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Review



20*20*60: A multilevel climate change analysis framework

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ABSTRACT

Cities worldwide have established plans and policies to achieve climate-neutral and climate-resilient objectives in recent decades. Researches have demonstrated that Climate Change Action Plans generally fail to include mitigation and adaptation approaches in their planning processes, despite their importance. A proposed multi-level assessment of Climate Change Action Plans, urban regeneration, and building projects was used to analyze the ten cities most sustainable in terms of developing environmental strategies, including local climate action to determine the degree of adaptation and mitigation integration in cutting-edge contexts and to identify measures that show synergies and co-benefits for urban design practices.

Climate Change Action Plans, urban regeneration and building projects have been evaluated through scoring methods to determine firstly the level of integration among adaptation and mitigation and secondly the most used urban design solutions that addresses both approaches. Almost all of Climate Change Action Plans have "moderate" and "early" integration, with the most advanced in North American cities including Toronto, Montreal, New York, and San Francisco. Climate Change Action Plans partly influence urban regeneration projects. Among the cities studied, Royal Seaport and Hammarby Sjöstad in Stockholm stand out as the most advanced in terms of including measures for both mitigating and adapting to climate change, as well as the extent of activities carried out. North American building projects have the highest adaptation and mitigation strategies. Climate Change Action Plans, urban regeneration initiatives, and building projects analyzed have displayed measures to include both climate change mitigation and climate change adaptation benefits into urban design.

1. Introduction

Climate Change Mitigation (CCM), as outlined by the Intergovernmental Panel on Climate Change (IPCC) in 2022 (Pörtner et al., 2022), involves the use of technologies, processes, or practices that help decrease GHG emissions or improve their absorption. This includes renewable energy technologies, waste reduction processes, the use of public transportation, green/blue infrastructure and ecosystems restoration. The IPCC (Pörtner et al., 2022) defines Climate Change Adaptation (CCA) as the process of adjusting to current or expected climatic conditions and their impacts to minimize damage or take advantage of beneficial possibilities. Adapting to the current climate and its impacts may help in adapting to the predicted climate and its impacts in natural systems.

Since the release of the fourth assessment report of the IPCC (AR4) and as noted in the latest report of the IPCC (AR6) (Pörtner et al., 2022), there has been a significant change in focus towards integrating both Mitigation (Mit) and Adaptation (Ad) in urban planning, aligning with the studies by Grafakos et al. (2019), Hurlimann et al. (Hürlimann et al., 2022), Codemo et al. (2021), Sharifi (2021), Pollo & Trane (Pollo and Trane, 2021), and Sharifi et al. (2021). Cities in the Global North are facing various climatic impacts such as flooding and heatwaves and need

Abbreviations: Adaptation, Ad; Built Environment, BE; Climate Change, CC; Climate Change Action Plans, CCAPs; Climate Change Adaptation, CCA; Climate Change Mitigation, CCM; European Union, EU; Green Building Rating System, GBRS; Intergovernmental Panel on Climate Change, IPCC; IPCC Fourth Assessment Report, AR4; IPCC Fourth Assessment Report, AR5; IPCC Fourth Assessment Report, AR6; Leadership in Energy and Environmental Design, LEED; Mitigation, Mit; Nature-based solutions, NBS; Positive Energy District, PED; Sustainable Development Goals, SDGs; Sustainable Urban Drainage Systems, SUDS; United States, USA; Urban Heat Island, UHI.

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to reduce their high carbon footprint, while cities in the Global South, while rapidly growing and suffering increasing impacts connected to multiple vulnerability conditions, are struggling between the growing request for investments in development based on conventional technologies and the potential of exploiting "leapfrogging" opportunities for integrated Mit and Ad (Ayers and Huq, 2009; Lwasa et al., 2018).

This paper explores the challenges for integrated climate action emerging in cities from the Global North, reflecting the levels of integration between CCM and CCA across strategic planning, urban regeneration, and building project initiatives.

Multiple research projects have shown that the difference between Ad and Mit has grown less clear. A survey of nine cities worldwide indicates that the majority of them use both Ad and Mit elements in their climate action strategies (Grafakos et al., 2019). Analyzing surveys conducted in 287 mid-size communities in the Great Lakes area of the US (Kalafatis, 2017) and 350 municipalities worldwide (Aylett, 2015) reveals that the gap between Ad and Mit is decreasing. Aboagye & Sharifi (Aboagye and Sharifi, 2024) have applied a framework to analyze 257 urban Ad and Mit plans around the world, finding that the most sampled plans achieved a medium level of integration and have shortcomings related to implementation and monitoring.

One advantage of incorporating both Ad and Mit measures in climate action plans is that this enhances people's understanding of how various measures may interact due to the intricate and evolving characteristics of space and time (Aylett, 2015; Caparros-Midwood et al., 2019; Sharifi, 2021). Increased awareness is necessary for optimizing action strategies (Caparros-Midwood et al., 2019). Discussions on interactions have greatly intensified since being acknowledged in the Paris Agreement (Dovie, 2019). Although integrated techniques have improved consideration of Mit-Ad relationships in certain circumstances (Aylett, 2015), more enhancements are still required according to some views. Caparros-Midwood et al. (2019) found that in European Union (EU), while having leading climate policies, only a tiny number of cities take into account the co-benefits and synergies of Mit and Ad. Analysis of mid-size cities in the US suggests that some local authorities may not be fully aware of the potential synergistic benefits that certain policy interventions might provide in terms of Mit and Ad. CCA advantages were overlooked in initiatives to promote pedestrian transportation, and CCM was not integrated into measures for reforming wastewater management (Kalafatis, 2017). According to the research, policymakers may not fully understand the advantages of some policy interventions, like enhancing tree canopy or increasing building energy efficiency, in terms of Mit and Ad. Thus, improving understanding of interactions is necessary to optimize the efficiency and efficacy of action plans (Dulal, 2017). Accounting for co-benefits and synergies may speed up the shift towards low-carbon and sustainable urban development (Ford et al., 2018).

Implementing a comprehensive and coordinated approach may lower emissions and can also avoid maladjustment measures by providing support for the realization of other Sustainbale Development Goals (SDGs). The city is the most suitable scale for promoting this integration, as stated by Grafakos et al. (2018). In particular, micro-urban and local scales may include local policy reasons, goals, and activities better reflecting specific priorities of urban communities (Raven et al., 2018; Tersigni and Leone, 2019).

One of the key disciplines required to achieve these goals is urban design, which may assist in combining passive and active techniques via the design of urban shapes and functions. De Gregorio Hurtado et al. (De Gregorio Hurtado et al., 2015), emphasizes that "*Urban design plays a pivotal role in enhancing cities' readiness to face climate change, as thoughtfully planned urban spaces can reduce vulnerabilities and* support *sustainable adaptation strategies across* European UnionEuropean Union *cities.*" This is particularly crucial to enrich the efforts for the deadline to address Climate Change (CC), set by scientists for 2030, considered as a tipping-point to maintain global systems in a safer zones.

Recently, some researches have been developed focusing on the assessment of urban regeneration projects such as Buzasi et al. (Buzási et al., 2021) and Privitera & Barbarossa (Privitera and Barbarossa, 2021), while Bologna & Hasanaj (Bologna et al., 2023) have provided a catalogue only for climate adaptation solutions without considering the integrations of both Mit and Ad.

Positive Energy Districts (PEDs) are emerging as a transformative element within urban regeneration strategies across Europe, especially in response to climate change. With the establishment of the "EU mission for 100 PEDs" by the European Commission's Joint Programming Initiative (JPI) in 2020 (Positive Energy Districts (P ED) [Internet]), these districts aim to reach energy efficiency and flexibility by producing a surplus of renewable energy while integrating diverse urban systems such as energy, mobility, and ICT. PEDs are thus positioned at the intersection of CCA and mitigation CCM strategies. They play a significant role in urban design by incorporating sustainable technologies—such as solar, geothermal, district heating, and waste heat recovery systems—that reduce emissions. PEDs also often incorporate nature-based solutions (NBS) like urban greenery and permeable surfaces, that could enhancing resilience against extreme weather. In this way, PEDs advance climate objectives through urban design, aligning with broader European goals for sustainable urbanization and creating urban spaces that are adaptive and conducive to climate-neutral development.

This Paper aims to assess the extent of integration of Mit and Ad strategies in cities most sustainable in terms of developing environmental strategies, including local climate actions. The goal is to identify best practices across various levels (climate action plans, policies, urban regeneration, and building projects) to guide urban design practices for a more comprehensive approach to climate-resilient development integrating CCM and CCA.

From this objective, two research questions emerge.

- What is the level of integration of CCM and CCA actions in Climate Change Action Plans (CCAPs), urban transformation projects, and building design in cities most sustainable in terms of developing environmental strategies, including local climate actions?
- Which are the common measures of Mit and Ad that could be implemented in urban design practices?

In addressing the aforementioned research questions, a series of indicators from previous studies were selected to evaluate the levels of integration between Ad and Mit. Specifically, for the analysis of CCAPs, we adopted the indicators used by Grafakos et al., 2019, 2020 and Pietrapertosa et al. (2019) to assess the level of integration between Ad and Mit in relation to the main categories proposed by the European Commission for the development of local action plans. For the analysis of urban regeneration projects, we employed the indicators proposed by Privitera & Barbarossa (Privitera and Barbarossa, 2021), Bologna & Hasanaj (Bologna et al., 2023), and Buzasi et al. (Buzási et al., 2021), both to understand whether the implemented actions addressed the selected macro-categories for Mit and Ad and to evaluate the project's capacity to align with the Mit and Ad goals of CCAPs. For the analysis of building-scale projects, a similar approach was applied, focusing on the identification of Ad and Mit actions for each project, their alignment with the Mit and Ad objectives outlined in CCAPs, and whether the project achieved certification under various GBRSs. The paper is organized as follows: Section 2 presents data, methodologies, and criteria used in the multilevel analysis framework. Section 3 displays the outcomes of the analysis for CCAPs, urban regeneration initiatives, and building projects. Section 4 describes the findings, best practices, and solutions that address both CCA and CCM in urban design processes. Section 5 concludes by examining the overall findings and future research prospects.

2. The multilevel analysis framework: data, methods and criteria

The multilevel analysis framework includes three level of analysis: the first focusing on current policies and planning practices to analyze the level of integration of CCAPs; the second focusing on urban projects delivering climate Mit and Ad solutions; the third focusing on the building scale to analyze recurring design and technical solutions (Fig. 1). The multilevel analysis framework has been applied to most sustainable cities in terms of development of environmental strategies including local climate actions. The following paragraphs will reports the methods of selection and analysis of cities.

2.1. Cities selection

The cities were chosen based on the Sustainability City Index (Arcadis), which evaluates cities according to 31 criteria to determine their sustainability in the social, economic, and environmental realms. Arcadis considers green areas, energy consumption, air pollution levels, CO_2 emissions, cycling infrastructure, and waste management when classifying cities in the environmental sector.

These factors are crucial for comprehending urban performances via an environmental lens, indicating that municipal policies have impacted these factors. The chosen cities most sustainable in terms of developing environmental strategies, including local climate actions are New York, Seattle, San Francisco, and Boston in the USA; Montreal and Toronto in Canada; Copenhagen in Denmark; Stockholm in Sweden; Zurich in Switzerland; and Amsterdam in The Netherlands.

2.2. Climate Change Action Plans

The most recent CCAPs published following the IPCC Fifth Assessment Report (AR5), the first to focus on urban climate change, were considered. Where no plans had been published between 2015 and 2022 in the cities analyzed, earlier plans were also taken into account, as in the cases of Copenhagen and New York. The study examined the most recent plans for adjusting to present and future effects of climate change (Ad), or to reduce emissions or enhance the sinks of GHG emissions (Mit), usually called CCAP according with Grafakos et al., 2019, 2020 or similarly defined as Climate Action Plan (CAP) by Aboagye & Sharifi (Aboagye and Sharifi, 2023, 2024) where there are plans aim to increase the capacity to cope, reorganising or responding to the effects of climate change in order to maintain the essential functions, identities and structure of cities, which are often referred as “Resilience Plan” or “City Resilience Strategy” (Table 1). The study employed two approaches to locate CCAPs for the selected cities, following the methodology outlined by Aboagye & Sharifi (Aboagye and Sharifi, 2023). The first approach involved consulting the Global Covenant of Mayors (GCOM) web platform (https://www.globalcovenantofmayors.org/our-cities/) and the C40 knowledge hub (https://www.c40knowledgehub.org/s/global-search/%40uri?language=en_US#q=climate%20action%20plan&t=Articles&sort=relevancy) to retrieve resources available for each city. When GCOM and C40 did not provide direct access to source documents, the second approach utilized a customized Google search. This search combined the selected city names with the phrase ‘climate action plan,’ supplemented by synonyms aligning with the various types of plans discussed by Aboagye & Sharifi (Aboagye and Sharifi, 2023). Table 1 shows the general information that was gathered for each place and each plan.

The 20 CCAP documents included in the analysis were evaluated using content analysis, a standard method in CC planning research to maintain an unbiased perspective without considering the influence of local policymakers (Grafakos et al., 2019, 2020; Pietrapertosa et al., 2019).

The CCAPs have been examined based on the indicators defined by Pietrapertosa et al. (2019), Grafakos et al. (2019), and Grafakos et al.

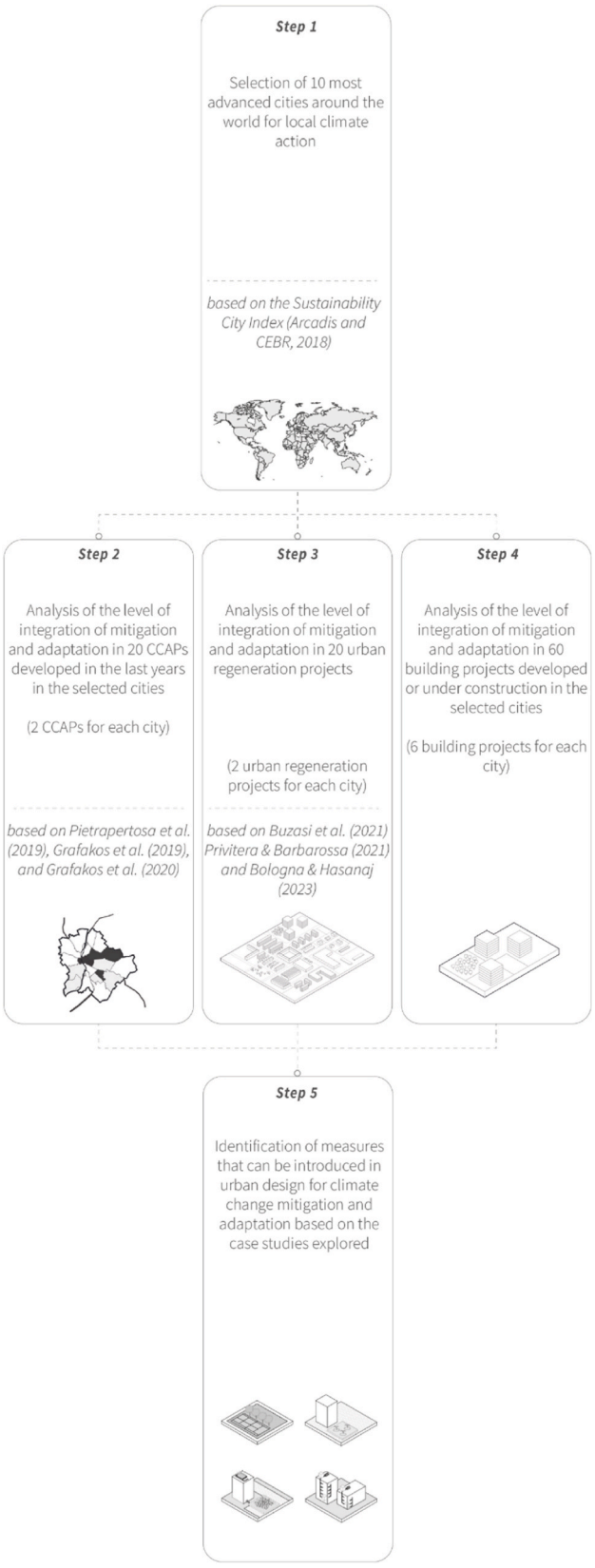


Fig. 1. Methodology implemented to understanding the level of integration of CCM and CCA strategies in local plans, urban regeneration projects and building projects in cities most sustainable in terms of developing environmental strategies, including local climate actions. Source: author’s illustration.

Table 1
General information collected for each selected city and plans identified for CCM and CCA.

Country	City	Population	Name of the plan	Year of publication	Is the plan focus on CCM?	Is the plan focus on CCA?	Mitigation topics included in the plan	Adaptation topics included in the plan
United States of America (USA)	Boston	654776 [(a)]	 Greenovate	2014	Yes	yes	a) Neighbourhoods b) Large Buildings and Institutions c) Transportation d) Climate Preparedness e) 80 × 50	a) Planning and Infrastructure b) Community Engagement c) trees and open space d) building and energy
			 Climate Ready Boston	2015	No	yes	a) infrastructure protection b) decentralized energy system c) zoning and coding d) buildings	
	New York	8467513 [(a)]	City's resiliency plan A Stronger, More Resilient New York 	2013	No	yes		a) Coastal Protection, b) Building, c) Insurance, d) Critical Infrastructure e) Healthcare f) Telecommunications g) Transportation h) Parks i) water and wastewater
			One New York (OneNYC): The Plan for a Strong and Just City 	2015	Yes	yes	a) reduction of GHGs b) zero waste c) air quality d) brownfields e) water management f) parks and natural resources	a) Neighbourhoods b) Buildings c) Infrastructures d) coastal defence
			 OneNYC 2050 Building a strong and fair city	2019	Yes	yes	a) ensure 100 clean electricity percent, b) pursue deep cuts in emissions and gains in efficiency across all buildings and infrastructure, c) adopt zero waste management strategies citywide	a) mitigate physical risks posed by CC by delivering critical projects, b) empower new yorkers to take climate smart adaptation measures, c) develop policies and governance structures to support climate resiliency and adapt use the best available science to inform a multi-hazard approach to climate adaptation
	Seattle	733919 [(a)]	Seattle climate action plan 	2013	Yes	no	a) transportation b) land use c) building energy d) waste	a) assessment and planning b) natural system c) utility system d) land use and BE e) community preparedness

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Table 1 (*continued*)

Country	City	Population	Name of the plan	Year of publication	Is the plan focus on CCM?	Is the plan focus on CCA?	Mitigation topics included in the plan	Adaptation topics included in the plan
			 Preparing for climate change	2017	No	yes		a) Transportation b) Land Use & BE c) City Buildings d) Parks e) Drainage & Water Supplies System f) Electricity System g) Community Prepardeness
	San Francisco	815201 [a]	 Hazards and Climate Resilience Plan	2019	No	yes		a) Infrastructures b) buildings c) communities
			Climate Action Plan 	2021	Yes	yes	a) energy b) buildings c) transportation d) housing e) zero waste	a)energy supply b) building operations c) transportation and land use d) housing e) responsible production and consumption f) healthy ecosystem
Canada	Montréal	1762949 (b)	 Climate Plan 2020–2030	2020	Yes	Yes	a) mobilization of the Montréal community b) Mobility, urban planning and urban development c) buildings d) exemplarity of the city e) governance	a) mobility urban planning and urban development b) buildings c) governance
			 climate change adaptation plan for the montréal urban agglomeration 2015–2020	2017	No	yes		a) higher average temperatures b) heavy rainfall c) heat waves d) destructive storms e) drought f) river floods
	Toronto	2794356 (b)	TransformTO Net Zero Strategy 	2021	Yes	yes	a) buildings b) energy c) transportation d) waste	
			Toronto Resilience Strategy 	2019	No	yes		a) people and neighbourhood b) infrastructure c) leading a resilient city

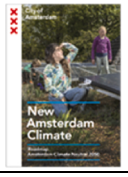
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Table 1 (*continued*)

Country	City	Population	Name of the plan	Year of publication	Is the plan focus on CCM?	Is the plan focus on CCA?	Mitigation topics included in the plan	Adaptation topics included in the plan
Denmark	Copenhagen	644431 [(c)]	 Copenhagen climate adaptation plan	2011	No	yes		a) more and heavier downpours in the future b) Urban Heat Island (UHI) effect and high surface temperatures c) indirect consequences d) A greener Copenhagen Urban scale
			CPH 2025 Climate Plan - A green, smart and carbon neutral city 	2015	Yes	no	a) energy consumption b) energy production c) green mobility d) city administration initiatives	
Sweden	Stockholm	978770 [(c)]	Climate Action Plan 2020–2023 	2020	Yes	no	a) traffic b) fuels and vehicles c) work machines d) shipping e) energy efficiency f) district heating g) oil burning h) electricity generation i) gas production and use	
			Environment programme 2020–2023 	2020	yes	yes	a) Reduced EUs — maximum 1.5 tonnes CO2e per resident b) Reduced climate impact from consumption c) Reduced EUs — maximum 105,000 tonnes CO2e from the City's operations d) Effective energy consumption	a) Improved ability to cope with effects of torrential rain b) Improved ability to cope with effects of heat waves
Switzerland	Zurich	443037 [(d)]	Environmental Strategy + Programm Klimaanpassung Fachplanung Hitzeminderung (Heat Mitigation Plan) 	2020	yes	yes	a) Climate Protection Target Net Zero Greenhouse Gases by 2040 b) Food strategy c) energy	a) Cold air generation areas and corridors b) Green spaces c) Green and open space connectivity d) Open and moving water surfaces e) Settlement structures and buildings f) Street and square spaces g) Anthropogenic heat influences h) Information management and awareness

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Table 1 (*continued*)

Country	City	Population	Name of the plan	Year of publication	Is the plan focus on CCM?	Is the plan focus on CCA?	Mitigation topics included in the plan	Adaptation topics included in the plan
The Netherlands	Amsterdam	883000 (e)	Strategy for climate adaptation Amsterdam 	2020	no	yes		a) heat b) drought c) waterlogging d) floods
			New Amsterdam Climate Roadmap Amsterdam Climate Neutral 2050 	2020	yes	no	a) the BE b) mobility c) electricity d) harbour and Industry	

Data source related to population are: (a) based on United States Census Bureau (2021); (b) Census Profile, 2021 Census of Population - Statistics of Canada; (c) Statista https://www.statista.com/statistics; (d) "Bevölkerungsbestand und -entwicklung - Stadt Zürichbestand". http://www.stadt-zuerich.ch (in German). Stadt Zürich Präsidialdepartment. Retrieved March 20, 2023; (e) https://www.statista.com/statistics/753235/total-population-of-amsterdam/.

(2020). These papers are considered because use indicators to assess the level of integration among Mit and Ad in CCAPs. Not all proposed indicators in the three studies are included. In this study, we considered the common indicators across the three studies by Pietrapertosa et al. (2019), Grafakos et al. (2019), and Grafakos et al. (2020) that align with the main categories identified by the European Commission for developing local climate action plans, as outlined in the Guidebook 'How to develop a Sustainable Energy and Climate Action Plan (SECAP)' (Research Centre et al., 2018). These categories include Baseline Emission Inventory, Climate Projections and Vulnerability Profiles, GHG Reduction and Adaptation Targets, Cost and Benefit Estimates of Climate Actions, Ad/Mit Integration and Interrelationships, Common Regulatory Framework and Monitoring Procedures, and Collaborations and Partnerships. The indicators, with the related category and references are reported in Table 2. As an example, the Urban Climate Change Integration Index (UCCII) by Grafakos et al. (2020) is not included in the indicators included. The indicators are detailed in Table 2, and the scoring method can be found in Appendix A.

The research chose 13 indicators reported in Table 2 that correspond to the three main planning phases outlined by Grafakos et al. (2019): "Identifying and Understanding," "Envisioning and Planning," and "Implementing and Monitoring." The document "Identifying and Understanding" covers GHG emissions profile, GHG emission forecast, vulnerability profile, and future climate projections. On the other hand, "Envisioning and Planning" includes GHG emissions reduction targets, Ad objectives, cost estimates of actions, benefit estimates of actions, and consideration of Ad/MIt interrelationships (co-benefits/synergies or trade-offs/conflicts). The "Implementing and Monitoring" group selects the mainstreaming potential of climate initiatives, a common policy or regulatory framework, collaborations, and a common monitoring technique or framework.

Plans have been classified into three groups based on initial content analysis: those emphasizing CCM with a climate-neutral objective, those emphasizing climate adaptation with a climate-resilient objective, and those incorporating analysis and future actions for both Ad and Mit. The cities are grouped based on the overall score of each CCAP derived from the chosen indicators after the first investigation. The Jenks Natural Breaks Classification approach, developed by Jenks (1967), was used to categorize the overall score acquired by plans into three levels. This strategy is the best suitable for optimizing the organization of a collection of values into "natural" classes. A natural class is the most efficient class interval identified organically within a dataset. A class range consists of objects with shared features that create a distinct group within a dataset. The final scores are categorized as follows: 6 to 9 is deemed "early stage" integration, 10 to 12 is defined as "moderate" integration, and 13 to 19 is labeled as "advanced" integration. Early-stage integrators include a limited number of integration aspects in their CCAPs, focusing mostly on either Mit or Ad. "Moderate integrators" include a greater number of integration aspects in their CCAPs compared to "early-stage integrators," and they take a more balanced approach towards addressing Mit and Ad, which is evident in at least two planning phases. "Advanced integrators" include integration components in all planning phases of their CCAPs while maintaining a well-balanced approach to addressing Mit and Ad.

Selected cities are being analyzed to assess the extent to which CCM and CCA strategies are integrated into urban renewal programs. Two urban regeneration initiatives focusing on environmental sustainability and climate action have been examined for each city, either completed or still in progress, aiming to improve particular areas of the BE. Thus, 20 regeneration initiatives were examined, as shown in Table 3.

2.3. Urban regeneration projects

The methodology for analyzing various urban regeneration projects involves examining actions categorized into four main strategies proposed by Privitera & Barbarossa (Privitera and Barbarossa, 2021) and Bologna & Hasanaj (Bologna et al., 2023): green infrastructure, sustainable urban drainage systems, re-energised land, and land and transportation, at both neighborhood and building scales. Green infrastructure and sustainable urban drainage systems may mitigate heatwaves, floods, water shortages, and landslides, while enhancing outdoor thermal comfort throughout the summer and CO_2 storage. Choosing Nature-Based Solutions (NBS) may enhance the thermal efficiency and insulation of buildings, leading to a decrease in energy consumption and carbon emissions. Solutions for revitalizing cities may enhance energy efficiency, decrease energy demand, and boost renewable energy generation while ensuring energy security in adverse weather conditions. Implementing land use and transportation options outlined in Appendix B may facilitate the redesign of streets and urban open spaces to encourage sustainable mobility and adapt these areas to the impacts of

Table 2
Indicators selected for CCAP analysis that are common among the framework analysis proposed by Grafakos et al. (2019), Pietrapertosa et al. (2019) and Grafakos et al. (2020). The description in based on the guidelines provided by Grafakos et al. (2020).

Categories for developing CCAPs	Indicator	Description	References
Baseline Emission Inventory	plan includes baseline emission inventory	the plan includes a baseline emission inventory (i.e. of current emissions)	Pietrapertosa et al. (Pietrapertosa et al., 2019)
GHG Reduction and Adaptation Targets	GHG Emissions Forecast	identify whether the CCAP has provided future GHG emissions forecasts in the form of text or chart (graph) that include a consideration of the city's current and projected growth of GHG emission, you will score this variable depending on the time horizon.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	GHG and % emissions reductions target	check whether the plan has set out city-level GHG emission reductions targets with time horizon, if so, score the variable based on the timescale of the targets.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	plan includes adaptation objectives	identify whether the plan has included a set of Ad objectives in order to cope with most pressing climate impacts for the city. CCA refers to *"The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects."* (IPCC, 2013:3).	Grafakos et al. (Grafakos et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
Climate Projections and Vulnerability Profiles	plan includes a current vulnerability profile	search whether the plan has provided the city's vulnerability profile that consider CC impacts by considering vulnerability factors such as exposure, sensitivity, and adaptive capacity into account. In many cases the vulnerability profile has the form of a Vulnerability Assessment, Vulnerability mapping, Climate Risk assessment and mapping.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	future climate projections	identify whether the plan has included climate projections in the form of text/graph that indicate projected changes of the city climate.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
Cost and Benefit Estimates of Climate Actions	Cost estimates of actions	check whether the plan has included cost estimates of implementation of proposed Ad/Mit actions	Grafakos et al. (Grafakos et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	Benefit estimates of actions	check whether the plan has recognized and estimated economic (individual or public) benefits of proposed actions.	Grafakos et al. (Grafakos et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
Ad/Mit Integration and Interrelationships	Consideration of Ad/Mit interrelationships (co-benefits/ synergies or trade-offs/conflicts)	identify whether the plan has suggested the interrelationships of Ad and Mit actions during the Prioritization process.	Grafakos et al. (Grafakos et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	Mainstream potential of climate actions	examine whether potentials of mainstreaming climate actions were considered in the plan. In the context of CC, mainstreaming refers to the incorporation of climate change considerations into established or on-going development programs, policies or management strategies, rather than developing Ad and Mit initiatives separately.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
Collaborations and Partnerships	Partnerships	identify whether the plan has stated the use of partnerships (public – private, local – other government, local government – civil society, etc.) to support the implementation of both Ad and Mit, for example, public-private-partnerships assist realization of climate actions through the committed financial support provided by private sector.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
Common Regulatory Framework and Monitoring Procedures	Common policy or regulatory framework	identify whether the plan has mentioned a common policy or regulatory framework that provides guidance and requirements of CC planning and implementation for both Mit and Ad actions.	Grafakos et al. (Grafakos et al., 2019) and Grafakos et al. (Grafakos et al., 2020)
	Common Monitoring procedure/ framework	check whether there was a common monitoring system or committee to review the performance of both Ad/Mit climate actions, allowing revisions and improvements through feedback mechanisms.	Grafakos et al. (Grafakos et al., 2019), Pietrapertosa et al. (Pietrapertosa et al., 2019) and Grafakos et al. (Grafakos et al., 2020)

CC. Solutions for transitioning to a circular system provide a decrease in GHG emissions and extend the lifespan of materials in building construction and open areas. In the analytical framework, solutions that minimize material consumption in construction or improve material reuse and recycling are explored for a comprehensive approach. The second component of the framework involves assessing whether the solutions for urban regeneration projects align with the goals of local CC strategies, as proposed by Buzasi et al. (Buzási et al., 2021) (Table 4). The grading method provides one point for each solution executed for various strategies. Consistency with CCAPs is evaluated using a binary condition: yes (1) or not (0). The potential solutions for each technique are detailed in Appendix B. The findings are classified based on three levels: low, medium, and high solutions executed at various scales for CC and the alignment of urban regeneration initiatives with local CCAPs. Each urban regeneration project's overall score is compared to the greatest achievable total score and shown as a percentage. The three classifications are categorized as: low (0%–33%); medium (34%–66%); and high (67%–100%).

2.4. Building projects

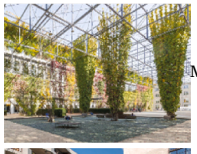
Six building projects were chosen for each of the 10 cities that were examined in this Paper as examples of successful building design strategies. 60 projects have been examined, as shown in Table 5. The projects were chosen by searching for the terms "green building" and "sustainable building" on Atlas of Architecture developed by Divisare (2023) for the topic "building in urban context". Divisare is the result of an effort of selection and classification of contemporary architecture

Table 3
Urban regeneration projects selected for the analysis. The columns report the city, the name of the project, the year when the design has started, the state of the art of the project, if completed or not, the CC hazard considered in the design and construction project to adapt the Built Environment (BE) to the effects of CC and the components of BE considered, such as open spaces or building.

City	Name	CC hazard considered	Year and state of the art	Open spaces	Buildings
Amsterdam	 GWL site	Extreme precipitation; heatwave	1998 completed	x	x
	Schoonschip 	Extreme precipitation; heatwave, water scarcity, sea level rise	2021 completed	x	x
Boston	 Talbot-Norfolk triangle eco-innovation district	Extreme precipitation, heatwave	2019 completed	x	x
	 Seaport Square Master Plan	Extreme precipitation, heatwave	2017 completed	x	x
Copenhagen	 The climate-resilient neighbourhood of Østerbro	Extreme precipitation; water scarcity	2012 In progress	x	x
	 UN17 Village	Extreme precipitation; water scarcity	2020 In progress	x	x
Montreal	 Bassins du Nouveau Havre	Estreme precipitation, water scarcity	2011 Completed	x	x
	Royalmount 	Extreme precipitation, water scarcity	2020 In progress	x	x
New York	Resilient Neighbourhood 	Extreme precipitation; sea level rise	2017 In progress	x	x
	 Hunter's Point South	Extreme precipitation, sea level rise, heat wave	2018 completed	x	

(*continued on next page*)

Table 3 (*continued*)

City	Name	CC hazard considered	Year and state of the art	Open spaces	Buildings
San Francisco	Mission Bay South 	Extreme precipitation, heatwave	2003 In progress	x	x
	 The Cove - Central Embarcadero Piers	Sea level rise, extreme precipitation, heatwave	2020 In progress	x	x
	Historic District  Yesler Terrace	Extreme precipitation, heatwave	2010 completed	x	x
Seattle	 Grow Community Bainbridge	Extreme precipitation, heatwave, water scarcity	2012 completed	x	x
Stockholm	 Hammarby Sjöstad	Extreme precipitation; water scarcity	2016 completed	x	x
	Royal Seaport 	Extreme precipitation; water scarcity	2012 In progress	x	x
Toronto	The Portlands 	Extreme precipitation, water scarcity, wind, extreme temperature	2013 In progress	x	x
	Regent Park 	Extreme precipitation, water scarcity	2009 In progress	x	x
Zurich	 MFO-Park	Extreme precipitation; heatwave	2022 completed	x	
	 Hunziker Areal	Heatwave	2015 completed	x	x

conducted for over twenty years. Information relating to CC in the project descriptions at the architectural design business was extracted. This section aims to categorize design strategies for decreasing carbon emissions, including enhancing envelope insulation, generating energy from renewable sources, and implementing measures to mitigate the impacts of heat waves, heavy rainfall, rising sea levels, and droughts, such as green roofs and rainwater collection (He, 2022). The final objective is to analyze the design solutions used at the building scale in cities most sustainable in terms of developing environmental strategies, including local climate actions, focusing on CCM and CCA strategies,

Table 4
Indicators selected to assess urban regeneration projects in cities most sustainable in terms of developing environmental strategies, including local climate actions.

Categories of urban regeneration project development for climate change	Indicator	description	references
Solutions implemented at different scale (building, open air spaces, neighborhood/district level)	Green infrastructure strategy	What green infrastructure measures have been incorporated into the project, such as the development of urban parks, community gardens, and green roofs; integration of urban agriculture like allotment gardens and urban farms; establishment of green corridors to mitigate habitat fragmentation; implementation of cycling and walking paths for enhanced accessibility; and design of multifunctional landscapes that balance conservation with urban growth?	Privitera & Barbarossa (Privitera and Barbarossa, 2021) Bologna & Hasanaj (Bologna et al., 2023)
	Sustainbale Urban Drainage System	What SUDS measures have been incorporated into the project, such as the use of permeable pavements and green roofs to reduce runoff, installation of rain gardens and bioswales in public spaces, creation of retention basins or wetlands to manage excess water, harvesting rainwater for reuse, and integrating SUDS with green infrastructure to enhance biodiversity?	Privitera & Barbarossa (Privitera and Barbarossa, 2021) Bologna & Hasanaj (Bologna et al., 2023)
	Re-energised cities	What energy-efficiency measures have been implemented in the project, such as the adoption of renewable energy sources like solar panels and wind turbines, retrofitting buildings with passive design features like green walls and insulation, establishing district heating systems, using micro-wind turbines and solar chimneys, and applying bioclimatic architecture principles for sustainable urban development?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
	Land use and transport integration	What measures have been applied to integrate land use and transport systems in the project, such as developing Transit-Oriented Developments (TODs) with mixed-use settlements near public transit hubs, implementing pedestrian zones and cycling lanes, integrating public transport networks with land-use plans, preserving open spaces, and promoting compact urban forms to reduce travel distances?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
	Zero waste and re use of material for construction	What zero-waste strategies have been adopted in the project, such as the use of recycled and reused materials in construction, application of modular and prefabricated building technologies, establishment of material recovery facilities, implementation of deconstruction practices to salvage materials, and designing buildings for extended lifespan and circular use?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
Other sustainable development solutions	Healthy city	What actions that enable "activity and exercise belts which create better conditions for play, social interaction, and activity" have been implemented in the urban regeneration project?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
Consistency with other policies	Explicit reference to Urban Regeneration program	Does the project explicitly reference an urban regeneration program?	Buzasi et al. (Buzási et al., 2021)
Consistency with local climate plan *Mit objectives*	Reduction of CO_2 emissions in the building sector	Does the project address the reduction of CO2 emissions in the building sector?	Buzasi et al. (Buzási et al., 2021)
	Reduction of CO_2 emissions in the transport sector	Does the project involve measures to reduce CO2 emissions in the transport sector?	Buzasi et al. (Buzási et al., 2021)
	Reinforcement of carbon sink capacities	Does the project include actions to reinforce carbon sink capacities?	Buzasi et al. (Buzási et al., 2021)
Consistency with local climate plan *Ad objectives*	Development of greenfield systems	Does the project involve the development or enhancement of greenfield systems?	Buzasi et al. (Buzási et al., 2021)
	Mit of the UHI effect in the BE	Does the project address the mitigation of the urban heat island effect in the built environment?	Buzasi et al. (Buzási et al., 2021)
	Transition towards sustainable water management, spreading sustainable water management practices	Does the project promote sustainable water management practices?	Buzasi et al. (Buzási et al., 2021)
	Moderate the adverse health effects of CC	Does the project address the moderation of the adverse health effects of climate change?	Buzasi et al. (Buzási et al., 2021)
	Reducing the vulnerability of natural and landscape value	Does the project involve measures to reduce the vulnerability of natural and landscape value?	Buzasi et al. (Buzási et al., 2021)
	Reducing the vulnerability of BE	Does the project address reducing the vulnerability of the built environment?	Buzasi et al. (Buzási et al., 2021)

while acknowledging that some measures may provide multiple advantages. Each building design measure applied is granted 1 point. The design measures were detailed in Appendix C. An attempt was made to determine whether project initiatives might be connected to the CCAP in the city and if the building has been accredited with a Green Building Rating Systems (GBRS) during the building investigation. The matrix used for the analysis is shown in Table 6.

2.5. Best practices selection for CCAPs, urban regeneration and building projects

To define and classify urban design measures as best practices for the integration of climate change mitigation (CCM) and adaptation (CCA), key criteria have been selected to assess the three levels.

- Demonstrate measurable benefits for both Mit and Ad goals. According to Masson-Delmotte et al. (2021), the key mitigation benefits of urban design measures include sequestering and storing carbon, reducing building energy use, decreasing municipal water use, and facilitating active mobility. Key adaptation benefits include reducing heat stress, mitigating flooding, improving health, enhancing air quality, and promoting biodiversity.
- Exhibit successful implementation with evidence-based outcomes.
- Be replicable and scalable across different urban contexts, with implementation demonstrated in at least three selected cities.
- Presence in the top-level cluster (top 25%) for each level analyzed, including CCAPs, urban regeneration projects, and building projects.

3. Results

3.1. CCAPs

3.1.1. Evaluation across different planning stages

The analysis findings of the CCAPs are shown in Fig. 2, displaying the overall scores for each plan and the scores achieved in various planning phases.

During the "Identifying and Understanding" step, research showed that 50% of CCAPs contained baseline emission inventory and GHG emission predictions, and 14 CCAPs conducted a current vulnerability assessment about the impacts of CC. Thirteen plans have incorporated future climate projections. The Boston Greenovate plan (City of Boston. Greenovate Boston, 2014) is the only one that does not include future climate projections, while all other plans that have analyzed current vulnerability have also developed future climate projections. Zurich is the only city among those with future climate projections that has not used a long-term period of time.

During the "Envisioning and Planning" phase, 12 plans included goals for reducing GHG emissions, while 15 plans included objectives for adapting to present and future CC. Half of the plans have established strategies for the long-term period up to 2050 for both GHG emissions reduction goals and future climate adaption objectives. Out of the 11 plans analyzed, only 2 plans, One New York (OneNYC): The Plan for a Strong and Just City (City of New York, 2015) and San Francisco Climate Action Plan (City of San Francisco, 2021), provide cost estimates for both Mit and Ad strategies in the same document. 11 strategies include benefit estimate, but no document has analyzed both Mit and Ad benefits at the same time.

Collaborations are crucial throughout the "Implementing and monitoring" phase of plans. All the plans reviewed have used collaborations with public or private entities to establish Mit and Ad goals. 16 CCAPs apply a standard policy within the regulatory framework in conjunction with other plans, initiatives, and local regulations. Regular monitoring processes are a crucial governance strategy for assessing the progress of Mit and Ad strategies. 17 plans have filed either Mit or Ad methods, whereas only 2 plans include common monitoring procedures for both Mit and Ad. 17 plans have highlighted the potential of integrating local CC actions into various programs and plans. In particular, the plans for the city of Toronto and the Environment Programme 2020–2023 of Stockholm (City of Stockholm, 2020a) have incorporated both Mit and Ad strategies simultaneously.

3.1.2. Grouping into clusters

Fig. 2 displays the plans analyzed and categorized into three groups based on their overall score: "early stage," "moderate," and "advanced," following the methodology outlined in Section 2. Numerical results are reported in Appendix D. The top five advanced CCAPs are: OneNYC 2050 in New York (City of New York. OneN and YC, 2050, 2019) (19 points), Climate Action Plan in San Francisco (City of San Francisco, 2021) (16 points), Climate Plan 2020–2030 in Montreal (City of Montreal, 2019) (16 points), One New York: The Plan for a Strong and Just City in New York (City of New York, 2015) (14 points), and TransformTO Net Zero Strategy in Toronto (City of Toronto, 2020) (14). All advanced proposals in the preliminary study have been evaluated to address both CCM and CCA themes. The most advanced plans are situated in North America, namely in the USA and Canada.

Climate Ready Boston (City of Boston, 2016), Greenovate Boston (City of Boston. Greenovate Boston, 2014), Copenhagen climate adaptation plan (City of Copenhagen, 2011), City's resiliency plan, A Stronger, More Resilient New York (City of New York. A Stronger, 2013), Seattle Climate Action Plan (City of Seattle, 2013), Hazards and Climate Resilience Plan in San Francisco (City of San Francisco, 2020), Toronto Resilience Strategy (City of Toronto, 2019), Environmental Strategy + Programm Klimaanpassung Fachplanung (City of Zurich, 2020) and the Climate Adaptation Strategy in Amsterdam (City of Amsterdam, 2020a) are categorized as "moderate." Upon comparing the results with the initial research, it was found that the majority of plans prioritize Ad, whereas the Seattle Climate Action Plan (City of Seattle, 2013) stands out for its emphasis on reduction. Two-thirds of plans focus on North American cities, with just three "moderate" integrator plans established in Europe, namely in Copenhagen, Zurich, and Amsterdam.

The following are the "early stage" integrator plans: Climate Action Plan 2020–2023 in Stockholm (City of Stockholm, 2020b), Climate change adaptation plan for the Montréal urban agglomeration 2015–2020 (City of Montreal, 2017a), CPH 2025 Climate Plan in Copenhagen (City of Copenhagen, 2017–2020), Environment Programme 2020–2023 in Stockholm (City of Stockholm, 2020a), New Amsterdam Climate Roadmap: Amsterdam Climate Neutral 2050 (City of Amsterdam, 2020b), and Preparing for Climate Change in Seattle (City of Seattle, 2017). Only one plan categorized as "early stage" integrator originates from a North American city, specifically focusing on CC preparation in Seattle. The other plans in this category are from European cities.

The top scores for the "Identifying and Understanding" stage of planning were achieved by OneNYC 2050 (City of New York. OneN and YC, 2050, 2019), the Climate Action Plan of San Francisco ((City of San Francisco, 2021), the Climate Plan 2020–2030 in Montreal (City of Montreal, 2019), and the Environmental Strategy + Programm Klimaanpassung Fachplanung Hitzeminderung in Zurich (City of Zurich, 2020). The plans OneNYC 2050 (City of New York. OneN and YC, 2050, 2019), the Climate Action Plan of San Francisco (City of Stockholm, 2020a), and OneNYC (City of New York, 2015) have achieved the highest score in the envisioning and planning phases. The implementation and monitoring phases of OneNYC 2050 (City of New York. OneN and YC, 2050, 2019) and the Climate Plan 2020–2030 (City of Montreal, 2019) in Montreal are farther advanced.

The analysis of CCAPs revealed that the most advanced plans focus on implementing strategies related to buildings, transportation, and zero waste to mitigate CC. Building infrastructure and transportation are the main areas of focus for CCA.

3.1.3. Best practices to support urban design for CCM and CCA

The CCAPs evaluated in this Paper include features that are suitable for facilitating urban design activities. New York City has created Climate Resiliency Design Guidelines (City of New York, 2022) to assist in designing procedures for adapting to the impacts of climate change. The One NYC plan for a strong and fair city (City of New York, 2015) utilizes basic metrics, scenario analysis tools, and computer modelling methodologies to assess the city's progress in enhancing its resilience. The city will collaborate with 100 Resilient Cities foundation to adopt a certain set of monitoring technologies. The San Francisco Climate Action Plan (City of San Francisco, 2021) evaluated two specific impact areas: community Ad and resilience, which refers to the information and services accessible to prepare for, respond to, and recover from a hazard event; and physical environment resilience, which involves changes to buildings and infrastructure, including nature-based infrastructure, aimed at reducing risks from hazards and pollution. This strategy outlines strategies and activities to promote Mit, Ad, and resilience.

Table 5
List of the building projects analyzed to identify the CCM and CCA measures proposed and implemented at the building scale.

City	Project	type	Year/state of the art	surface (m^2)
Amsterdam	 The Edge	Private - Office	2016 completed	40000
	 Valley	Private - Mixed use	2023 completed	75000
	 Brink tower	Private - Residential	2021 ongoing	30184
	 Amsterdam university project	Public - University	2012 completed	5800
	Goede Doelen Loterijen & Dutch Charity Lotteries Head Offices	Private - Office	2018 completed	15200
	 House 2.0	Private - Residential	2002 completed	230
Boston	 Interdisciplinary Science and Engineering Complex	Private - University	2016 completed	21947
	 E + Housing Catherine Street	Private - Residential	2013 completed	522
	 E + HOMES: 226-232 HIGHLAND	Private - Residential	2013 completed	732
	 Atlantic Wharf building	Private - Mixed use	2011 completed	111483
	 181 COLERIDGE AVE RESIDENCES	Private - Residential	2018 In progress	3251

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Table 5 (*continued*)

City	Project	type	Year/state of the art	surface (m^2)
	 Spaulding Rehabilitation Hospital	Private - Hospital	2013 completed	35151
Copenhagen	Green Lighthouse project	Public - University	2009 completed	970
				
	 Copenhagen international school	Public - School	2017 completed	6048
	 UN City	Private - Institutional	2013 completed	20000
	 Nordea bank Headquarter	Private - Headquarter	2017 completed	46600
	 Maersk Tanum Panum Building	Private - University	2017 completed	42700
	 Carlsberg Central Office	Private - Headquarter	2021 completed	23200
Montreal	 Pavillon d'accueil du Parcours Gouin	Private - University	2017 completed	375
	 La Bibliothèque du Boisé	Public - Library	2013 completed	5000
	Ericsson Canada – Campus corporatif et Centre R&D	Private - Headquarter	2017 completed	24650
				
	 RIO TINTO ALCAN PLANETARIUM	Private - educational	2014 completed	7900

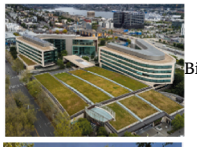
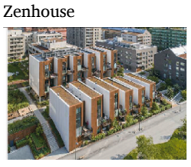
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Table 5 (*continued*)

City	Project	type	Year/state of the art	surface (m^2)
	 Lemay Headquarter – The Phenix	Private - Headquarter	2019 completed	8000
	Centre de transport Stinson de la STM	Private - Commercial	2014 completed	38400
	 Pierhouse & 1 Hotel Brooklyn Bridge	Private - Mixed use	2017 completed	57705
New York	 Manhattan Districts 1/2/5 Garage & Spring Street Salt Shed	Public - civic infrastructure	2015 completed	40069
	 Kew Gardens Hills Library	Public - Library	2017 completed	278
	 The House at Cornell Tech	Public - University Campus	2018 completed	984
	 The Kathleen Grimm School for Leadership and Sustainability at Sandy Ground	Public - School	2015 completed	6317
	 The New School University Center	Private - University	2016 completed	34838
	 Salesforce's 350 Mission Office Tower	Private - Office	2015 completed	42000
San Francisco	 California academy of science	Private - Museum	2008 completed	43000
	 The Exploratorium at Pier 15	Private - Museum	2013 completed	27973

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Table 5 (*continued*)

City	Project	type	Year/state of the art	surface (m^2)
	 Nancy and Stephen Grand Family House	Private - Residential	2016 completed	2957
	New San Francisco Federal Building	Public - Office	2007 completed	56206
				
	 Rene Cazenave Apartments	Private - Residential	2013 completed	6941
Seattle	Bullit Center	Private - Foundation	2013 completed	4800
				
	 Bill & Melinda gates foundation campus	Private - Foundation	2013 completed	59457
	 Seattle City Hall	Public - Civic Center	2013 completed	18580
	 Ballard library and neighbourhood center	Public - Library	2005 completed	15000
	 Footprint at bridge	Private - Residential	2001 completed	3859
	 Federal Center South Building 1202	Public - Office	2012 completed	19416
Stockholm	 79&Park Hillside	Private - Residential	2018 completed	25000
	 Forskaren, a New Health and Life Science Innovation Center	Private - Innovation center	2020 ongoing	24000
	Zenhouse	Private - Residential	2017 completed	3200
				

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Table 5 (*continued*)

City	Project	type	Year/state of the art	surface (m^2)
	 Brick Housing in Royal Seaport	Private - Residential	2020 ongoing	7000
	 Karolinska Hospital	Public - Hospital	2018 completed	26000
	Stockholm Waterfront Congress Centre	Private - Conference center	2010 completed	24600
Toronto	 York University's McEwen Building	Private - University	2019 completed	6165
	 Daniels Building at One Spadina Crescent	Private - University	2017 completed	11441
	 Centre for Green Innovation at Evergreen Brick Works	Private - education	2010 completed	11743
	 60 Richmond Street East	Private - Residential	2010 completed	9250
	160 Front Street	private - Office	2023 completed	151000
	 Albion District Library	Public - Library	2015 completed	10432
Zurich	 Bellerivestrasse 36 Zürich	Private - Office	2019 ongoing	20000
	 TWIST Studentisches Wohnen ETH Science City	Public - Residential	2016 completed	22475
	 Kalkbreite	Private - Residential	2014 completed	22900

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Table 5 (*continued*)

City	Project	type	Year/state of the art	surface (m^2)
	 Tamedia office	Private - Office	2013 completed	10120
	 Binzstrasse 29	Private - Commercial	2021 ongoing	7000
	 Swiss Re Next	Private - Office	2018 completed	32148

Enhancing climate resilience in San Francisco neighborhoods involves anticipating, preparing for, and responding to various risks to better deal with their repercussions. The Climate 2020–2030 plan (City of Montreal, 2019) from the municipal of Montreal outlines action number 43, which introduces a 'climate test' to assess the impact of major municipal decisions on GHG emissions and climate adaptation. This test will gradually apply to all significant decisions, starting with large infrastructure projects, and aims to maximize climate benefits while minimizing adverse environmental impacts. The TransformTO plan (City of Toronto, 2020) includes an appendix highlighting the advantages of efforts to decrease GHGs in Toronto for increase climate resilience. Urban regeneration projects.

3.1.4. *Grouping into clusters*

Fig. 3 displays the results of the urban regeneration projects analysis for Mit and Ad across different scales. Numerical results are reported in Appendix E. Fig. 4 shows the overall consistency of each urban regeneration project with the CCAPs developed in each city.

After analyzing the results, it is evident that the Royal Seaport in Stockholm (City of Stockholm. Sustainable Urban Development Programme, 2021) and the GWL site (Foletta and Henderson, 2016) in Amsterdam achieved the highest score for green infrastructure, incorporating all available solutions. In contrast, the urban regeneration project of Schoonschip (VvE Schoonschip, 2019) in Amsterdam only implemented the action allotment garden, influenced by the project's context of floating houses and open-air spaces on the river water. Hammarby Sjöstad (Urban Green, 2016), Royal Seaport (City of Stockholm. Sustainable Urban Development Programme, 2021), and The Portlands (WaterfronToronto, 2024) have achieved the highest scores for their sustainable urban drainage system solutions, which aim to improve water management on surfaces. The Hunziker project (Mehr als and Wohnen, 2022) in Zurich earned the lowest possible score for this approach due to the implementation of just two solutions: a green roof and permeable surfaces. The Portlands (WaterfronToronto, 2024), Talbot Norfolk (Queeley, 2016), Schoonschip (VvE Schoonschip, 2019), and Hunziker Areal (Mehr als and Wohnen, 2022) have the highest score in the re-energised city plan for regeneration projects. Hammarby Sjöstad (Urban Green, 2016), Royal Seaport (City of Stockholm. Sustainable Urban Development Programme, 2021), and The Portlands (WaterfronToronto, 2024) have fully developed solutions for integrating land use and transport, while Østerbro (Klimakvarter. The Climate Resilient Neighbourhood Østerbro, 2016) and MFO Park (Hoory, 2017) in Zurich have each implemented one action: reducing space for cars and establishing a car-free zone, respectively. UN17 Village (Lendager

Table 6
Indicators selected to assess building projects in cities most sustainable in terms of developing environmental strategies, including local climate actions.

Categories of building project development for climate change	Indicator	description	references
Building CC solutions	Mit (Reduction of GHG emission trough design and technological systems)	How many measures have been implemented in the building project related to the reduction of GHG emission trough design and technological systems?	He (He, 2022)
	Ad (Heat Island, Sea Level Rise, Flooding and Storm, Water scarcity, winds and fire)	How many measures have been implemented in the building project, and what specific measures have been taken to address adaptation challenges such as heat island mitigation, sea level rise, flooding and storms, water scarcity, winds, and fire?	He (He, 2022)
Building Sustainable solutions	Other Environmental sustainability solutions (land, water ecc.)	How many measures have been implemented in the building project, and what specific measures or strategies have been applied to enhance environmental sustainability solutions, such as those addressing land, water, and other natural resources?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
	Other Sustainable solution (social, economic)	How many measures have been implemented in the building project, and what specific actions have been taken to promote other sustainable solutions, including social and economic aspects?	Privitera & Barbarossa (Privitera and Barbarossa, 2021)
Consistency with CCAPs	Mit (Reduction of GHG emission trough design and technological systems)	Is the building project aligned with local CCAPs to reduce GHG emissions? If so, which CCAPs specifically?	New indicator based on Buzasi et al. (Buzási et al., 2021)
	Ad (Heat Island, Sea Level Rise, Flooding and Storm, Water scarcity, winds and fire)	Is the building project aligned with local CCAPs to adapt to heat island, sea level rise, flooding and storm, water scarcity, winds and fires? If so, which CCAPs specifically?	New indicator based on Buzasi et al. (Buzási et al., 2021)
Green Building Certification	Green Building Certification Achieved	Has the building project obtained a GBRS certification? If yes, how many GBRS certifications have been obtained?	He (He, 2022)

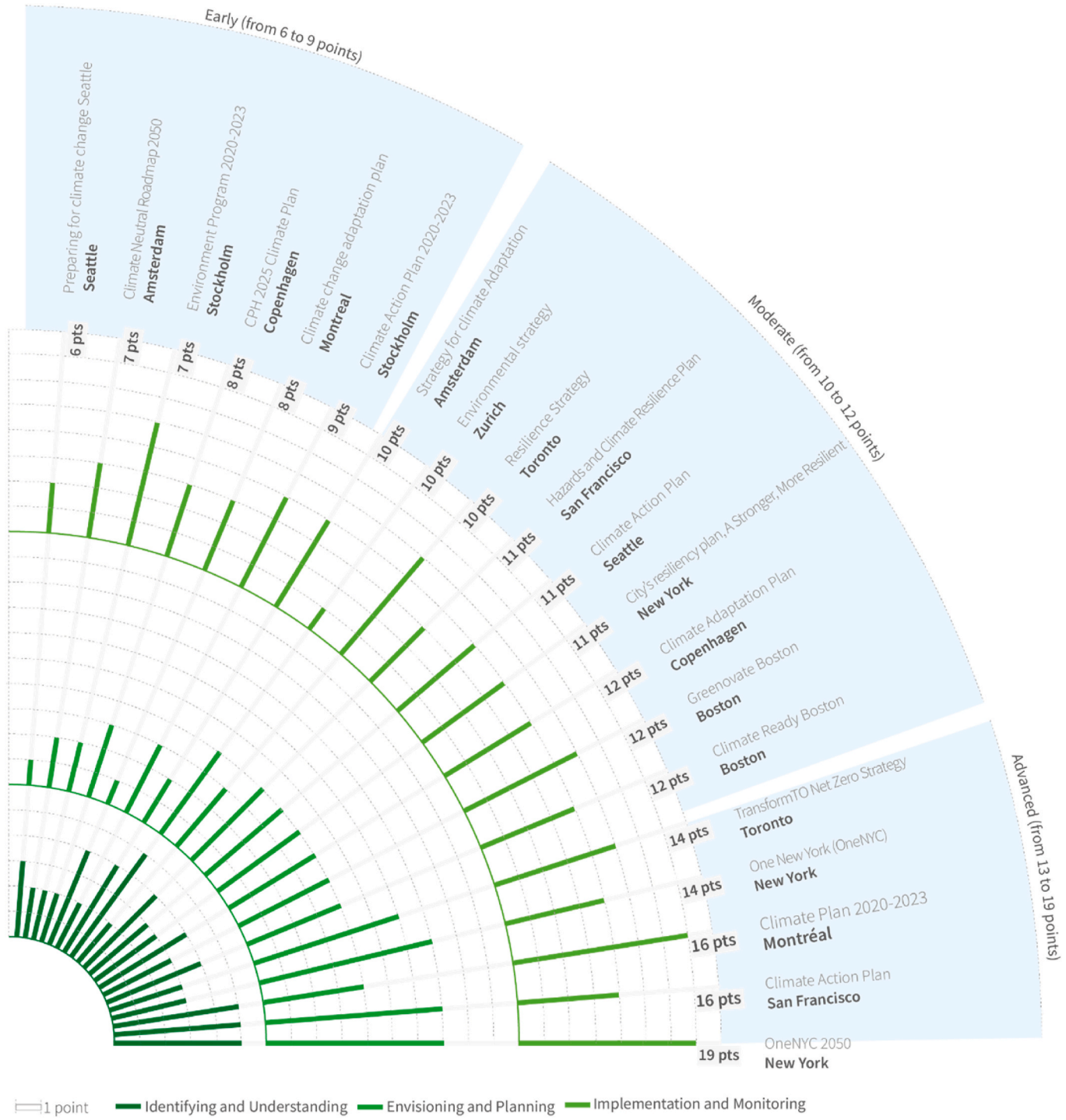


Fig. 2. Clusterization of CCAPs based on Content Analysis related to the integration of CCM and CCA actions. The three groups are subdivided in advanced, moderate and early integration. Source: author's illustration.

Group. UN17 Village, 2020) has included all four methods for zero waste and material reuse in its new community design, while Royal Seaport (City of Stockholm. Sustainable Urban Development Programme, 2021) has adopted all four alternatives as well. Some projects, like the climate-resilient neighborhood of Østerbro (Klimakvarter. The Climate Resilient Neighbourhood Østerbro, 2016), the Resilient Neighborhood (City of New York, 2020) in New York, Yesler Terrace (Seattle Housing Authority, 2016) in Seattle, Bassins du Nouveau Havre (City of Montreal, 2017b), and Royalmount (Royalmount. Royalmount, 2021) in Montreal, don't have plans in place for zero trash and reusing building materials. All urban regeneration initiatives have included measures to create "activity and exercise belts" that enhance circumstances for play, social contact, and physical activity, except for Resilient Neighborhood (City of New York, 2020) in New York.

The projects with the highest number of actions implemented among the 5 strategies and a percentage above 67% (indicating a high level of integrated solutions development) are Royal Seaport (City of Stockholm. Sustainable Urban Development Programme, 2021) and Hammarby Sjöstad (Urban Green, 2016), in Stockholm, Talbot Norfolk (Queeley, 2016) in Boston, The Portlands (WaterfronToronto, 2024) in Toronto,

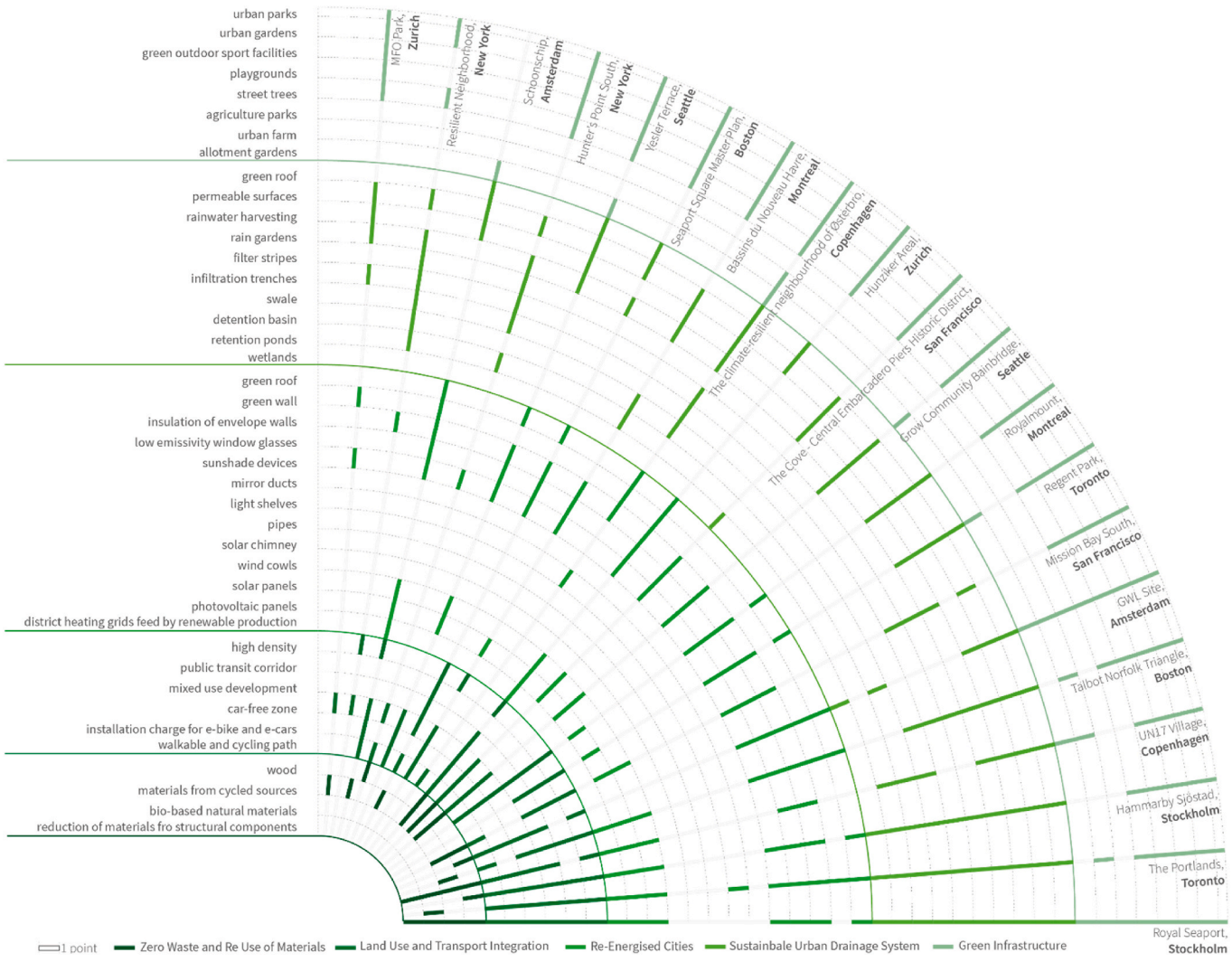


Fig. 3. Results obtained by the analysis of the level of integration of solutions implemented at different scale (district, open air spaces and buildings) among CCM and CCA in urban regeneration projects. Source: author's illustration.

and UN17 Village (Lendager Group. UN17 Village, 2020) in Copenhagen. Other urban regeneration projects have achieved a percentage ranging from 34% to 67% with a moderate degree of integrated solutions development.

Before assessing the connection of urban regeneration projects with CCAPs, it was discovered that four urban initiatives were not initiated by the city for urban regeneration. Each project description lacks mention of a comprehensive regeneration plan. The projects mentioned include UN17 Village (Lendager Group. UN17 Village, 2020) in Copenhagen, MFO Park (Hoory, 2017) in Zurich, the GWL site (Foletta and Henderson, 2016), and Schoonschip (VvE Schoonschip, 2019) in Amsterdam.

When evaluating the alignment of urban regeneration projects with local CCAPs, it is evident that three projects – MFO (Hoory, 2017) in Zurich, Resilient Neighborhood (City of New York, 2020), and Hunter's Point South (New York City Economic Development Corporation, 2022) in New York – have not taken steps to decrease carbon emissions from buildings and transportation, or to enhance the city's carbon sequestration capabilities. Furthermore, out of the 13 urban regeneration projects listed, 3 lack consistency with Mit efforts, while the other 10 have not implemented solutions to enhance the city's carbon sink capacity (Fig. 4). Based on the method used to assess the alignment of urban regeneration projects with CCAPs, only Schoonschip (VvE Schoonschip, 2019) in Amsterdam did not implement activities for the greenfield system. Schoonschip (VvE Schoonschip, 2019) in Amsterdam, Resilient Neighborhood (City of New York, 2020) in New York, Yesler Terrace (Seattle Housing Authority, 2016) and Grow Community Bainbridge (Grow Community, 2021) in Seattle, Bassins du Nouveau Havre (City of Montreal, 2017b), and Royalmount (Royalmount. Royalmount, 2021) in Montreal lack strategies to reduce the impact of UHIs. The Hunziker area (Mehr als and Wohnen, 2022) is the only project that has not successfully transitioned to sustainable water management despite the limited solutions offered for the sustainable urban drainage system concept. Urban regeneration projects and CCAPs show a lack of consistency in lowering the vulnerability of natural and landscape assets. 11 urban redevelopment initiatives have failed to reach this aim. All regeneration initiatives have included measures to decrease the susceptibility of the BE.

Urban regeneration projects that meet with local CCAPs with a score above 67% are Royal Seaport (City of Stockholm. Sustainable Urban Development Programme, 2021) and Hammarby Sjöstad (Urban Green, 2016) in Stockholm, Talbot Norfolk (Queeley, 2016) in Boston, The Portlands in Toronto (WaterfronToronto, 2024), and UN17 Village (Lendager Group. UN17 Village, 2020) in Copenhagen. Other urban regeneration projects have achieved a consistency level ranging from 34% to 67% in implementing Mit and Ad techniques in local CCAPs.

3.1.5. Best practices to support urban design for CCM and CCA

The Royal Seaport (City of Stockholm. Sustainable Urban

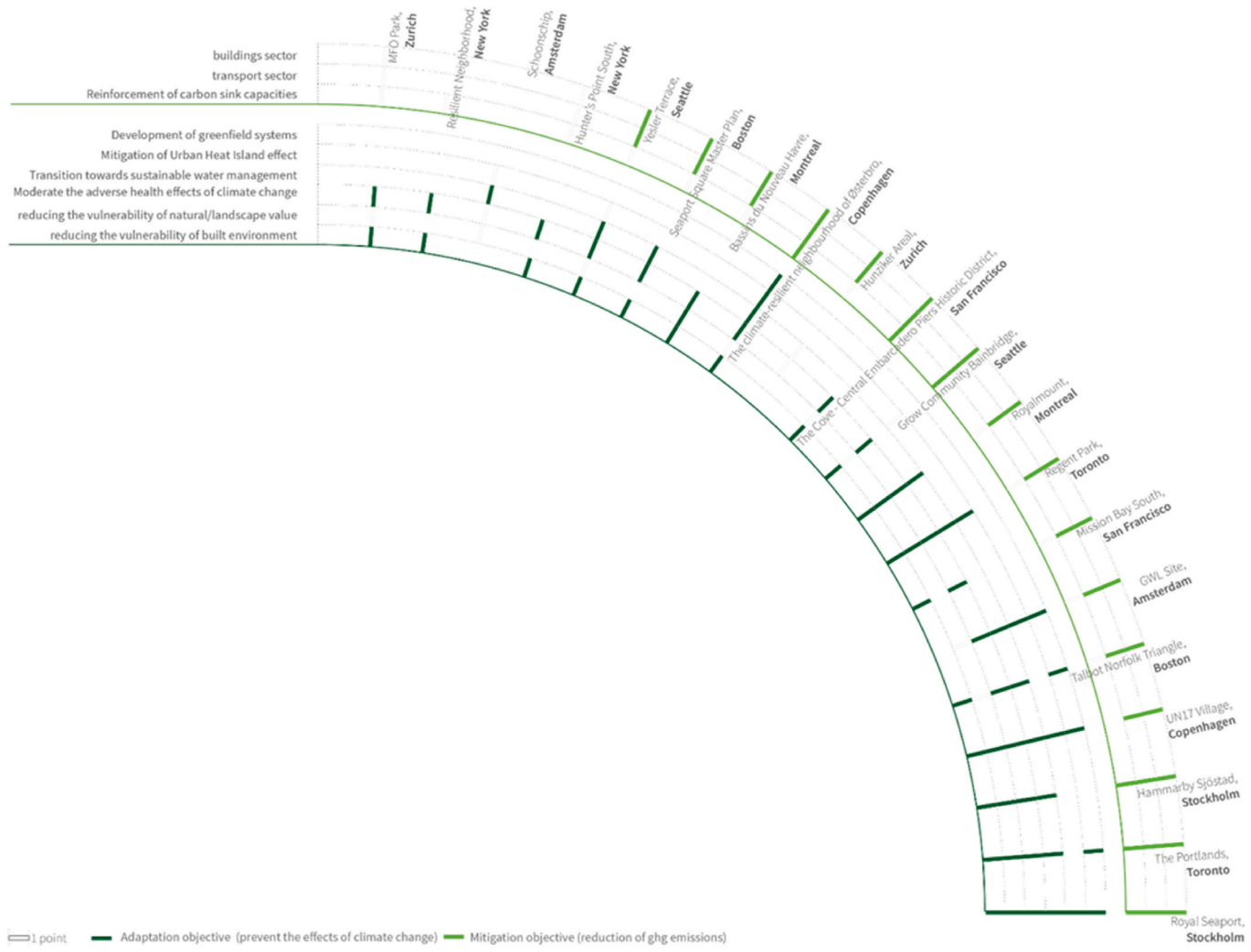


Fig. 4. Results obtained by the analysis of the consistency with local CC action plans. Source: author's illustration.

Development Programme, 2021) in Stockholm has achieved the highest grade for implementing solutions at various scales for mitigating and adapting to CC, as well as for the project's alignment with CCAPs. The project represents worldwide best practices in urban redevelopment, with a strong focus on CC and sustainability. The project demonstrates the use of green infrastructure, sustainable urban drainage systems, revitalized cities, integration of land use and mobility, and ideas and activities for transitioning to a zero-waste circular economy. During its Environmental Program 2008–2011, Stockholm City Council determined that Stockholm Royal Seaport should have a unique environmental focus, relying on lessons learned from Hammarby Sjöstad (Urban Green, 2016). Stockholm Royal Seaport will enhance Stockholm's status as a top capital city in climate initiatives, promote Swedish environmental technology, and foster the development of new technologies in conjunction with all housing projects in Sweden. Hammarby Sjöstad (Urban Green, 2016) in Stockholm shares the principles of the Royal Seaport concept, but places less emphasis on green infrastructure and the shift towards a circular system. The Portlands (WaterfronToronto, 2024) in Toronto is an urban regeneration project focused on enhancing knowledge with the ability to include various solutions for Mit and Ad. It aims at remodelling a section of the city to safeguard inner urban neighborhoods from flooding caused by river floods and anticipated sea level rise.

These actions involve various scales, including urban spaces, courtyards, streets, and buildings, to safeguard the BE from CC effects and enhance biodiversity.

3.2. *Building projects*

The analysis of building projects' results is presented in Fig. 5. Extended numerical results are reported in Appendix F. It includes the solutions applied for Mit and Ad, the consistency of each project with the developed CCAPs in each city, and the GBRS achieved by each project.

York University's McEwen Building in Toronto has the highest number of carbon reduction measures implemented, with 18 measures identified. This is followed by Lemay Headquarter—The Phenix in Montreal, La Bibliothèque du Boisé in Montreal, and the Kathleen Grimm School for Leadership and Sustainability at Sandy Ground, each with 12 measures identified. The Valley in Amsterdam has implemented the lowest number of Mit solutions at the building level with only 1 measure. Brink Tower in Amsterdam, Kew Garden Hills Library in New York, Forskaren in Stockholm, Brick Housing in Royal Seaport in Stockholm, TWIST Studentisches Wohnen ETH Science City in Zurich, Kalkbreite in Zurich, Amsterdam University in Amsterdam, Manhattan Districts ½/5 Garage & Spring Street Salt Shed in New York, and Bellerivestrasse 36 in Zurich have each implemented 2 measures. 181 Coleridge Ave homes and Albion District Library in Toronto have undertaken the most Ad measures, with 11 and 10 measures, respectively. Several building projects, including The House at Cornell Tech in New York, Swiss Re Next in Zurich, Binzstrasse and Tamedia in Zurich, House 2.0 in Amsterdam, and the Waterfront Congress in Stockholm, have not included Ad strategies to reduce the impacts of CC. The building projects largely aligns with local CCM programs, rather than CCA strategies.



Fig. 5. Results obtained by the analysis of the measures implemented to reduce carbon emissions and prevent the effects of CC at the building level. In addition, there are also the results to identify the consistency with local CCAPs in terms of Mit and Ad and if the building project has obtained a GBRS. Source: author's illustration.

Passive design, high-performance thermal insulation, natural ventilation, increased daylight design, and low-energy windows were implemented in various numbers of building projects to reduce carbon emissions. Durable natural resources and recycled materials are the most often utilized material categories in 11 and 14 construction projects, respectively. Photovoltaic panels, waste energy recovery from ventilation, and green roofs are primary methods for energy sources and carbon emission reduction. The most frequently used Ad measures are green roofs (33 occurrences), trees (11 occurrences), rainwater harvesting (33 occurrences), passive design (building orientation, building

shape, compact form, mass compact) (16 occurrences), automatic or manual solar shading (14 occurrences), high-performance thermal insulation (18 occurrences), natural ventilation (18 occurrences), and permeable paving (31 occurrences).

GBRS has not been given to the Copenhagen International School, the Maersk Tanum Panum Building, or The Carlsberg Central Office in Copenhagen. It has also not been given to 79&Park Hillside, Zenhouse, or the Brick Housing in Royal Seaport in Stockholm; the Tamedia Office; Binzstrasse 29 in Zurich; Brink Tower and House 2.0 in Amsterdam; Rene Cazenave Apartments in San Francisco; or The Ballard Library in

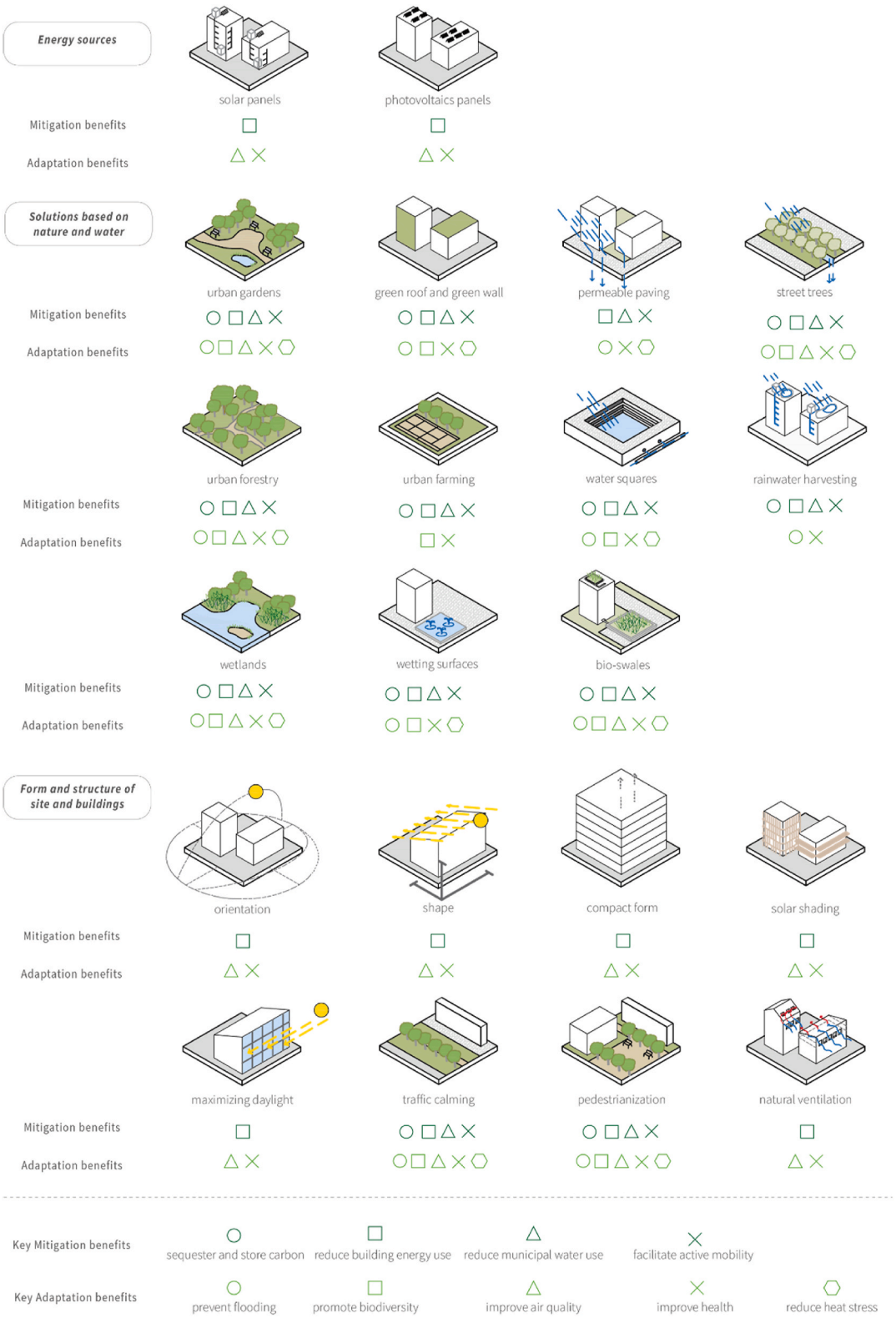


Fig. 6. Key urban design measures that incorporate simultaneously CCM and CCA benefits. Source: author's illustration based on Pörtner et al. (Pörtner et al., 2022); Masson-Delmotte et al. (Masson-Delmotte et al., 2021) and Leone & Tersigni (Tersigni and Leone, 2019).

Seattle. Some projects have achieved multiple GBRS, including Swiss Re Next in Zurich, The House of Cornell Tech in New York, The Lemay Headquarter in Montreal, and 160 Front Street in Toronto. The most prevalent certification system is the LEED.

3.2.1. Best practices to support urban design for CCM and CCA from building design

York University in Toronto has shown the most solutions applied in a building's design, including solutions for building geometry, building envelope, materials, energy sources, and green solutions.

Mit efforts commonly include designs to increase daylight, green roofs, natural ventilation, advanced building management systems, and low-energy windows. Ad measures feature permeable paving, rainwater harvesting, green roofs, trees, and enhanced green spaces. Notably, projects such as the Copenhagen International School, The Kathleen Grimm School for Leadership and Sustainability (New York), E + Homes in Boston, the Spaulding Rehabilitation Hospital (Boston), and the Center de Transport Stinson (Montreal) simultaneously implement these common measures. All projects align with local mitigation and adaptation policies, showcasing a dual-purpose approach to address environmental challenges. This integrative design not only adheres to local frameworks but also exemplifies comprehensive strategies for climate resilience and sustainability. The Boston public administration has significantly contributed to advancing climate resilience in buildings, districts, and waterfronts in recent years. The "E+ green building program" (Boston Planning and Development Agency, 2011) is now showcasing and validating the practicality of regenerative multi-unit residential complexes, introducing energy-efficient and environmentally friendly houses to various neighborhoods in Boston. The goal is to showcase innovative and model CCM and CCA efforts in Boston. Solutions vary from techniques used at the building, site, and district levels. Every chosen property surpasses the fundamental criteria for an elevated ground floor, energy efficiency, and landscaping.

3.3. Best practices to support urban design integrating CCM and CCA from the multilevel analysis

Urban regeneration and building design projects under the CCAPs identify solutions that can be applied in urban design practices. In this paragraph, we report measures that meet all four criteria outlined in Section 2.5. Specifically, all measures depicted in Fig. 6 satisfy these criteria: they have been implemented in urban regeneration or building projects already completed, applied in at least two of the analyzed urban contexts, and are present in the highest cluster in terms of integration of Mit and Ad across all analyzed levels. Furthermore, Fig. 6 illustrates the fourth criterion, which emphasizes the capacity of each measure to address both Mit and Ad goals.

The main strategies and their related measures are categorized into three groups:

Energy sources.

- Utilizing renewable energy sources like solar panels, photovoltaic panels, geothermal sources, or wind turbines for district heating, cooling, or electricity production is crucial in preventing service disruptions in the local energy grid or blackouts during extreme heatwaves.

Solutions based on nature.

- Solutions based on nature like permeable paving, urban gardens, street trees, green walls, and green roofs can enhance outdoor and indoor comfort during heatwaves and improve building performance by enhancing insulation, thus reducing the energy needed for cooling and heating. In addition to this, NBS can serve as a carbon sink for urban areas. Utilizing bio-materials or cooling materials on horizontal and vertical surfaces helps prevent buildings from overheating, therefore decreasing the need for cooling energy during summer months and enhancing outdoor thermal comfort (He, 2022). NBS may serve as a crucial method to mitigate floods and enhance water management systems.

Form and structure of site and buildings.

- Passive design strategies such as building orientation, shape, compact form, and mass compact, along with automatic or manual solar shading, high-performance thermal insulation, natural ventilation, and maximizing daylight, as detailed in Appendix C, are effective measures that can provide benefits for both Mit and Ad. These strategies are especially useful during extreme heat events, enhancing human comfort in buildings and preventing overheating.

4. Discussion

The research aims to investigate the extent of integration between CCM and CCA across CCAPs, urban regeneration and building projects. The proposed methodology might influence urban design approaches comprehensively in future design processes, including all elements connected to CC.

The most advanced CCAPs have implemented comprehensive strategies for buildings, infrastructure, transport, and zero waste, which align with the findings of Landauer et al. (2019), Demuzere et al. (2014), and other studies. The main findings from the best practices identified in CCAPs emphasize the importance of implementing strategies for both Mit and Ad. This involves not only making physical changes at the building level but also considering the interconnection between buildings, clusters of buildings, and open spaces within the neighborhood as a primary scale for urban regeneration, as outlined in the Boston Greenovate Plan (City of Boston. Greenovate Boston, 2014). Design principles, such as those outlined in the "Climate Resiliency Design Guidelines" (City of New York, 2022) are crucial for urban practitioners to facilitate the shift towards a resilient city. Testing the suggested activities in each CCAP for Mit and Ad is a significant problem, as shown by the city of Montreal in its CCAPs. One important idea in the City of Toronto's TransformTO (City of Toronto, 2020) plan is to green cities and make buildings more energy efficient in the way to consider the relationship among these two areas to increase CCM and CCA (Fig. 7). The city of Amsterdam suggests the "klimaatlas of Amsterdam metropolitan areas.", that is a free digital support system to help urban planners and designers understand the impacts of CC on severe events, including temperature changes, precipitation, sea level rise, windstorms, droughts, fires, and landslides. This system should also investigate the potential for mitigating carbon emissions in the BE, not only addressing CCA.

From the study of urban regeneration projects, it can be concluded that greater degrees of integration do not always correspond to high levels of integration of Mit and Ad strategies. Hammarby Sjöstad and Royal Seaport in Stockholm are advanced urban regeneration projects that focus both on CCM and CCA. However, they do not arise in cities that have achieved advanced integration between Mit and Ad CCAPs.

Advanced urban regeneration projects show that highly integrated actions can be carried out at the district scale for green infrastructure, sustainable urban drainage systems, revitalized cities, land use and transport integration, and zero-waste circular transition strategies. As underlined in the introduction section, PEDs might serve as a significant paradigm for achieving high-level energy sustainability in urban regeneration projects, especially within the European setting. Thus, although the importance of PEDs in reducing carbon emissions from energy production and building use for CCM is evident, there is a lack of focus on developing a comprehensive strategy to climate action that includes Ad. Utilizing renewable energy sources like solar panels, photovoltaic panels, geothermal sources, or wind turbines for district heating or cooling and energy production is crucial for guarantee energy safety and operational continuity in faced of potential interruptions or

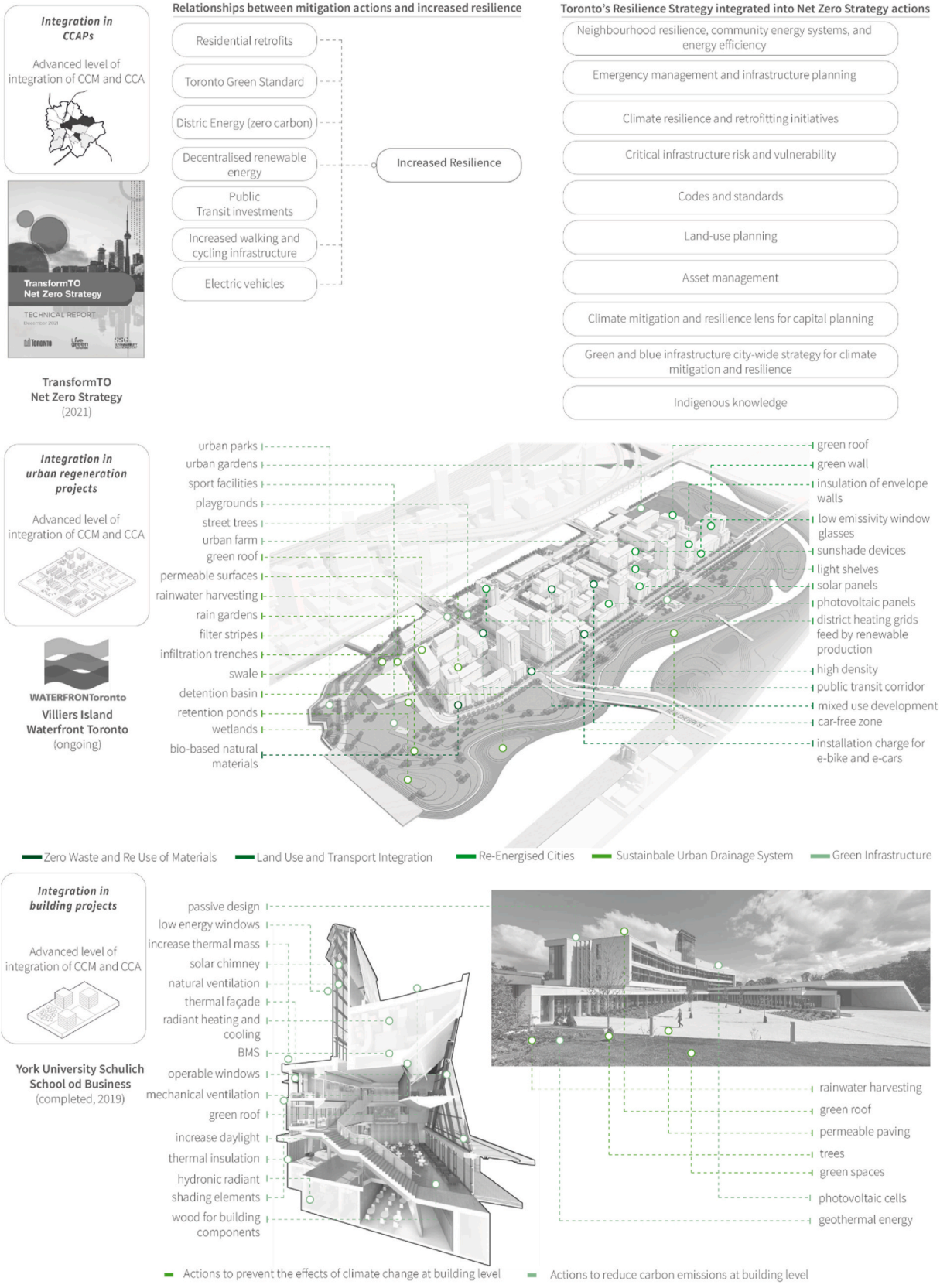


Fig. 7. Example of a city with most advanced integration among CCM and CCA in CCAPs, urban regeneration and building projects (City of Toronto). Source: author's illustration.

blackouts caused by extreme weather events such as heatwaves, flooding, tornadoes, hurricanes, etc. Energy efficiency may be accomplished by including measures from the beginning of the project to reduce the impacts of warming in severe heatwaves and floods in extreme precipitation events, as shown in the projects cited above.

Analysis of the building projects confirmed that urban buildings in North America, including those in the USA and Canada, have adopted the most Mit and Ad actions and measures with potential co-benefits. CCAPs with high integration for CCM and CCA may achieve superior physical transformation at the building scale. Out of the first 20 slots, only one EU building project, developed in Copenhagen (Fig. 5), is included. The GBRSs are a valuable tool for aiding urban regeneration and building design in the realm of either CCM or CCA. Public programs that promote a climate-neutral and resilient BE serve as a comprehensive tool for integrating Mit and Ad efforts at the local level to support urban practitioners. An example of this is the "E + Building Program" implemented by the City Council of Boston (Boston Planning and Development Agency, 2011). This program focuses on developing building projects that holistically address reducing carbon emissions and adapting various climate-related hazards, including extreme temperatures, precipitation, sea level rise, droughts, windstorms, and landslides. It is crucial for public administration to refrain from implementing sectoral initiatives focused just on one aspect, as the "Resilient Neighborhood" program created by the City of New York (City of New York, 2020).

The relevance of this research lies in the attempt of analyzing the integration between Mit and Ad at all three levels simultaneously: climate action planning, urban regeneration, and building projects, while previous studies such as Grafakos et al. (2019), Grafakos et al. (2020), Sharifi (2021), Sharifi et al. (2021), Aboagye & Sharifi (Aboagye and Sharifi, 2024), Pietrapertosa et al. (2019) have focused only on the level of CCAPs and Buzasi et al. (Buzási et al., 2021) have only analyzed an urban regeneration project in the city of Budapest considering only the consistency with local CCAPs.In addition, the study presents an additional level of novelty because it is one of the first attempt to analyze the integration of CCM and CCA at building level, because only He (2022) has explored some Ad solutions to adjust the conditions of buildings related to heat and health nexus. However, including urban regeneration initiatives and building projects on a larger scale allow to provide input not only to strategic planning and policymaking level, but also to design in a multi-scale perspective.

Future analyses might focus on the cities most sustainable in terms of developing environmental strategies, including local climate actions considering geographical contexts from all continents. In the future, indicators to evaluate the economic field related to local climate action might be included into the multilevel analysis framework, which is crucial for comprehending each project's readiness to provide CC solutions.

Additional development is required to enhance the analysis by conducting interviews with public administration and real estate developers to gain a deeper understanding of processes, dynamics, and relationships not included in official city documents. Furthermore, the multilevel approach might be extended to other cities across other continents to compare not only the cities most sustainable in terms of developing environmental strategies, including local climate actions.

5. Conclusions

The research endeavours to explore the integration between CCM and CCA across various urban levels, encompassing planning, urban regeneration, and building projects. Through a comprehensive analysis of CCAPs, urban regeneration initiatives, and building projects, significant insights have been gleaned regarding the extent of integration and the associated challenges and opportunities. Notably, cities such as New York, San Francisco, Montreal, and Toronto in North America have demonstrated commendable progress in integrating Mit and Ad strategies, aligning with previous research findings. The examination of best practices highlighted the critical importance of implementing strategies for both Mit and Ad, underscoring the interconnectedness of buildings, clusters of buildings, and open spaces within neighbourhoods. This Paper discusses which are the best practices to support urban design processes to take into account simultaneously CCA and CCM in aspects of urban planning, urban regeneration projects and building design (form and structures, materials, green solutions, energy sources). Furthermore, the Paper emphasizes the need for rigorous testing of suggested activities within CCAPs, as exemplified by Montreal's efforts. Moreover, the potential for complementary digital support systems, as proposed by Amsterdam, could significantly aid urban planners and designers in comprehending the impacts of extreme events intensified by CC and reducing carbon emissions in the BE. The analysis of urban regeneration projects elucidated that, while greater degrees of integration do not always correspond to high levels of integration of Mit and Ad strategies, advanced projects like Hammarby Sjöstad and Royal Seaport exemplify the possibilities of integrating CC considerations at district scale. Additionally, the paradigm of PEDs presents promising avenues for achieving high-level energy sustainability, albeit with a current lack of focus on comprehensive climate action that includes Ad measures.

This research presents certain limitations, notably the narrower selection of indicators for assessing the integration of CCM and CCA in CCAPs compared to prior studies; additionally, language barriers may impede full comprehension of non-English materials—such as the plans for Zurich—and the study lacks global representation, with cities from all continents not included, and omits indicators related to economic budgets for plan design, urban regeneration, and construction projects as recommended by Grafakos et al., 2019, 2020. Recommendations for future research include expanding the multilevel analysis framework to include cities from all continents, incorporating indicators to evaluate economic budgets, and conducting interviews with key stakeholders to gain deeper insights into processes and dynamics not captured in official documents.

Nevertheless, the current analysis of the level of integration among CCM and CCA and the possible solutions emerged is primarily quantitative and future works should collect more evidence from survey on the site and interviews with stakeholders, and integrating field experiments and numerical simulation to assess the performance of the selected solutions. An integrated framework of indicators for CCM and CCA to assess urban design scenario is expected to be developed to support the performance assessment.

CRediT authorship contribution statement

Guglielmo Ricciardi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Guido Callegari:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Mattia Federico Leone:** Writing – review & editing, Validation, Funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Indicators used to assess CCAPs based on Pietrapertosa et al. (2019), Grafakos et al. (2019), and Grafakos et al. (2020)

#	Indicator	value	comment	value	comment	value	comment
1	plan include baseline emission inventory	1	yes	0	no		
2	GHG Emissions Forecast	1	provides future GHG emissions forecast beyond 2022	0	does not contain a GHG emission forecast.		
3	GHG and % emissions reductions target	2	provides reductions target in the short-term (up to 2050)	1	provides reductions target in the short-term (up to 2030)	0	does not provide a GHG emissions reduction target
4	plan include a current vulnerability profile	2	contains a full vulnerability profile of the city	1	suggests that a vulnerability profile has been completed but its data is not stated within the plan. OR CCAP mentions some vulnerability issues for the city, but does not provide a concise overview	0	does not mention any vulnerabilities that the city will face.
5	future climate projections	2	provides future climate projections in the long-term (up to 2050).	1	provides future climate projections in the short-term (up to 2030)	0	does not mention any future climate projections for the city.
6	plan include adaptation objectives	2	contains adaptation objectives in the long term (more than 5 years).	1	contains adaptation objectives in the short term (up to 5 years). OR CCAP mentions adaptation objectives without specific timescale.	0	does not state any adaptation objective.
7	Cost estimates of actions	2	provides cost estimates of both adaptation or mitigation actions.	1	provides cost estimates of either adaptation or mitigation actions.	0	does not include any
8	Benefit estimates of actions	2	provides benfits estimates of both adaptation or mitigation actions.	1	provides benefits estimates of either adaptation or mitigation actions.	0	does not include any
9	Consideration of Ad/Mit interrelationships (co-benefits/ synergies or trade-offs/conflicts)	2	provides both synergies or conflicts of adaptation and mitigation.	1	provides either synergies or conflicts of adaptation and mitigation.	0	does not include any
10	Mainstream potential of climate actions	2	mention mainstreaming potential of both	1	mention mainstreaming potential of either	0	does not include any
11	Common policy or regulatory framework	2	mention common policy or regulatory of both	1	mention common policy or regulatory of either	0	does not include any
12	Partnerships	2	mention partnership of both	1	mention partnership of either	0	does not include any
13	Common Monitoring procedure/ framework	2	mention monitoring procedures of both	1	mention monitoring procedures of either	0	does not include any

Appendix B

Actions used to assess urban regeneration projects based on Privitera and Barbarossa (2021).

Green Infrastructure	Sustainable Urban Drainage System	Re-energised cities	Land use and transport integration	Zero waste and re use of materials
urban parks urban gardens green outdoor sport facilities playgrounds street trees urban agriculture agriculture parks	green roofs permeable surfaces rainwater harvesting rain gardens filter stripes infiltration trenches swale basin	green roof green wall insultation of envelope walls low emissivity window glasses sunshade devices mirror ducts light shelves pipes solar chimney	public transit corridors high density mixed-use development car-free zone installation charge for e-bike, e-cars	materials from re-cycled sources wood bio-based and natural materials reduction of materials for structural components

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Green Infrastructure	Sustainable Urban Drainage System	Re-energised cities	Land use and transport integration	Zero waste and re use of materials
urban farms allotment gardens	ponds wetlands	wind cowls solar panels photovoltaic panels district heating grids feed by renewable production		

Appendix C

Actions obtained from the analysis of building projects for CCM and adaptation.

Mitigation measures
Form and structure
passive design (building orientation, building shape, compact form, mass compact)
automatic/manual solar shading
high performance thermal insulation
high performance curtain wall
natural ventilation
design to increase daylight
solar chimney
bioclimatic greenhouse
sloped ceiling
increase thermal mass
glass column is a heat exchanger
concrete thermal separation
Envelope
ventilated façade
low energy windows (triple glazed windows)
brie soleil (wood, aluminium)
thermal façade (double skin façade)
openable panels for ntaural ventilation
shade elements
translucent walls
operable windows
limitation of glazing
Materials
phase change materials
durable natural materials (such as recycled copper and bamboo)
wood for structure
material re-use/recycled material
prefabbricated building components
strategy to reduce material consumption and transport (embodied carbon)
Energy sources
photovoltaic panels
solar heating and cooling (solar panel)
seasonal storage (electrict)
thermal energy storage
geothermal heating
heat pump
building cooling/heating with water
link to district heating
waste energy re-use (energy recovery ventilation)
heat pipes
Low-energy heating/cooling
wind mill
cogeneration plant
ice storage system
hydronic heating system
radiant heat
drain water heat recovery
chilled beam,
solar wall
heat recovery
energy sharing among buildings
energy battery storage
rooftop cooling tower

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Mitigation measures
Form and structure
building management system (smart control)
use of LED
Green solutions
food production in the garden
green roof
green wall
Adaptation measures
Green solutions
green roof
community garden
tree façade
roof garden
garden balcony
drought resistance species
green spaces
trees
green wall
urban permaculture
Blue solutions
green roof
rain garden
detention ponds
rainwater harvesting
water channel
rainwater collection
rainwater infiltration
fountain
retention basin
natural filtration
grass swale
Grey solutions
passive design (building orientation, building shape, compact form, mass compact)
automatic/manual solar shading
phase change materials
High performance thermal insulation
natural ventilation
ventilated façade
mechanical ventilation
permeable paving
controlled use of water for irrigation and other uses
cool roof materials
elevated electrical and mechanical system
emergency lighting communication
enhanced structural elements
courtyard above the projected sea level rise
dry flood underground parking
low reflectance materials for open air spaces
design for strong winds and snowstorms
high albedo materials
underground parking to avoid UHI
sport & playground

Appendix D

Results obtained through the assessment of integration level of mitigation and adaptation in CCAPs.

Name of the plan	Indicator #1	Indicator #2	Indicator #3	Indicator #4	Indicator #5	Indicator #6	Indicator #7	Indicator #8	Indicator #9	Indicator #10	Indicator #11	Indicator #12	Indicator #13	total
Climate Ready Boston	0	0	0	2	2	2	1	1	0	1	1	1	1	12
Greenovate Boston	1	1	1	1	0	1	0	1	1	1	1	2	1	12
City's resiliency plan, A Stronger, More Resilient New York.	0	0	0	1	2	2	1	1	0	1	1	1	1	11
One New York (OneNYC): The	0	0	2	1	2	2	2	1	0	1	1	1	1	14

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Name of the plan	Indicator #1	Indicator #2	Indicator #3	Indicator #4	Indicator #5	Indicator #6	Indicator #7	Indicator #8	Indicator #9	Indicator #10	Indicator #11	Indicator #12	Indicator #13	total
Plan for a Strong and Just City														
OneNYC 2050 BUILDING A STRONG AND FAIR CITY	1	1	2	1	2	1	1	1	2	1	2	2	2	19
Seattle climate action plan	1	1	2	0	0	0	0	1	1	1	1	1	1	10
Preparing for climate change	0	0	0	1	2	1	0	0	0	1	0	1	0	6
Hazards and Climate Resilience Plan	0	0	0	2	2	2	1	0	1	1	0	1	1	11
Climate Action Plan	1	1	2	1	2	1	2	1	1	1	1	1	1	16
Climate Plan 2020–2030	1	1	1	1	2	2	0	1	0	1	2	2	2	16
climate change adaptation plan for the Montréal urban agglomeration 2015–2020	0	0	0	2	2	1	0	0	0	1	1	1	0	8
TransformTO Net Zero Strategy	1	1	2	1	0	0	1	1	2	2	1	1	1	14
Toronto Resilience Strategy	0	0	0	0	2	1	0	0	2	2	1	1	1	10
copenhagen climate adaptation plan	0	0	0	2	2	2	1	1	0	1	1	1	1	12
CPH 2025 Climate Plan - A green, smart and carbon neutral city	1	1	1	0	0	0	1	1	0	0	1	1	1	8
Climate Action Plan 2020–2023	1	1	2	0	0	0	1	0	0	1	1	1	1	9
Environment programme 2020–2023	0	0	1	0	0	1	0	0	0	2	0	2	1	7
Environmental Strategy + Programm Klimaanpassung	1	1	2	2	1	2	0	0	0	0	0	1	0	10
Strategy for climate adaptation Amsterdam	0	0	0	2	2	2	0	0	0	1	1	1	1	10
New Amsterdam Climate Roadmap Amsterdam Climate Neutral 2050	1	1	1	0	0	0	1	0	0	0	1	1	1	7

Appendix E

Results obtained through the assessment of the level of integration among CCM and adaption measures in urban regeneration projects.

	green infrastructure strategy		Sustainbale Urban Drainage System	re-energised cities		land use and transport integration	zero waste and re use of material for construction		actions that enable "activity and exercise belts"		Total	%
The climate-resilient neighborhood of Østerbro	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, urban farm, allotment gardens	7	green roof, permeable surfaces, rainwater harvesting, rain garden, infiltration trenches, swale, basins,	7	green roof, green wall, insulation of envelope walls, light shelves	4	less space for car	1	0	yes 1	20	49
UN17 Village	Urban parks, urban gardens, green outdoor sport facilities,	6	green roof, permeable surfaces, rainwater	7	insulation of envelope walls, sunshade devices, solar panels,	5	high density, mixed use, car free zone, installation	5	materials from cycled sources, wood, bio-based and	4	yes 1	28	68

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	green infrastructure strategy		Sustainbale Urban Drainage System		re-energised cities		land use and transport integration		zero waste and re use of material for construction		actions that enable "activity and exercise belts"			Total	%
	playgrounds, urban farm, allotment gardens		harvesting, rain garden, swale, basins, ponds		photovolatic panels, distrct heating grids feed by renewable production		charge for e-cars, less space for car and more for walkable and cycling path		natural materials, reduction of materials for structural components						
Hammarby Sjöstad	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees	5	green roof, permeable surfaces, rainwater harvesting, rain garden, filter stripes, infiltration trenches, swale, detention basins, ponds, wetlands	10	green roof, insulation of envelope walls, low emissivity window glasses, sunshine devices, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	7	public transit corridor, high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	6	wood	1	yes	1	30	73
Royal Seaport	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, urban farm, agriculture farm allotment gardens	8	green roof, permeable surfaces, rainwater harvesting, rain garden, filter stripes, infiltration trenches, swale, detention basins, ponds, wetlands	10	green roof, insulation of envelope walls, low emissivity window glasses, sunshine devices, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	7	public transit corridor, high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	6	materials from cycled sources, wood, bio-based and natural materials, reduction of materials for structural components	4	yes	1	36	88
MFO-Park	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	permeable surfaces, rainwater harvesting, rain garden, infiltration trenches,	4	green wall, sunshide devices,	2	car free zone	1	materials from cycled sources	1	yes	1	14	34
Hunziker Areal	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	green roof, permeable surfaces	2	green roof, green wall, insulation of envelope walls, low emissivity window glasses, sunshine devices, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	8	high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	5	materials from cycled sources, wood,	2	yes	1	23	56
GWL site	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, urban farm, agriculture farm allotment gardens	8	green roof, permeable surfaces, rainwater harvesting, wetlands, detention basin	5	green roof, green wall, insulation of envelope walls, low emissivity window glasses, sunshine devices	5	high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	5	wood	1	yes	1	25	61
Schoonschip	allotment gardens	1	green roof, permeable surfaces, rainwater harvesting,	3	green roof, green wall, insulation of envelope walls, low emissivity window glasses, sunshine devices, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	8	high density, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	4	materials from cycled sources, wood,	2	yes	1	19	46

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	green infrastructure strategy		Sustainbale Urban Drainage System	re-energised cities		land use and transport integration		zero waste and re use of material for construction		actions that enable "activity and exercise belts"			Total	%
Resilient Neighborhood	urban parks, urban gardens, street trees	3	permeable surfaces, rain garden, filter stripes, infiltration trenches, swale, detention basins, ponds, wetlands	8	insulation of envelope walls,	1	high-density, car free zone,	2		0	no	0	14	34
Hunter's Point South	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	permeable surfaces, rain garden, filter stripes, infiltration trenches, swale, ponds, wetlands	7	sunshade devices	1	less space for car and more for walkable and cycling path, car free zone	2	wood	1	yes	1	17	41
Mission Bay South	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	permeable surfaces, rain garden, filter stripes, infiltration trenches, swale,	5	insulation of envelope, low emissivity windows glasses, sunshade devices, PV panels, solar panels,	5	public transit corridor, high density, mixed use, less space for car and more for walkable and cycling path	4	materials from cycled sources, wood,	2	yes	1	22	54
The Cove - Central Embarcadero Piers Historic District	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	permeable surfaces, rainwater harvesting, rain garden, wetlands	4	insulation of envelope, low emissivity windows glasses, sunshade devices, PV panels, solar panels,	5	car free zone, installation charge for e-bike and e-cars, less space for car and more for walkable and cycling path	3	materials from cycled sources, wood,	2	yes	1	20	49
Yesler Terrace	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, allotment gardens	6	green roof, permeable surface, rainwater harvesting, raingarden	4	green roof, insulation of envelope, low emissivity windows glasses, sunshade devices, PV panels, solar panels,	6	car free zone, installation charge for e-bike and e-cars, less space for car and more for walkable and cycling path	3		0	yes	1	20	49
Grow Community Bainbridge	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, allotment gardens	6	permeable surfaces, rainwater harvesting, rain garden, filter stripes	4	insulation of envelope, low emissivity windows glasses, sunshade devices, PV panels, solar panels,	5	car free zone, installation charge for e-bike and e-cars, less space for car and more for walkable and cycling path	3	materials from cycled sources, wood,	2	yes	1	21	51
TALBOT-NORFOLK TRIANGLE ECO-INNOVATION DISTRICT	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, urban farm	6	green roof, permeable surfaces, rain garden, rainwater harvesting, filter stripes, infiltration trenches, swale,	7	green roof, green wall, insulation of envelope walls, low emissivity window glasses, sunshine devices, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	8	public transport corridor, high density, mixed use, car free zone, less space for car and more for walkable and cycling path	5	materials from cycled sources	1	yes	1	28	68
Seaport Square Master Plan	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	green roof, permeable surfaces and raingardens	3	green roof, insulation of envelope walls, low emissivity window glasses, sunshine devices,	4	public transport corridor, high density, mixed use, car free zone, less space for car and more for walkable and cycling path	5	materials from cycled sources	1	yes	1	19	46
Bassins du Nouveau Havre	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	permeable surfaces, rainwater harvesting, rain garden,	5	insulation of envelope walls, low emissivity window glasses, sunshade devices, photovoltaic panels	4	high density, mixed use, car free zone, installation charge for e-cars, less space for car	5		0	yes	1	20	49

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	green infrastructure strategy		Sustainbale Urban Drainage System	re-energised cities		land use and transport integration		zero waste and re use of material for construction		actions that enable "activity and exercise belts"			Total	%
			detention basin, retention ponds				and more for walkable and cycling path							
Royalmount	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees,	5	green roof, permeable surfaces, rain garden, rainwater harvesting,	4	green roof, insulation of envelope walls, low emissivity window glasses, sunshade devices, photovoltaic panels	5	public transit corridor, high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	6		0	yes	1	21	51
The Portlands	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, urban farm	6	green roof, permeable surfaces, rainwater harvesting, rain garden, filter stripes, infiltration trenches, swale, detention basins, ponds, wetlands	10	green roof, green wall, insulation of envelope walls, low emissivity window glasses, sunshine devices, light shelves, solar panles, photovoltaic panels, distrct heating grids feed by renewable production	9	public transit corridor, high density, mixed use, car free zone, installation charge for e-cars, less space for car and more for walkable and cycling path	6	bio-based and natural materials	1	yes	1	33	80
Regent Park	Urban parks, urban gardens, green outdoor sport facilities, playgrounds, street trees, allotment gardens	6	green roof, permeable surfaces, rain garden, rainwater harvesting,	4	green roof, insulation of envelope walls, low emissivity window glasses, sunshade devices, photovoltaic panels	5	public transit corridor, high density, mixed use,	3	bio-based and natural materials	1	yes	1	20	49

Appendix F

Results obtained through the assessment of the level of integration among CCM and adaption measures in building projects.

Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
Valley	building management system,	1	tree façade	1	In line to initiative from the Climate Neutrality Plan (2020) in order to guarantee the carbon neutrality of the city for 2050 through actions in BE and Electricity areas.	1	In line to green initiative from Climate Adaptation Plan (2020), in order to avoid the heat stress phenomenon	1	aim for a BREEAM-NL Excellent rating.	1	5
Stockholm Waterfront Congress Center	photovoltaic panels/cells, solar panels, building cooling with water, material re-use	4		0	In line with the initiative related to STOCKHOLM ACTION PLAN FOR CLIMATE AND ENERGY 2010–2020 – (2009) in terms of reduction energy	1		0	LEED Gold	1	6
Brink tower	photovoltaic panels/cells, green roof	2	rainwater harvesting, green roof	2	Anticipate some initiatives from the Climate Neutrality Plan (2020) in order to guarantee the	1	Anticipate initiative from Climate Adaptation Plan (2020), in order to avoid the	1		0	6

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
					carbon neutrality of the city for 2050 through actions in BE and Electricity areas.		waterlogging through collecting rain water during extreme events to reuse water for toilets or reduce the flow of sewere system.				
Kew Gardens Hills Library	green roof, design to increase daylight,	2	green roof	1	In line to PlanNYC 2030 (2007 and 2011) goals of Energy and Climate Change	1	PlanNYC 2030 A Greener Greater New York, a stronger more resilient New York (2014)	1	LEED Silver certification	1	6
Forskaren, a New Health and Life Science Innovation Center	solar heating and cooling, mechanical ventilation, geothermal heating	3	rainwater harvesting,	1	In line to climate action 2020–2023 related to use natural material with less GHG emissions	1	In line with the Environmental action plan 2020–2023 (re use of water to reduce the charge on sewere system during extreme precipitation)	1	will pursue LEED Platinum certification	0,5	6,5
Brick Housing in Royal Seaport	photovoltaic panels/cells, green roof	2	green roof, rainwater harvesting, permeable paving	3	In line with the initiative related to STOCKHOLM ACTION PLAN FOR CLIMATE AND ENERGY 2010–2020 – (2009) in terms of reduction energy	1	In line to the ADAPTATION PLAN of 2007	1	not sdpecified	0	7
TWIST Studentisches Wohnen ETH Science City	prefabbricated building components, wood for structure	2	community garden, permeable paving,	2	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society and production of local renewable energy	1	In line to the strategies Zurich 2035 to face the challenge of local heat island in dense urban city scape	1	Minergie P® ECO standard	1	7
Kalkbreite	prefabbricated building components, wood for structure	2	community garden, permeable paving,	2	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society and production of local renewable energy	1	In line to the indication of 1991 about solution toward climate change adaptation	1	Minergie P® ECO standard	1	7
Amsterdam university project	green roof, building management system,	2	rainwater harvesting, green roof	2	Anticipate some initiatives from the Climate Neutrality Plan (2020) in order to guarantee the carbon neutrality of the city for 2050 through actions in BE and Electricity areas.	1	Anticipate initiative from Climate Adaptation Plan (2020), in order to avoid the waterlogging through collecting rain water during extreme events to reuse water for toilets or reduce the flow of sewere system.	1	Greencalc + rating of 200.	1	7
Manhattan Districts 1/2/5 Garage & Spring Street Salt Shed	ventilated façade, green roof	2	green roof, rainwater harvesting	2	In line to PlanNYC 2030 (2007 and 2011) goals of Energy and Climate Change	1	PlanNYC 2030 A Greener Greater New York, a stronger more resilient New York (2014)	1	LEED Gold certification	1	7
The Exploratorium at Pier 15	building cooling/ heating with water, photovoltaic	3	rainwater collection	1	In line to Climate Action Strategy (2013) in order to Energy Use in	1	In line to Climate Action Strategy (2013) in order to	1	LEED Platinum status	1	7

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	panels/cells, durable natural materials				Buildings and San Francisco Sustainability Plan (1997)		climate adaptation measures				
Bellerivestrasse 36 Zürich	photovoltaic panels/cells, green roof	2	green roof, rain garden, community garden	3	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society and production of local renewable energy	1	In line to the strategies Zurich 2035 to face the challenge of local heat island in dense urban city scape	1	Swiss Minergie-A sustainability certification	0,5	7,5
House 2.0	high performance thermal insulation, low energy windows, durable natural materials, photovoltaic cells/ panles, wind mill, thermal energy storage, heat pipes	7		0	Anticipate some initiatives from the Climate Neutrality Plan (2020) in order to guarantee the carbon neutrality of the city for 2050 through actions in BE and Electricity areas.	1		0	not specified	0	8
79&Park Hillside	passive design (building orientation, building shape), brie soleil, wood for structure, prefabbricated module, green roof	4	green roof, permeable paving, coomunity garden	3	In line with the initiative related to STOCKHOLM ACTION PLAN FOR CLIMATE AND ENERGY 2010–2020 – (2009) in terms of reduction energy	1	In line to the ADAPTATION PLAN of 2007	1	not sdpecified	0	9
Tamedia office	wood for structure, waste energy re-use (for cooling and heating), low energy windows, high performance thermal insulation, natural ventilation, geothermal heating, heat pump, brie soleil (wood, aluminium)	8		0	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society and production of local renewable energy	1		0		0	9
Binzstrasse 29	natural ventilation, ventilated façade, mechanical ventilation, strategy to reduce material consumption (embodied carbon), heat pump, geothermal heating, photovoltaic panels/cells, automatic/manual solar shading	8		0	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society and production of local renewable energy	1		0		0	9
UN City	link to district heating, automatic/manual solar shading, photovoltaic panels/cells, building cooling with water, building management system (smart control)	5	automatic/manual solar shading, rainwater harvesting	2	In line to the policies published in 2015 in CPH 2026	1	Some solutions (e. g. green roofs) are in line to the initiatives promotes in the Climate Adaptation Plan 2011	1	LEED Platinum certified	1	10
Nordea bank Headquarter	ventilated façade, natural ventilation,	4	ventilated façade, natural ventilation,	3	In line to the policies	1	Some solutions (e. g. green roofs) are	1	LEED Platinum certified	1	10

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	automatic/manual solar shading, low energy windows		automatic/manual solar shading,		published in 2015 in CPH 2026		in line to the initiatives promotes in the Climate Adaptation Plan 2011				
Maersk Tanum Panum Building	waste energy re-use, automatic/ manual solar shading, green roof	3	automatic/manual solar shading, permeable paving, retention ponds, green roof, rainwater harvesting	5	City Council adopted in 2009. A midterm goal was to reduce carbon emissions by 20% by 2015, which is a goal Copenhagen met already in 2011. Anticipate the policies published in 2015 in CPH 2025	1	Some solutions (e. g. green roofs) are in line to the initiatives promotes in the Climate Adaptation Plan 2011	1	not sdpecified	0	10
Zenhouse	solar panels, durable natural materials, building management system (smart control), high performance thermal insulation, green roof	5	high performance thermal insulation, green roof, detention ponds	3	In line with the initiative related to STOCKHOLM ACTION PLAN FOR CLIMATE AND ENERGY 2010–2020 – (2009) in terms of reduction energy	1	In line to the ADAPTATION PLAN of 2007	1	not sdpecified	0	10
Swiss Re Next	building cooling with water, heat pump, material re-use (concrete), photovoltaic panels/cells, strategy to reduce material consumption and transport (embodied carbon), use of LED, thermal façade	7		0	In line to the strategies Zurich 2035 for energy comsuption towards 2000 Watt Society	1		0	Minergie-P-Eco, LEED Platinum,	2	10
Goede Doelen Loterijen & Dutch Charity Lotteries Head Offices	solar heating and cooling (solar panel), photovoltaic cells/ panels, high performance thermal insulation (reflective foliage, power windows glass panels, shades elements, material re-use	5	rainwater harvesting, roof garden	2	Anticipate some initiatives from the Climate Neutrality Plan (2020) in order to guarantee the carbon neutrality of the city for 2050 through actions in BE and Electricity areas.	1	Anticipate initiative from Climate Adaptation Plan (2020), in order to avoid the waterlogging through collecting rain water during extreme events to reuse water for toilets or reduce the flow of sewere system.	1	BREEAM Outstanding	1	10
Nancy and Stephen Grand Family House	green roof, solar heating and cooling (solar panel), mechanical ventilation system, shade elements,	4	rainwater collection, green roof, permeable paving	3	In line to Climate Action Strategy (2013) in order to Energy Use in Buildings and San Francisco Sustainability Plan (1997)	1	In line to Climate Action Strategy (2013) in order to climate adaptation measures	1	LEED Platinum status	1	10
160 Front Street	passive design (building orientation, building shape, compact form, mass compact), design to increase daylight, high performance	4	green roof, design for strong winds and snowstorms	2	In line to TransformTO (2016) actions of supporting energy efficiency in buildings, and raising the bar for new construction	1	In line to the initiatives of ResilientTO 2019 to build more resilient district to the effects of climate change	1	LEED® Platinum and WELL Building Standard®	2	10

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	curtain wall, green roof,				& community energy						
Carlsberg Central Office	durable natural materials (such as recycled copper and bamboo), photovoltaic panels/cells, waste energy re-use, green roof	4	detention ponds, rainwater harvesting, permeable paving, green roof, water channel	5	City Council adopted in 2009. A midterm goal was to reduce carbon emissions by 20% by 2015, which is a goal Copenhagen met already in 2011. Anticipate the policies published in 2015 in CPH 2025	1	Some solutions (e.g. green roofs) are in line to the initiatives promotes in the Climate Adaptation Plan 2011	1	not sdpecified	0	11
Karolinska Hospital	green roof, link to district heating, geothermal heating, waste energy re-use, mechanical ventilation	5	green roof, permeable paving, coomunity garden	3	In line with the initiative related to STOCKHOLM ACTION PLAN FOR CLIMATE AND ENERGY 2010–2020 – (2009) in terms of reduction energy	1	In line to the ADAPTATION PLAN of 2007	1	LEED Gold	1	11
The House at Cornell Tech	passive design (building orientation, building shape, compact form), prefabbricated building components, low energy windows, high performance thermal insulation, waste energy re-use (energy recovery ventilation), Low-energy heating/cooling, comcrete thermal separation, use of led,	8		0	In line to PlanNYC 2030 (2007 and 2011) goals of Energy and Climate Change	1		0	Passive House standards, rack to earn LEED for Homes Midrise v2010 Platinum certification	2	11
Salesforce's 350 Mission Office Tower	thermal energy storage, heat pump, low energy windows, shgade elements, design to increase daylight, strategy to reduce material consumption and transport (embodied carbon), material re-use/recycled material	7	rainwater harvesting,	1	In line to Climate Action Strategy (2013) in order to Energy Use in Buildings and San Francisco Sustainability Plan (1997)	1	In line to Climate Action Strategy (2013) in order to climate adaptation measures	1	LEED Platinum status	1	11
New San Francisco Federal Building	natural ventilation, durable natural materials, material re-use/recycled material, double façade, design to increase daylight,	5	permeable paving, rainwater infiltration, underground parking to avoid UHI	3	In line to Climate Action Strategy (2013) in order to Energy Use in Buildings and San Francisco Sustainability Plan (1997)	1	In line to Climate Action Strategy (2013) in order to climate adaptation measures	1	LEED-Silver	1	11
Rene Cazenave Apartments	passive design (building orientation, building shape, compact form), natural ventilation, design to increase	6	green roof, permeable paving, rainwater collection	3	In line to Climate Action Strategy (2013) in order to Energy Use in Buildings and San Francisco	1	In line to Climate Action Strategy (2013) in order to climate adaptation measures	1		0	11

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	daylight, low energy window, hydronic heating system, green roof				Sustainability Plan (1997)						
Pierhouse & 1 Hotel Brooklyn Bridge	natural ventilation, passive design (building orientation, building shape), building management system, green roof	4	rainwater harvesting, permeable paving, garden balcony, green roof, Elevated building entry to adapt to sea level rise and heavy storm	5	In line to PlanNYC 2030 (2007 and 2011) goals of Energy and Climate Change	1	PlanNYC 2030 A Greener Greater New York, a stronger more resilient New York (2014)	1	designed to achieve LEED Silver certification, but not obtained	0,5	11,5
The New School University Center	use of LED, cogeneration plant, design to increase daylight, shade elements, waste energy re-use (energy recovery ventilation), ice storage system, green roof, durable natural materials	8	green roof, rainwater harvesting,	2	In line to PlanNYC 2030 (2007 and 2011) goals of Energy and Climate Change	1	PlanNYC 2030 A Greener Greater New York, a stronger more resilient New York (2014)	1	LEED Gold certification	1	13
California academy of science	green roof, mechanical ventilation, building energy management system, waste energy re-use (energy recovery ventilation), shade elements, re use/ recycled materials, photovoltaic panels/cells, natural ventilation	8	green roof, rainwater harvesting,	2	In line to Climate Action Strategy (2013) in order to Energy Use in Buildings and San Francisco Sustainability Plan (1997)	1	In line to Climate Action Strategy (2013) in order to climate adaptation measures	1	LEED Platinum status	1	13
Federal Center South Building 1202	passive design (building orientation, building shape, compact form), geothermal heating and cooling, thermal storage, shade elements, low energy window, wood for structure and components and façade, material re-use/ recycled material	7	detention ponds, raingarden, wet ponds,	3	Climate action program 2013, in line with the building energy emissions strategy (energy supplies and performance requirements)	1	Anticipating the actions to building level to adapt the BE to the effects of climate change (2017)	1	LEED Gold	1	13
Atlantic Wharf building	high performance thermal insulation, low energy windows, green roof, rooftop cooling tower, material re-use/ recycled material	5	green roof, rainwater harvesting, rooftop cooling tower, public garden and parks, drought tolerant species,	5	In line to climate action plan of Boston (2007), in the area of buildings and other structures, in line with the update of 2011 of CAP, and in line with the Large Buildings and Institutions focus area of CAP 2014	1	Some design practice anticipated adaptation measure defined in the CAP of 2014	1	LEED Platinum	1	13
60 Richmond Street East	green roof, high performance thermal insulation, low energy windows, mechanical system, heat recovery, drain	6	rainwater harvesting, green roof, cistern, urban permaculture	4	Anticipate the Toronto plan for energy of 2013.	1	Anticipate the initiatives of ResilientTO 2019 to captured stormwater to reduce the charge of sewer system for the city.	1	LEED Gold	1	13

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	water heat recovery,										
The Edge	passive design, solar panels, openable panels for ntaural ventilation, photovoltaic panels/cells, design to increase daylight, building management system (smart control), use of LED, waste energy re-use, thermal energy storage,	9	rainwater harvesting, ecological corridor	2	Anticipate some initiatives from the Climate Neutrality Plan (2020) in order to guarantee the carbon neutrality of the city for 2050 through actions in BE and Electricity areas.	1	Anticipate initiative from Climate Adaptation Plan (2020), in order to avoid the waterlogging through collecting rain water during extreme events to reuse water for toilets or reduce the flow of sewere system.	1	BREEM NL New Construction	1	14
Green Lighthouse project	passive design (building orientation, building shape), automatic/manual solar shading, phase change materials, photovoltaic panels, solar heating and cooling, seasonal storage, use of LED, geothermal heating, link to district heating	9	passive design (building orientation, building shape), aautomatic/ manual solar shading, phase change materials	3	City Council adopted in 2009. A midterm goal was to reduce carbon emissions by 20% by 2015, which is a goal Copenhagen met already in 2011. Anticipate the policies published in 2015 in CPH 2025	1	Some solutions (e. g. green roofs) are in line to the initiatives promotes in the Climate Adaptation Plan 2011	1	LEED Gold rating	1	15
Bullit Center	automatic/manual solar shading, design to increase daylight, natural ventilation, photovoltaic cells/ panels, high performance thermal insulation, waste energy re-use (energy recovery ventilation), heat pump system, material re use,	8	rainwater harvesting, rainwater collection, detention pond, permeable paving	4	In line to city green building team + sustainability (2012), and climate action program 2013 in the area of building	1	Some actions are in line to the Climate Action Program 2013 indication to adapt the buildings to climate change effects	1	Living Building Challenge	1	15
Seattle City Hall	design to increase daylight, mechanical ventilation, solar heating and cooling (solar panel), low energy window, shade elements, green roof, durable natural materials	7	rainwater harvesting, green roof, permeable paving, fountain, detention pond	5	In line to city green building team + sustainability (2012), and climate action program 2013 in the area of building	1	Some actions are in line to the Climate Action Program 2013 indication to adapt the buildings to climate change effects	1	LEED Gold	1	15
Ballard library and neighborhood center	photovoltaic cell/ panels, design to increase daylight, shade elements, building management system, green roof, brie soleil, wood for structure and components, use of LED,	8	permeable paving, trees, green roof, drought tolerant species, controlled use of water for irrigation and other uses	5	Seattle City Light's Green Power Program Green Building Team 1999	1	Some actions have anticipated the Climate Action Program 2013 indication to adapt the buildings to climate change effects	1		0	15
E + Housing Catherine Street	passive design (building orientation, building shape, compact form), design to increase	8	rainwater harvesting, permeable paving, rainwater infiltration, drought tolerant plantings,	4	Insert in the E + Building program developed by the 2011 Greenovate Cliamte Action Plan in the	1	Some design practice anticipated adaptation measure defined in the CAP of 2014	1	LEED Platinum	1	15

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	daylight, heat pump, waste energy re-use (energy recovery ventilation), photovoltaic cells/ panels, wood for structure, components and façade, food production in the garden,				Buildings and Energy Sources area,						
Footprint at bridge	design to increase daylight, natural ventilation, wood for structure and components and façade, translucent walls, waste energy re-use (energy recovery ventilation), hydronic heating, shade elements, drain water heat recovery, solar heating and cooling (solar panel)	9	drought tolerant species, community garden, permeable paving, rainwater harvesting,	4	Seattle City Light's Green Power Program Green Building Team 1999	1	Some actions have anticipated the Climate Action Program 2013 indication to adapt the buildings to climate change effects	1	LEED Platinum	1	16
Northeastern University Interdisciplinary Science and Engineering Complex	waste energy re-use (energy recovery ventilation), natural ventilation, brie soleil, chilled beam, building management system, solar wall, design to increase daylight, heat recovery,	8	bioswale, trees, permeable paving, drought resistant species, rainwater harvesting,	6	In line to climate action plan of Boston (2007), in the area of buildings and other structures, in line with the update of 2011 of CAP, and in line with the Large Buildings and Institutions focus area of CAP 2014	1	Some design practice anticipated adaptation measure defined in the CAP of 2014	1	LEED Gold	1	17
RIO TINTO ALCAN PLANETARIUM	natural ventilation, high performance thermal insulation, wood for building components, green roof, design to increase daylight, energy sharing among buildings, strategy to reduce material consumption and transport (embodied carbon), material re-use/recycled material	8	rainwater harvesting, retention basin, green roof, permeable paving, trees, drought resistance plants	6	Anticipate the initiatives Plan de réduction des émissions de gaz à effet de serre corporatives 2013–2020 (2013)	1	Anticipate initiatives of Climate Change adaptation plan for the montréal urban agglomeration 2015–2020	1	LEED Platinum	1	17
Copenhagen international school	High performance thermal insulation, photovoltaic panels/cells, solar heating, mechanical ventilation, passive design, low energy windows, green roof, prefabbricated components, LED, natural ventilation	10	High performance thermal insulation, mechanical ventilation, natural ventilation, passive design (building orientation, building shape), green roof Rainwater harvesting	6	In line to the policies published in 2015 in CPH 2025	1	Some solutions (e.g. green roofs) are in line to the initiatives promotes in the Climate Adaptation Plan 2011	1	Low Energy standard (not specified)	0	18
The Kathleen Grimm School for Leadership and	passive design (building orientation,	12	green roof, permeable paving, sports and playground,	3	In line to PlanNYC 2030 (2007 and 2011)	1	PlanNYC 2030 A Greener Greater New York, a	1	LEED®certification	1	18

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
Sustainability at Sandy Ground	building shape, compact form), design to increase daylight, photovoltaic cells/ panles, high performance thermal insulation, bioclimatic green house, green roof, building management system, geothermal heating and cooling, solar heating and cooling (solar panel), wind mill, sloped ceiling, prefabbricated building components				goals of Energy and Climate Change		stronger more resilient New York (2014)				
E + HOMES: 226–232 HIGHLAND	passive design (building orientation, building shape, compact form), design to increase daylight, photovoltaic cells/ panles, high performance thermal insulation, building management system, natural ventilation, solar heating and cooling (solar panel), waste energy re-use (energy recovery ventilation), wood for façade, durable natural materials,	10	permeable paving, drought tolerant species, rainwater harvesting, controlled use of water for irrigation and other uses, rain garden,	5	Insert in the E + Building program developed by the 2011 Greenovate Cliamte Action Plan in the Buildings and Energy Sources area,	1	Some design practice anticipated adaptation measure defined in the CAP of 2014	1	LEED Platinum	1	18
Spaulding Rehabilitation Hospital	high performance thermal insulation, low energy windows, shading elements, design to increase daylight, natural ventilation, combined heat and power system (cogeneration), green roof,	7	elevated groundfloor, all patients room above 1st floor, crictical systems on the roof, weaving, rainwater harvesting, green roof, permeable paving, garden space	8	In line to climate action plan of Boston (2007), in the area of buildings and other structures, in line with the update of 2011 of CAP, and in line with the Large Buildings and Institutions focus area of CAP 2014	1	Some design practice anticipated adaptation measure defined in the CAP of 2014	1	LEED V2 Gold Certification	1	18
Center de transport Stinson de la STM	building management system, heat recovery, heat re-use, material re-use/recycled material, wood for building components, design to increase daylight, energy battery storage	7	green roof, green wall (outdoor), trees, permeable paving, green spaces, water retention basin, controlled use of water for irrigation and other uses, drought tolerance species,	8	Anticipate the initiatives Plan de réduction des émissions de gaz à effet de serre corporatives 2013–2020 (2013)	1	Anticipate initiatives of Climate Change adaptation plan for the montréal urban agglomeration 2015–2020	1	LEED Gold	1	18
Pavillon d'accueil du Parcours Gouin	high permformance thermal insulation, low energy windows,	9	bio retention basin, rainwater harvesting, cool roof material, green roof, trees,	7	Plan de réduction des émissions de gaz à effet de serre corporatives	1	Climate Change adaptation plan for the montréal urban	1	LEED Gold	1	19

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	geothermal energy, heat recovery, photovoltaic panels/cells, passive design (building orientation, building shape, compact form), design to increase daylight, strategy to reduce material consumption and transport (embodied carbon), durable natural materials		permeable paving, community garden		2013–2020 (2013) and Sustainable Montréal 2016–2020		agglomeration 2015–2020				
Ericsson Canada – Campus corporatif et Center R&D	building management system, waste energy re-use (energy recovery ventilation), design to increase daylight, durable natural materials, material re-use/ recycled material, strategy to reduce material consumption and transport (embodied carbon), wood for components, low energy windows	9	cool roof materials, green spaces, trees, low reflectance materials for open air spaces, controlled use of water for irrigation and other uses, rainwater harvsting, permeable paving,	7	Plan de réduction des émissions de gaz à effet de serre corporatives 2013–2020 (2013) and Sustainable Montréal 2016–2020	1	Climate Change adaptation plan for the montréal urban agglomeration 2015–2020	1	LEED® NC Gold	1	19
Center for Green Innovation at Evergreen Brick Works	high permformance thermal insulation, green roof, shade elements, solar chimney, natural ventilation, heat recovery, radiant heating, photovoltaic panels/cells, use of LED, material re-use/recycled material	10	green roof, cool roof materials, rainwatercollection, permeable paving, green spaces, natural filtration,	6	Anticipate the Toronto plan for energy of 2013.	1	Anticipate the initiatives of ResilientTO 2019 to captured stormwater to reduce the charge of sewer system for the city.	1	LEED Platinum Certification	1	19
Albion District Library	photovoltaic panels/cells, design to increase daylighting, green roof, wood for structure and building components, brie soleillle, passive design (building orientation, building shape, compact form, mass compact),	6	retention basin, detention pond, permeable paving, green roof, grass swale, community garden, rainwater harvesting, trees, drought tolerant species, high albedo material	10	In line to TransformTO (2016) actions of supporting energy efficiency in buildings, and raising the bar for new construction & community energy	1	Anticipate the initiatives of ResilientTO 2019 to captured stormwater to reduce the charge of sewer system for the city.	1	Tier 1 Toronto Green Standards	1	19
Daniels Building at One Spadina Crescent	design to increase daylight, limitation of glazing, natural ventilation, operable windows, building management system, green roof, passive design (building orientation,	9	green roof, bioswale, rain garden, retention cistern, rainwater harvesting, permeable paving, trees, green spaces	8	In line to TransformTO (2016) actions of supporting energy efficiency in buildings, and raising the bar for new construction & community energy	1	Anticipate the initiatives of ResilientTO 2019 to captured stormwater to reduce the charge of sewer system for the city.	1	In line with LEED parameter	0,5	19,5

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	building shape, compact form, mass compact), shading elements, low energy windows,										
Bill & Melinda gates foundation campus	solar heating and cooling (solar panel), low energy window, design to increase daylight, mechanical ventilation, natural ventilation, radiant heat, waste energy re-use (energy recovery ventilation), thermal energy storage, green roof, strategy to reduce material consumption and transport (embodied carbon), material re-use/recycled material	11	green roof, rainwater harvesting, permeable paving, green spaces, drought resistance species, detention ponds, trees,	7	In line to city green building team + sustainability (2012), and climate action program 2013 in the area of building	1	Some actions are in line to the Climate Action Program 2013 indication to adapt the buildings to climate change effects	1	LEED Platinum	1	21
181 Coleridsge Ave Residences	high performance thermal insulation, low energy windows, heat pump, photovoltaic cells/ panles, natural ventilation, building management system, design to increase daylight,	7	cool roof materials, elevated electrical and mechanical system, emergency lighting communication, enhancec structural elements, permeable paving, courtyard above the projected sea level rise, dry flood underground parking, drought tolerant species, rain garden, rainwater harvesting, rainwater infiltration	11	In line to climate action plan of Boston (2007), in the area of buildings and other structures, in line with the update of 2011 of CAP, and in line with the Large Buildings and Institutions focus area of CAP 2014	1	In line with CAP 2019, and Climate ready Project	1	LEED v4 Homes Multifamily Lowrise Platinum certification	1	21
La Bibliothèque du Boisé	geothermal heating, waste energy re-use (energy recovery ventilation), building smart management system, use of LED, wood for building components, material re-use/ recycled material, strategy to reduce material consumption and transport (embodied carbon), durable natural materials, low energy windows, design to increase daylight, green roof, glass column is a heat exchanger,	12	cool roof material, green roof, raingarden, rainwater harvesting, permeable paving, detention pond, green space	7	The Bibliothèque du Boisé predicts a reduction in energy consumption of over 60% compared to the Model National Energy Code for Buildings (1997). Anticipate the initiatives Plan de réduction des émissions de gaz à effet de serre corporatives 2013–2020 (2013)	1	Anticipate initiatives of Climate Change adaptation plan for the montréal urban agglomeration 2015–2020	1	LEED Platinum	1	22
Lemay Headquarter – The Phenix	high performance thermal insulation, wood for building components, low energy windows, use of LED, building	12	rainwater harvesting, permeable surfaces, green spaces, trees, green wall (indoor)	5	Sustainable Montréal 2016–2020	1	Climate Change adaptation plan for the montréal urban agglomeration 2015–2020	1	3-star Fitwel rating, LEED-Platinum, Living Building Challenge – Petal Certification	3	22

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Project	Mitigation measures		Adaptation measures		Consistency with local mitigation goals		Consistency with local adaptation goals		Green Building Certification		total
	management system, design to increase daylight, solar wall, photovoltaic panels/cells, hydronic radiant heating, thermal and electrical energy storage, material re-use/ recycled material (re-use of existing building), operable windows,										
York University's McEwen Building	passive design (building orientation, building shape, compact form), low energy windows (triple glazed windows), increase thermal mass, solar chimney, natural ventilation, photovoltaic cells, geothermal energy, thermal façade (double skin façade), radiant heating and cooling, building management system, operable windows, mechanical ventilation, green roof, design to increase daylight, high performance thermal insulation, hydronic radiant, shading elements, wood for building components,	18	rainwater harvesting, green roof, permeable paving, trees, green spaces,	5	In line to TransformTO (2016) actions of supporting energy efficiency in buildings, and raising the bar for new construction & community energy	1	In line to the initiatives of ResilientTO 2019 to build more resilient district to the effects of climate change	1	LEED Gold	1	26

Data availability

No data was used for the research described in the article.

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