatures in cities, cope with more irregular precipitation, withstand more frequent storms at unusual times of the year, adjust to longer growing seasons, and possibly resist new kinds of pests. Since not all trees adapt equally well, reliable guidance on how these new challenges are best addressed at the selection and planting stage is still lacking. Current research is wide-ranging and covers topics such as the suitability of different tree species and varieties, and of substrates and soils, or the water and maintenance requirements of specific trees, their watering frequencies and fertilizer duration. The results depend heavily on where the data are recorded, and the findings must be adapted to the existing species of trees in a city as well as the new tree species to be planted.

The goal is—and must be—to allow street trees to develop over a long period of time in a manner appropriate to the species, as it can take decades for trees to mature and develop their full potential. Therefore, not only the number of trees, but also their size and health are of great importance for their climatic effectiveness. Research into the life expectancy of street trees has been contradictory, and the findings do not apply equally to every location anyway. In a study from the end of the last century, for example, Gary Moll came to the startling conclusion that a tree in the center of an American city survives on average for only seven years.

Another study by Lara A. Roman et al. from 2001 compiled and compared several existing American studies on the survival rate of street trees along with one study from Belgium, England, and China respectively. In addition, the authors undertook their own research on field maple (*Acer campestre*) trees in Philadelphia, PA, USA, planted over a ten-year period. They concluded that these studies do not corroborate the very low life expectancy of street trees in Moll's study. In view of this, the annual survival rate was between 94.9 and 96.5 percent, i.e., only about 5 percent of newly planted trees die within the first year after planting.

A field maple's estimated average life expectancy was found to be between 19 and 28 years. Since this refers to the period after planting—trees are planted after 12 or more years' growth in a tree nursery—their average life expectancy is about 35 years. While significantly longer than Moll's claim, it is still cause for concern as most trees do not develop their specific form and full ecological potential until they reach this age. Many trees never make it to this stage because they do not grow healthily or are removed. If half of the trees are indeed removed, or ideally replaced, in such young "tree years," they never reach their full ecological potential. The overall ecological effect actually sinks because older trees naturally reach the end of their lifetime and can only be replaced by young trees. A way out of this dilemma could be to plant significantly more trees in cities, and especially in the central districts—but there is often not enough space to plant sufficient trees and allow them to develop in a species-appropriate way. In any case, trees need intensive care and support to grow as much as possible—and the money is well spent, since planting new young trees at ever shorter intervals is certainly more expensive than the proper, regular care and upkeep of trees.

Overall, the general condition of existing street trees in large cities is moderate and often poor, although these findings refer to trees planted in the past. Regulations on suitable substrates and maintenance patterns during their initial growth and later maturing phases have not always existed. Many cities, including Toronto, have since developed guidelines for planting and maintenance, as well as for species and cultivar selections for street trees. The target is typically a life expectancy of 40 years and a mature trunk diameter of 40 centimeters at chest height.

In Toronto, trees were previously planted in 6 to 10 cubic meters of soil or substrate per tree at 6-meter spacings. Today, 20 to 30 cubic meters and 10-meter spacings are recommended. Planting fewer trees with wider spacing improves the chance that trees will grow to their full size. Since tree grates have so far been very small at 1.25 square meters, new guidelines specify at least 1.5 square meters or larger open planting areas with a greater capacity to absorb rainwater in the root zone. Also, tree grates should be covered with mulch and the root areas irrigated with collected rainwater. According to the current guidelines, 30 native and non-native tree species are being recommended for new tree planting. If, as predicted, climate change causes a general rise in temperatures and decrease in regular rainfall, the recommended tree species may need to be adjusted in future.

The following two projects are examples of the sustainable development of former commercial sites in Toronto as described by Joe Lobko, partner in the landscape architecture and urban design firm DTAH. In both projects, building structures as well as outdoor areas were defined by their respective original use and transformed as part of an intensive design process to serve their new purposes. With sustainability as a core principle, they are now vibrant amenities for their respective neighborhoods and for the city. Both projects were developed by non-profit organizations with committed civic involvement from the local communities in raising funding, determining the usage profile, and undertaking administrative tasks.

EVERGREEN BRICK WORKS

The former brick works is situated in the Don Valley, one of Toronto's typical ravines, which is part of the Don River and Mud Creek floodplain. Founded in 1889, it remained in operation for nearly 100 years, producing bricks for the construction of the many single-family homes so characteristic of Toronto. After the natural resources were largely depleted and clay mining ceased in the 1980s, the site was sold. It was initially offered to the local authorities, because its location in an ecologically sensitive ravine implied a potential for development as part of the river valley parkland. However, due to the economic recession in the early 1980s and the complex task of redeveloping a clay quarry and brick plant, the city declined the offer. Instead, a private developer took on the property with the intention of building an extensive residential project. After the site was partially filled and building permission was granted, local residents became aware of the project and opposition to the development in the sensitive, flood-prone river valley grew. The protests eventually led to the city reclaiming and buying back the 5-hectare site, which includes 16 historically listed buildings.

The Conservation Authority began converting the clay pit into a recreational area called a "quarry garden." Measures included daylighting Mud Creek, creating ponds and meadows, and planting native trees, shrubs, and wildflowers. Before long the park had become a popular local amenity and is now considered a model example of the successful ecological development of a river valley. It was only later that the non-profit organization Evergreen Canada embarked on the development of the landmarked buildings on the site. In fact, its mission is to bring nature back into the cities of Canada and to promote environmentally sound, socially progressive urban development. Further areas of focus include environmental education and schoolyard greening. The extensive planting work in the lower Don River water catchment area caught the attention of the organization's founding director, Geoff Cape. He immediately saw the potential of developing the clay quarry and buildings as a community environmental center that could house his own organization and others with a similar focus. His vision is that of a hub for people to explore the relationship between nature, culture, and society, and to plan a green future for Toronto and other cities. Since diversity is a key aspect of Evergreen Canada's philosophy, both in terms of healthy ecosystems and an open, sustainable society, it likewise informed the organizational, architectural and landscaping realization of the project. Working with a variety of partners—three architecture offices, two landscape architecture firms, plus engineers, ecologists, hydrologists, environmental educators, and other professionals—Evergreen was able to consider and incorporate many different perspectives throughout the project planning process.

The most important elements of the development and design of this landscape were both its natural features and the anthropogenic alterations it had experienced. The design encompasses waterways, slopes and edges, planting schemes and wooded areas as well as bike lanes, a road, an expressway, two railroad lines and a power line fed by a hydroelectric plant.

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Just how deep the pit was when still in operation can be seen on a photographic mural on the wall of one of the old buildings in the brick works.

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Entire neighborhoods of Toronto were built from bricks sourced from this clay pit.

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The site of the former clay pit was partially filled in and turned into a park with paths through the natural vegetation.

7
The combination of natural vegetation and water creates a special habitat for animals and plants and a tranquil amenity for local residents.

8
The height difference is considerable despite partial filling of the terrain, resulting in a variety of biotopes with their own microclimate in the valley.

After completion of the park, Evergreen embarked on reuse concepts for the existing buildings, recognizing that repurposing existing structures is the "greenest" approach. At the heart of the brick works site is the Centre for Green Cities, a new building with LEED Platinum certification grafted onto an existing structure. Besides serving as a visitor center and presenting green technologies, it also houses exhibitions and conferences. Accessibility to the somewhat outlying site has been improved, with cycle paths and pedestrian connections to the city, as well as a car-sharing service and the provision of a shuttle bus service to and from the nearest subway station.

Since its completion in 2010, Evergreen Brick Works has certainly lived up to the hopes and expectations of the project and has become an ecological hub for the entire city. This involves a weekly farmers' market, a comprehensive program of environmental activities for children, and a variety of events showcasing local foods. In addition to these local activities, it also hosts conferences and workshops on topics ranging from the future of cities to the development of a green economy.

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