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Climate change adaptation and mitigation and historic centers preservation. Underway and repeatable technological design solutions

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ABSTRACT

Since the Paris Agreement, European member countries have been committed to mitigating climate change and adapting to its effects. Climate action planning allows cities to organize their approach. It is critical to ensure that investments in infrastructure and services have a low-carbon impact and consider likely climate change perspectives. The output of this process is the climate action plan (CAP): one or more documents where a city sets out its roadmap to reduce greenhouse gas emissions and strengthen climate resilience throughout the community. Many cities have already developed and published a Paris Agreement-compatible CAP. The quality and compliance of these plans will also influence the achievement of the goals of the United Nations Framework Convention on Climate Change (UNFCCC, 2015). Thus, cities are crucial players in global climate change mitigation and adaptation efforts, and how they engage in climate policy is currently under debate. The paper is intended to support technological design, selecting good practices from the latest and most complete ones for climate mitigation and adaptation in urban settings. In particular, the paper focuses on public space and built environment regeneration actions that can tangibly contribute to the global climate resilience movement. Considering the operational difficulty that could arise in planning climate adaptation measures in historical urban contexts, the study critically analyzes current strategies in sedimented landscape realities of high cultural-historical value. The goal is to draw from them a cognitive and expeditious method of intervention that can be reiterated for similar contexts and is compatible with the consistency and value of urban and built heritage. The theme is timely and falls into Sustainable Development Goals No. 11 (sustainable cities and communities) and No. 13 (climate action).

1. Introduction

In recent decades, the climate change trend shows that cities are expected to experience exponential temperature growth, resulting in an average increase of over 1.5 °C between 2030 and 2050 (Antolini et al., 2021). The effects of global warming are already evident: fire seasons are getting longer and longer, and extreme weather events such as cyclones and floods are more frequent and large-scale. One example is the recent violent flooding in Emilia-Romagna and Tuscany, Italy (May 2023), which displaced thousands of people. The leading cause of climate change is the greenhouse effect, with direct consequences on air quality, fires, infrastructure, biodiversity, energy, and urban heat islands. There are also indirect effects associated with the heat waves that occur on the city system, including energy demand peaks for cooling with consequent power outages, alteration of production cycles, health risks to the population, interruptions and delays in service delivery, decrease in the flow rate of urban waterways, damage to public greenery, etc. Moreover, this could reduce the use of public spaces and collective transportation systems, limit social life, generate widespread conditions of discomfort in daily life, and produce adverse effects on cities' tourism and productive economy (Hennessy et al., 2022).

The issue is the subject of all current global policies: the Strategy for a Resilient Energy Union (2019) is accompanied by a forward-looking climate change policy based on five dimensions: decarbonization, energy efficiency, energy security, fully integrated energy market, research, innovation, and competitiveness (European Commission, 2019). On June 30, 2021, Parliament passed the European Climate Act, which makes legally binding the goal of 55 % emission reduction by 2030 and climate neutrality by 2050 (European Commission, 2021); this commitment was reaffirmed by the new European Energy Performance of Buildings Directive (Sept. 14, 2022), which requires member states to adopt National Plans that include measures to double the annual rate of energy renovation by 2030 (European Commission, 2022). It is also worth recalling the yearly UN Conference, the latest COP28 held in

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Egypt in November 2022, which spotlighted implementing international climate commitments and Europe's more ambitious Green Deal initiative. Finally, in the framework of the conflict in Ukraine, when addressing dependence on Russian fossil fuels, the European Parliament notably voted in December 2022 for additional measures to accelerate the share of renewables in the EU.

Historical urban fabrics have huge potential regarding climate change adaption: with their thick perimetral walls, masonry buildings have good thermal inertia, associated with limited energy needs; historical buildings' covering systems (tiles) have higher albedo than in recent constructions (Nicolini, 2022); in many historical centers, the traditional pavement's permeability (polished stones, cobblestone, etc.) allows decreasing runoff and favors rainwater absorption, while its high transpirability keeps the thermal exchanges between the surface and air constant. Historical urban centers are a critical ground to build resilience to climate change, as any event could affect the recognizability of the settlement structure. In a consolidated historical urban fabric, as stated by the Europe Landscape Convention (Stati membri del Consiglio d'Europa, 2024), the first goal is to exalt landscape quality. This priority is followed by the safeguard of the characters defining the landscape's identity and readability and the protection of the pre-existing elements characterizing the historical urban layout.

A recent political document about climate action for the World Heritage drafted by the UNESCO General Assembly of States Parties encourages the World Heritage Center, in collaboration with advisory bodies, to find ways to integrate the climate risk management mechanisms in the existing World Heritage processes (UNESCO, 2023). The Document recognizes that adaption is a global challenge and must be dealt with at multiple levels. World Heritage assets and values can contribute to resilience by supporting the sense of place, continuity, and identity. In the report "Future of Our Pasts: Engaging Cultural Heritage in Climate Action," ICOMOS concludes that we need to update how we conceive and manage heritage. New multidisciplinary approaches are needed to understand the vulnerability of cultural heritage sites and historical centers to climate-related risks (Climate Change and Cultural Heritage Working Group International, 2019).

A limited number of recent studies highlight that historical urban centers, due to being highly stratified and dense, are the most vulnerable places to ongoing climate change. The analyses often focus on large metropolises rather than foundation and historical cities. One of them notes that urban areas have higher temperature anomalies than the contemporary threshold; in particular, the greatest changes are in Paris, the only one with a valuable historical center among the analyzed ones. In Paris, the increase in the average temperature of 5-day and 10-day heat waves is respectively 3.4 °C and 1.7 °C, while the rate of 10-day heat waves has increased by 130 % in the last 100 years (Brown, 2020).

Another study compares the temperatures recorded in the same city – Athens – by considering two different contexts, the urban and the rural ones. It confirms the marked difference between the two contexts and associates the high urban amplification of extremely hot nights with atmospheric pollution (Van der Schriek et al., 2020). One of the most evident examples of climate change threatening cultural heritage is Venice's lagoon, where water rises and flooding becomes increasingly frequent. An analysis of climate change risks by the Euro-Mediterranean Center on Climate Change (CMCC) shows that the urban environment warms up more than the surrounding areas, leading to the definition of "urban heat islands" associated with increasing trends of average temperature and maximum daily precipitation. This has increased awareness in all cities, with the need to include climate risk in territorial evaluations (Centro Euro-Mediterraneo sui cambiamenti climatici, 2024).

Since the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC, 2015), European nations have pledged to keep global temperature rises below 2 °C compared to pre-industrial levels. Since the Accord, member countries have strengthened their capacities to increase cities' resilience to climate change's impacts. Urban center regeneration is a crucial node in this effort.

The first Global Stocktake (GST) (UNFCCC, 2023), a UN assessment report released on Sept. 08, 2023, on the implementation status of the Paris Agreement, highlighted member states' slow pace of action, urging greater industriousness on all fronts. Global emissions are not aligned with modeled global mitigation pathways consistent with the goals of the Paris Agreement. In 2019, European CO_2 atmospheric concentrations reached an annual average of 410 ppb, higher than at any time in recent decades, while CH_4 concentrations reached 1860 ppb and nitrous oxide concentrations reached 332 ppb, the highest in recent years. The global average temperature of the earth's surface during 2011–2020 was about 1.1 °C higher than the pre-industrial average.

One of the main problems is a deficit of strategic planning and, specifically, incomplete CAPs in cities (TSO Key Result No. 10). A 2018 study analyzing the state of urban planning for climate change in 885 urban areas in the EU-28 found incomplete existing strategic planning, in which mitigation is often dealt with and sometimes adaptation. Integration of adaptation and mitigation can be observed in only 3 % of the examined Plans and mainly in two countries where local climate plans are mandatory, namely France and the United Kingdom, although Finland was a pioneer in this regard (Reckien et al., 2018). Compared to 2018, although awareness has increased and the most recent Plans are increasingly comprehensive, most Local Plans still examine partial aspects of climate change in stand-alone documents related to specific sectors. One example is energy, which is the main focus of the SECAP or SEAP (Salvia et al., 2021).

Two years later, a 2020 study updated the 2018 analysis. Screening the 885 urban areas identified 147 CCAPs that combine adaptation and mitigation policy goals in the same Plan. Among these Plans, most have integrated the two aspects to a limited extent. Some, again French and British, are distinguished by "advanced" completeness: Southampton, City of Dundee, Lincoln, Hastings and Coventry (UK), Frejus, Annemasse Agglo, Carino, Béziers, Martigues and Albi (France) (Grafakos et al., 2020).

These and other studies (Neder et al., 2021; Leiter, 2021; UNFCCC. Adaptation Committee (AC), 2021; Tompkins et al., 2018; Broto and Bulkeley, 2013; Pasimeni et al., 2019) have evaluated the quality of cities' Climate Action Plans. Still, few of them have displayed virtuous management cases, including aspects of both climate mitigation and adaptation in urban settings. None of these studies ascertained the relationship and compatibility of actions with the historic urban landscape, and there is no explicit decalogue of recommended measures in such contexts. Moreover, in some cases, the term "mitigation" is used for climate change risk (adaption) rather than to reduce greenhouse gas emissions. This can have relevant implications regarding the clear articulation of policies to deal with climate change (Hurlimann et al., 2021).

The literature review has highlighted an urgent need to increase knowledge on how synergistic measures for environmental change adaptation and mitigation can be implemented in urban settings. The systematization of shared measures in best-performing plans, proposed in this research, is a starting point to help local governments improve their climate-environmental planning. In an environment of historic-landscape significance, interventions must result from a comparative evaluation of all solutions to the context's intrinsic problems. The design solution is the result of comparing the objectives and constraints of the historic city, safeguarding the characteristics that define the landscape's identity and legibility, and preserving the pre-existing peculiarities of the historic urban fabric. No focus on these aspects of the city has been found in the state of the art. Therefore, this study analyzes how ongoing practices, deemed "virtuous" for climate resilience in urban settings, are adopted in a built environment of high cultural-historical value and how they relate to it. This could help governance, technicians, and possible stakeholders identify innovative solutions to make urban systems more resilient to climate change by considering the complex interactions of the historic urban landscape.

2. Method

The study examines city CAPs where the local government for the historic urban center has synergistically prepared actions for climate change mitigation and adaptation. This is to improve knowledge of design measures and solutions applicable in similar contexts. The proposed methodology systematizes good practices and then synthesizes the most virtuous actions, and it is divided into three phases:

1. the first concerns the examination of the state of the art concerning good practices in historic urban landscapes resulting from evaluation processes;
2. the second phase involves the description and critical analysis of strategies, objectives, and actions;
3. the third phase synthesizes specific socio-technical solutions for the built environment (construction and urban space).

From the first phase of the research, developed by analyzing the state of the art on climate adaptation processes of cities aligned with major European guidelines, climate resilience measures of historic European urban settings such as Dublin (IE), Paris (FR), London (GB), Barcelona (ES), Oslo (NO), Bologna (IT) and Turin (IT) were examined. The study shows they all follow a standardized model, starting with context analysis related to the regulatory framework, spatial, urban planning, demographic, economic, energy, and climate aspects. Based on it, climate change risks and spatial vulnerabilities are defined from the climate, socioeconomic, and physical-environmental perspectives. Mitigation and adaptation actions are concrete policies for reducing energy consumption and increasing the resilience of the urban environment to the effects of climate change.

The selection of case studies derives from a careful study of reports and documents, including international-level scientific research, strategic governance documents from European countries, technical documents from the European Commission, and evaluation reports prepared by public and/or private entities in collaboration with member states and/or supporting bodies to the European Commission. We focused only on the most recent documents (starting from 2020). The search for scientific articles was performed through the main citation databases: Scopus, Web of Science, etc.

The critical description of best practices aims to contextualize strategic planning within the challenges of each context and then highlight the prevailing strategy and the resulting specific actions through a brief description of the interventions.

The design solutions were selected for their effectiveness, adaptation to climate change, and impact on the historic and natural landscape, analyzing how they relate to the city as a whole and its historic core, natural and man-made historic infrastructure, and the type of public spaces. A comparison of national and European best practices enabled the identification of strategic actions and intervention plans at various scales and urban projects. For example, solutions for greening, passive cooling, shading, and ventilation and management technologies for water, mobility, and MSW. The proposed actions include applicable socio-technical solutions to achieve greater environmental sustainability, self-sufficiency, and the possibility of integration into the historic city. Therefore, the desired result of the study is the systematization of the information collected that highlights the relationship between goals, actions, and design solutions to be exported and repeated in other contexts. Such information could help public administrations target climate action planning for complex territories, such as the historic urban center.

3. CAP, SEAP, and SECAP. Virtuous practices in European urban centers

The European Union has made combating climate change one of the priorities of its action agenda. The first Climate and Energy Framework (2008), whose targets were to be achieved by 2020, promoted the Covenant of Mayors. The signatory Local Authorities committed to translating these goals into measures and actions outlined in a Sustainable Energy Action Plan (SEAP) in areas they could directly and indirectly affect, involving local households and businesses. In 2015, the new European policy framework (2030 Climate and Energy Framework, Adaptation Strategy, and Energy Strategy) led to the launch of the new Covenant of Mayors for Climate and Energy, which extended mitigation targets to 2030 by harmonizing them with EU policies and complemented them with adaptation targets to reduce the adverse effects of climate change. This new vision aims to accelerate the decarbonization process of our territories (−40 % CO_2 by 2030) along with their resilience to climate change effects. The signatories of the New Covenant of Mayors aim at more ambitious commitments and translate them into a Sustainable Energy and Climate Action Plan: the SEAP became the SECAP. Indeed, the idea of exclusively reducing emissions was not enough, as cities must aim at covering the known impacts with adaptation and mitigation. Today, the Signatories who voluntarily join the European initiative commit to continue to reduce greenhouse gas emissions in their territory, coherently with EU targets; increase the resilience of territories to the foreseeable adverse effects of climate change; and tackle energy poverty to ensure an equitable transition (European Commission, 2020).

Thus, especially since adopting the Paris Agreement, 2015 tangibly stood as a turning point in global efforts to mitigate climate change and adapt to its effects. EU member countries have pledged to keep global warming below 2 °C of pre-industrial levels and aspire to limit temperature increase to 1.5 °C. The result of these intentions is the Climate Action Plan: a document in which a city sets out its roadmap to reduce greenhouse gas emissions and strengthen climate resilience throughout the community (UNFCCC, 2018). Many cities have already developed and published a Climate Change Adaptation and Mitigation Plan or Climate Action Plan compatible with the Paris Agreement. The Climate Action Plan (CAP) is placed within the strategic planning framework of the Sustainable Energy and Climate Action Plan (SECAP). Based on an assessment of an area's climate change-induced risks and vulnerabilities, it identifies objectives and measures to mitigate impacts and build a more resilient community. The CAP must include both mitigation and adaptation actions: the former tackle the causes of climate change, with the primary goal of reducing sources or increasing sinks of greenhouse gases; the latter are aimed at reducing local vulnerability to climate change by transforming natural or anthropogenic systems in response to current or expected climate change and its effects (Shukla et al., 2022).

The Paris Agreement set an agenda for global balance, examining overall progress in achieving the global goal and placing an increasing focus on assessing cities' strategies for mitigating and adapting to climate change.

Among the studies pursuing this evaluative process, we would like to mention the most recent ones, considering a larger sample of case studies. Reckien et al. (2023) examined 327 European cities and surveyed 167 (51 %) with a climate action plan. Most are in the United Kingdom (30 plans), Poland, France (22 plans each), and Germany (19 plans). The index for assessing the quality of plans is based on the comprehensiveness of measures, implementation, monitoring, and social participation in response to the current needs. As a result, the cities with the highest ranking are Sofia (BG), Galway (IE), and Dublin (IE).

The latest analysis was conducted by the Carbon Disclosure Project (CDP), a nonprofit environmental organization, in collaboration with ICLEI - Local Governments for Sustainability, an international nongovernmental organization. It is updated in real-time and used as a reference by the European Environment Agency (EEA) and the Intergovernmental Panel on Climate Change for annual reports. The analysis gives 27 European cities the highest possible score for their transparency and action on climate. To obtain a top score (A) (CDP - Carbon Disclosure Project, 2023), cities must meet several criteria demonstrating transparency and climate action. Cities must publicly disclose environmental data through the CDP-ICLEI Track system and have a climate action plan and a citywide emissions inventory. All List A cities have renewable energy targets and long-term (by 2050) or medium-term zero-emissions goals in limiting warming to 1.5 °C. Since 2019, CDP and ICLEI have collaborated with C40 Cities Climate Leadership Group Inc. and Global Covenant of Mayors to streamline the climate reporting process for cities and present a unified reporting platform. The cities on the CDP's A List in Europe are Florence (IT), Barcelona (ES), Madrid (ES), Vitoria-Gasteiz (ES), Paris (FR), Hague (NL), Mannheim (DE), Porto (PT), Braga (PT), Guimaraes (PT), Athens (EL), Belfast (GB), London (GB), Edinburgh (GB), Dundee (GB), Newcastle (GB), Leeds (GB), Nottingham (GB), Leicester (GB), Malmö (SE), Oslo (NO), Trondheim (NO), Oulu (FL), Lahti (FL), Vantaa (FL), Tampere (FL), and Turku (FL). A-list cities are demonstrating climate leadership through concerted and effective action, as national governments were requested at COP28, and are taking three times more mitigation and adaptation measures than non-A-list cities. According to the CDP database (CDP - Carbon Disclosure Project, 2020) (CDP, 2019), the main types of adaptation planned by European cities are related to hazard mapping, greening solutions, disaster management, and community education.

The study of Linton et al. (2022) examines the technical and policy processes toward deep decarbonization developed in local government plans that aim for a net 80–100 % reduction in greenhouse gas emissions by 2050 or earlier. From the CDP Database, the study identified eight best practices, of which two were European: Lahti (FL) and Oslo (NO). The surveyed local government plans' strategies mainly focus on five priority sectors: electricity, buildings, transportation, waste, sinks, and carbon storage. In particular, Oslo (NO) stands out for its focus on upgrading and improving the efficiency of existing buildings.

Another study evaluates the long-term sustainability performance of 35 leading European smart cities, selected based on the Smart City Index 2020 (Kutty et al., 2022). It examines how they address sustainability regarding energy and environmental resources, governance and institutions, economic dynamism, social cohesion and solidarity, climate change, and energy security. The results show that Dublin (IE) ranks first in social cohesion and climate change, followed by Oslo (NO), Zurich (CH), and Amsterdam (NL).

The main database for investigating the status of local adaptation planning in Europe is the Joint Research Centre Data Catalogue (European Commission, n.d.-a). Its datasets include the data on local mitigation policies as part of the Covenant of Mayors-related emissions monitoring inventory. This dataset provides quantitative and qualitative information on local mitigation policies implemented to achieve the 20 % carbon reduction target (as in the first Covenant of Mayors time horizon) by local authorities that submitted an emissions monitoring inventory by 2016. As of a 2019 version (Palermo et al., 2020), only 226 of the 2021 signatories to the adaptation in 34 member countries have conducted a self-assessment of their progress. In addition to not being updated for the last three years, the Covenant database only details some selected – completed or advanced – actions but does not provide a comprehensive overview of all planned or implemented actions.

The guidelines, "How to Develop a Sustainable Energy and Climate Action Plan (SECAP) System - Policies, key actions, good practices for mitigation and adaptation to climate change and Financing SECAP(s)," by the Joint Research Centre, point to Bologna (IT), which developed adaptation strategies before the adoption of the national strategy, and Turin (IT) which has increased sustainability in buildings by requiring environmental requirements in tenders regarding lighting performance and environmental comfort (e.g., reduction of CO2 emissions; reduction of energy consumption; air quality; thermal conditions, etc.) (Bertoldi, 2018).

Bologna, Turin, and Milan (IT)'s strategic planning shows greater consideration for climate change adaptation than other Italian cities. The three cities have promoted climate change adaptation in various areas, such as local planning, energy, air, forests, and disaster risk reduction. In particular, Turin (IT) stands out for adaptation interventions related to the built environment (Serra et al., 2022).

The European Climate Adaptation Platform Climate-ADAPT established in partnership between the European Commission and the European Environment Agency (EEA), with the support of the European Topic Centre on Climate Change impacts, vulnerability and Adaptation (ETC/CCA), outlines some climate action plans as a useful model for cities beginning to develop climate adaptation and mitigation planning. While stressing that CAPs can vary widely in content, ambition, and coverage, the EU Commission urges member states to examine different documents, compare and use their best aspects as practical examples, and, if possible, connect with other urban areas facing similar climate challenges. Among the recommended examples, those facing the highest climate impacts are Ghent (BE), Dresden (DE), Stuttgart (DE), Helsinki (FL), Paris (FR), London (GB), and Bologna (IT) (European Commission and the European Environment Agency, 2023; Kazmierczak et al., 2020).

One more research question to find the most virtuous practices involved how the best-known sustainable cities certification bodies, LEED for Cities and Communities (U.S. Green Building Council. LEED for Cities and Communities, n.d.) and BREEAM Communities and Urban Design (Building Research Establishment, n.d.), had identified policies related to the global climate action movement. Indeed, these certifications have now taken on a well-known role in helping local leaders create and operationalize responsible, sustainable, and specific plans to improve cities' overall sustainability and quality of life. U.S. Green Building Council and Green Business Certification Inc. announced that Savona (IT) is the first city in Europe to register under the LEED for Cities and Communities protocol, the new certification system that combines environmental sustainability and social welfare aspects with urban-scale analyses (Bisello et al., 2021). The University of Savona campus has developed a polygeneration microgrid to make buildings self-sufficient. These strategies have inspired the city's governance to define appropriate low-carbon initiatives, instrumental in transforming the entire city into a low-carbon urban center.

Among the cities already mentioned, Barcelona (ES) and Turin (IT), along with Lisbon (PT), are the European cities involved in the EU-funded H2020 international research project CONEXUS, in which Europe and Latin America are in synergy toward global-local challenges of climate change adaptation and environmental quality (Kauark-Fontes et al., 2023).

The state of the art drawn from the academic scientific literature, reports and ratings submitted by satellite organizations to the EU Commission, and documents from the Commission itself offers a collection of local pathways to deep decarbonization that has been empirically affirmed to a greater extent in some of the cities mentioned above. The research paper, which aims to contribute to scientific studies on climate mitigation and sustainability management, analyzes practices that the wide-ranging literature considers virtuous. Practices cited by more than one paper analyzed are the strategic plans of Dublin (IE), Paris (FR), London (GB), Barcelona (ES), Lahti (FL), Oslo (NO), Bologna (IT), and Turin (IT).

The selection parameters have mainly considered the administrations' capacities to innovate and pursue fixed goals through concrete actions, monitoring, and evidence proving the result. Some criteria are the pioneering capacity in proposing climate change mitigation and adaptation strategies and awards and commitment for the global movement. The following table (Table 1) reports a synthesis, with the bibliographic references and the reasons for identifying the practices listed here as virtuous.

4. Results and discussion

4.1. Analysis of the main actions of the most virtuous European CAPs

This section analyzes the local action models showing more

Table 1
Cities with virtuous Climate Action Plans. Main selection parameters and Bibliography.

Cities	Main selection parameters	References
Dublin (IE)	The plan contains an evaluation of the climate risk of the urban area and formulates tangible adaption goals for the identified risks. It also includes a well-structured description of the implementation tools regarding priority, responsibility, time schedules, budget, monitoring, and evaluation.	(Kutty et al., 2022; Reckien et al., 2023)
Paris (FR)	The city pioneered the fight against global warming by adopting its first Climate Plan in 2007. Paris diversifies its ways to cool the city, such as promoting green and blue urban spaces. The city has reached its 2020 objectives of the climate action plan and developed an online map that localizes and provides information on cool islands.	(CDP - Carbon Disclosure Project, 2020; CDP - Carbon Disclosure Project, 2023; Kazmierczak et al., 2020)
London (GB)	London has focused on raising awareness of inter-sectorial risks, coordinating pre-existing adaptation efforts, involving stakeholders, and creating continuity of purposes through numerous political administrations. London's size, economic, historical, and cultural status, and leadership in promoting global urban adaption, have made its efforts against climate change an example.	(CDP - Carbon Disclosure Project, 2020; CDP - Carbon Disclosure Project, 2023; Kazmierczak et al., 2020)
Barcelona (ES)	Barcelona has tried to guarantee its inhabitants a higher quality of life in its highly dense environment, realizing an additional 1 m^2 of green space per inhabitant. The administration has drafted a plan for green infrastructures and a guide for green roofs, increasing their presence and emphasizing urban agriculture.	(CDP - Carbon Disclosure Project, 2020; CDP - Carbon Disclosure Project, 2023; Kauark-Fontes et al., 2023)
Lahti (FL)	In 2021, Lahti was selected as the European Green Capital Award (EGCA) winner. The city's circular economy innovations were the main reasons why Lahti won the award. Most cases include compensation strategies for carbon emissions, with an increase in carbon stocking capacity and the use of waste as energy through incineration and biofuel for transport.	(CDP - Carbon Disclosure Project, 2020; CDP - Carbon Disclosure Project, 2023; Linton et al., 2022)
Oslo (NO)	Some empirical results show that the city has recognized that including energy efficiency improvement in building regeneration is a key aspect of decarbonization. Moreover, providing tools and incentives for residents' and enterprises/ organizations' actions is a positive strategy. Oslo has also started pilot construction projects without fossil fuels, which has become a requirement for the city's urban development.	(CDP - Carbon Disclosure Project, 2020; CDP - Carbon Disclosure Project, 2023; Kutty et al., 2022; Linton et al., 2022)
Bologna (IT)	Bologna has participated in international projects to protect nature and environmental policies. It was the first Italian municipality to develop a Climate Action Plan. The city is part of European networks, such as ICLEI and Eurocities, has adhered to the Covenant of Mayors and the Mayors Adapt initiatives, and is actively committed to realizing the actions in the plan.	(Bertoldi, 2018; Kazmierczak et al., 2020; Serra et al., 2022)
Turin (IT)	Turin aims to innovate governance and public green and tree heritage management through public and private partnerships. It has the lowest diversity of policies and a more centralized political approach for NBS integration through an organized hierarchial approach between plans.	(Bertoldi, 2018; Kauark-Fontes et al., 2023; Serra et al., 2022)

sensitivity toward global climate resilience goals, appearing as the most virtuous in the state of the art. The study examines urban centers of various sizes and focuses, in particular, on modus operandi in settings with strong historical value. The purpose is to investigate which technological design solutions are the least invasive to historic city centers and, therefore, most suitable in this dense urban dimension, creating the conditions for climate neutrality. Based on the virtuous practices compared, this section outlines a summary of design actions referring to prevailing environmental systems that can be replicated in similar contexts.

Specifically, the Climate Action Plans of Dublin (IE), Paris (FR), London (GB), Barcelona (ES), Oslo (NO), Bologna (IT), and Turin (IT) were examined to understand their approach and common highlights. All analyzed cities have dense, historic urban centers of significant value and provide them with climate change mitigation solutions (leading to the goal of reducing greenhouse gas emissions – GHGE). Climate change mitigation solutions sometimes coincide with climate change adaptation actions. Lahti (FL) was excluded from the analysis because, despite a few buildings from the fifteenth century, its urban development is more recent (only during the 1900s) (MacGregor-Fors et al., 2021) and, compared to the other cities mentioned above, does not have a rooted historical center. On the other hand, Savona (IT) was included because, in addition to having a well-known historic city center of ancient origins, it is the only LEED-certified city in Europe. The following table (Table 2) shows the action time range, structure, and main actions listed for each strategy under the Plan.

The political tool to achieve the EU's climate ambition is the commitment of EU member states to develop a vision for 2050 with Long-Term National Strategies (LTS) and a short-term implementation roadmap for 2030 with National Energy and Climate Plans (NECPs) (European Commission, n.d.-b). The first consideration arising from the analysis of the Plans above is that they have been drafted following the NECP concerning the short-term perspective – mainly 10-year periods – coherently with the 2030 roadmap. The structure of the plans is and must be suitable for the specific contexts. The basis for all plans is the analysis of the climatic, demographic, economic, and social context and the aspects related to energy, carbon footprint, and the use of fossil fuels and renewable sources. Another critical element is forecasting future trends according to whether the proposed targets – coinciding with community targets – (regarding temperature rise, precipitation decline, effects on people's health and quality of life, cost of living, environmental impacts on landscape, resources, and pollution) are met.

Adaptation actions focus on expected risk in cities, developing timely strategies to improve resilience to specific extreme events or at least reduce their impacts. This is where their time-related limit emerges. The actions do not incorporate projects that can respond to long-term

Table 2
Virtuous Climate Action Plans. Time range and main actions.

Climate Action Plan	Period	Structure of the Plan	Main actions
Dublin City Council Climate Change Action Plan (Dublin City Council, 2019)	2019–2024	1. Context analysis. 2. Main impacts and risks 3. Adaptation and mitigation baseline 4. Action areas 5. Implementation 6. Monitoring and Interaction	- Energy and buildings: public lighting upgrades; building retrofits with energy performance guarantees; energy master-planning; Dublin district heating system; home energy saving kits in all DCC libraries. - Transport: electrification of Council fleet; constructing segregated cycle routes and footpaths; expanding bike share schemes; working with stakeholders to improve bus routes; implementing or supporting walking and cycling campaigns; staffing mobility hubs in civic offices - Flood resilience: building flood defenses; flood resilient urban design; coordinating emergency response plans; carrying out flood awareness campaigns; expanding rainfall sensors and weather stations; implementing sustainable urban drainage guidelines. - Nature-based solutions: green roof on civic buildings; developing green infrastructure; protecting native species; maintaining public parks; implementing action plan for conservation of species sensitive to climate change; implementing biosphere work program; constructing wetland habitats in parks and city-wide; planting and maintaining trees across the city. - Resource management: waste prevention initiatives with staff and the public; implementing water conservation in civic buildings; installation of solar compactor bins; creative food waste campaign for businesses/schools.
Barcelona Climate Plan (Ajuntament de Barcelona, 2018)	2018–2030	1. Context analysis. 2. Forecasting future performance 3. Strategic goals and action lines 4. Time schedule 5. Monitoring 6. Map of actions	- Reduce GHG emissions by 45 % per capita compared to 2005 by means of: reduce travel by private motor vehicle by 20 %, increase solar power generation fivefold, and renovating, in energy terms, 20 % of residential budlings that are over 40 years old. - Increase urban green space by 1.6 ^{km2} - Obtain 100 % clean funding. - Achieve a domestic potable water consumption rate of less than 100 l per inhabitant daily. - Have zero energy poverty. - Allocate €1.2 million in grants for collaborative citizen projects.
Paris Climate Action Plan (City of Paris, 2018)	2018–2030	1. Principles of the Paris Agreement 2. Actions taken in the last ten years 3. Current consumption and future goals 4. 2030 and 2050 Strategies 5. Actions	- Energy: achieve energy savings of at least 50 % by 2030 for public lighting; achieve heat recovery from wastewater; purchase green energy to supply municipal buildings and the district heating network. -Mobility: replace 1200 gasoline-powered public vehicles with clean vehicles; encourage walking and bicycling, public transportation, and car sharing; create telecommuting spaces in the suburbs. - Buildings: reduce the energy consumption of the entire building stock by 40 % in 2030; establish the position of energy ambassador as a liaison with site managers, engineers, and management departments; design with the criterion of multi-purpose for new municipal facilities. - Urban planning: prepare a Local Land Use Plan that provides carbon neutrality for new urban projects and methods for monitoring urban development operations through new energy facilitator (eco-managers) roles. -Waste: establish

(continued on next page)

Table 2 (*continued*)

Climate Action Plan	Period	Structure of the Plan	Main actions
			separate waste collection with efficient collection and treatment systems; achieve 100 % recovered organic waste; encourage low-carbon construction sites. - Food at 0 km: encourage short supply chains and local production; prepare a Sustainable Food Plan; cooperate with other cities to promote sustainable food and agriculture.
London Climate Action Strategy (City of London, 2020)	2020–2027	1. Context analysis: risks and opportunities 2. Vision and goals 3. Actions 4. Climate Action Dashboard 5. Monitoring reports.	- Actions to support the achievement of net zero: transforming the energy efficiency of existing buildings; new zero-carbon and energy-efficient buildings; maximizing the use of renewable energy sources; new management practices for urban spaces to maximize carbon removal and optimize their biodiversity and resilience value; incorporating circular economy principles into projects; Increasing green roofs and urban greenery (from 11.200^{m2} to 65,800^{m2}; water footprint management; design of buildings that prioritize water conservation. - Actions to build climate resilience: develop a climate-related food security alert system; add more urban greenery, flood-resistant road surfaces, and heat-resistant materials; manage storm and surface water, resulting in water recycling and sustainable urban drainage; create an energy grid. - Actions to champion sustainable growth: share best practices on standards, tools, platforms, and expertise to facilitate green and sustainable investment and growth; support financial institutions committed to achieving net zero by 2040; support the implementation of technical solutions to increase data comparability and ease of reporting.
Climate Strategy for Oslo (City of Oslo, 2020)	2020–2030	1. Status and strategy 2. Initiatives in the Climate and Energy Strategy 3. Actions 4. Participatory process 5. Reports and Monitoring	- Land use: protection of fjord forest areas, parks, and outdoor recreation areas; waterway restoration; Oslo will develop the city from the center outward and densify around public transportation hubs. - Transportation: organize urban space to favor walking, bicycling, and public transportation; all private cars and public transportation must be zero-emission in 2030; all port operations and fjord traffic will be emission-free. - Building and construction: building and construction activities will be free of fossil fuels and thus emissions by 2030. - Waste: circular waste and wastewater management system based on reuse, material recycling, and energy recovery with no greenhouse gas emissions. - Energy: local energy produced from renewable energy and various building-integrated energy solutions that complement each other. - Consumption: goods and services with low greenhouse gas emissions; limiting emissions associated with consumption of building construction materials.
Adaptation Plan of the city of Bologna (Bologna Municipality, 2015)	2015–2025	1. Context analysis. 2. Description of the participatory course 3. Actions 4. Strategies and related actions 5. Monitoring	- Water shortage issue: limit deep groundwater extraction; ensure minimum flow rate in Reno and intake for superficial circulation in the canals of Bologna and agricultural uses even in critical months; continue efficiency actions in the civil water distribution network; reduce domestic water consumption and drinking water consumption for non-domestic uses. - Urban area heat wave

(*continued on next page*)

Table 2 (*continued*)

Climate Action Plan	Period	Structure of the Plan	Main actions
			issue: plant 5000 trees by 2025; increase urban gardens to 5 ha; provide greening interventions on at least ten public buildings and public areas in the historic center. - Extreme rainfall events and hydrogeological risk issues: minimize further growth of impervious land within 200 ha; equip by 2025 at least 1 % of waterproofed surfaces with sustainable drainage systems that reduce surface runoff.
Climate Resilience Plan of Turin (Città di Torino, 2020)	2020–2030	1. Context analysis 2. Climate vulnerability and risks 3. Risk response actions already started and to be started 4. Open space design for climate resilience 5. Methodological approaches for service evaluation	- Heatwave issue: increase green areas with trees and permeable areas and reduce land consumption; establish climate-proof criteria in new construction/ renovation; activate the annual Heat Emergency Plan; make public services cool and comfortable (through green roofs and walls, reflective paints, cooling systems, shielding systems); implementation of solutions with water presence in squares or streets (e.g., Waterfalls, pools, fountains). - Flood/inundation problem: increase permeable areas and guarantee hydraulic invariance in new transformations; identify solutions for rainwater drainage; map critical areas; maintain drains; update the Municipal Emergency Plan; prepare rainwater drainage areas along the urban road infrastructure and green areas for the collection of rainwater and subsequent runoff; carry out preventive structural interventions such as bank defenses, creating and raising embankments.
Climate change adaptation plan of Savona (Comune di Savona, 2019)	2019–2030	1. Context background 2. General goal and specific objectives 3. Expected outcomes. 4. Activities 5. Pilot actions	- Improving the geo-hydrological conditions of the area: hydraulic efficiency restoration work of runoff sections; nature-based solution (NBS) along slopes; increase soil permeability and reduce land consumption; embankment upgrades with restoration of continuity of works and/or raising of works for both banks; verification of suitability, geometries, and routes of urban disposal works. - Increasing the resilience of the population and assets at risk: real-time consultation of monitoring data within the alert system with a technologically efficient and effective monitoring network; adaptation of the Emergency Plan. - Improve governance: rehabilitation of areas with permeable surfaces; increase in rainwater harvesting and storage systems; prevention actions in buildings and activities in at-risk areas.

climate risks; they are separate sectoral measures for cities or parts of cities. Such a single-event approach does not consider cascading and long-term risks. It fails to converge global disaster management interventions into climate adaptation planning, with crucial adverse outcomes for global resilience and equitable development. According to the 2021 IPCC Report, the urgency of responding to rapid-onset calamities, such as floods and heat waves, is at the expense of slow-onset, long-term profound changes such as mugginess, drought, melting ice caps, rising temperatures and sea levels, or ocean acidification – that is, events that are already irreversibly underway (IPCC, 2021). Each city might farsightedly start verifying the impact of its actions on a global scale and whether it is worth extending them to the neighboring to amplify it, serving as the leader of a network in a longer-term vision. Indeed, municipalities on the fringes of the metropolitan cities analyzed are not mentioned. In the hypothesis that each municipality adopts its own Plan, this could result in repetitive or disconnected actions between neighboring municipalities and between them and the metropolitan city at the expense of additional resources.

Indeed, the CAP is a complex plan that cuts across other plans addressing climate resilience in a sectoral way (Sustainable Mobility Urban Plan, Sustainable Energy Action Plan, Circular Economy and Remediation Plan, Urban Waste Management Plan, etc.), and the CAPs reviewed above prove this heterogeneous articulation by including different aspects of urban contexts. However, there is an explicit reference to the Sector Plans only in a few cases; moreover, these are still not updated according to the new CAP arrangements. This keeps the actions at a preliminary stage. Priority sectors can be identified as energy, built environment, transportation, and resources. These sectors account for most city-level emissions, and local governments have jurisdiction over them only to a given extent.

The examined Plans are more focused on adaptation actions in response to risks than mitigation (although Turin's CAP clarifies the need to reduce greenhouse gas emissions, and Dublin, Barcelona, and Oslo set the greenhouse gas emission percentages to 2030). Moreover, they show the issue of the ambiguity of the term “mitigation,” which is wrongly associated with risk, as it has emerged in the literature. For example, Bologna's CAP reports “extreme temperatures mitigation,” “summer temperature mitigation,” “hydrological impact mitigation,” and “risk mitigation,” while Paris' CAP reports “mitigating the heat island phenomenon,” and London's “mitigating flooding.”

Examining the actions in the studied CAPs allows for defining the strategic priority areas they respond to; the structure of some Plans, such as those of Paris and Barcelona, clearly outlines these areas and the related actions. The table below (Table 3) combines all the actions the Plans provide for and indicates which ones outline them explicitly. It was noted that some of these actions, although not mentioned in the CAP, are already in place in the cities or planned in the Sector Plans. One example is the electrification of the municipal fleet, which is present in all the cities surveyed at varying degrees. It cannot be said that such cities lack that action; instead, the completeness of the CAP is questioned. A reference to sector plans might be sufficient for the CAP. The table below lists the physical-structural actions, i.e., those that could result in a morphological change to the existing landscape; other actions that the Plans envisage have a social nature, leading to community involvement and institutional actions concerning the jurisdictional sphere. Moreover, a column (M/A) specifies whether the mentioned actions can directly address both mitigation (reduction of GHGE) and adaptation (addressing CC impacts such as floods, heatwaves, drought, etc.).

Planning strategies include actions to adapt buildings and urban space to withstand temperature variations better, referring to an overall multi-sector strategy aimed at the adaptation to heat islands. The most virtuous practices are those whose actions generate benefits regarding both mitigation and adaptation: for example, improving buildings' thermal insulation performance also adapts the built environment to the effects of current climate change and mitigates the impacts of future climate change by decreasing the need for indoor heating and cooling and, therefore, greenhouse gas emission into the atmosphere. Similarly, urban greening actions or sustainable urban transportation systems adapt the existing context to current needs and are vital in moderating the climate change process. Green infrastructure can produce several benefits in urban areas: carbon absorption, holding capacity, rainwater drainage, and cooling effects.

4.2. *Analysis of the main actions of the most virtuous European CAPs concerning the historic urban landscape*

Since many climate change adaptation and mitigation projects involve infrastructural interventions, another issue is the relationship with the city within the planned actions. In particular, the relationship with the high-value historic or landscape area, which targeted design not to impact the pre-existing structures to be safeguarded. SECAPs and PACs must contend with the city's local management plans – the

Table 3
Physical-structural actions for climate change mitigation and adaptation.

Scope		Physical-structural actions (modifying the built environment)	M/A	Climate Action Plans							
				Dublin	Barcelona	Paris	London	Oslo	Bologna	Turin	Savona
Energy		*Redevelopment of public lighting*		●		●					
		Electrification of the municipal fleet		●		●	●	●		●	
		Energy from renewable sources		●	●	●	●	●	●	●	●
		Diversification of energy supply				●		●			
Built environment	Buildings	*Energy retrofit*	●	●	●	●	●	●	●	●	●
		Energy-efficient technologies		●							
		Green roofs and walls	●	●			●		●	●	
		Multi-purpose buildings				●					
		Cool materials	●		●						
		Technologies for storing, filtering, and recirculating rainwater.	●	●			●	●	●	●	
		Measures of resilience and structural strength							●	●	
	Urban infrastructure and landscape	*Permeable road surfaces*	●				●	●	●	●	●
		Cool materials	●		●						
		Technologies for storing, filtering, and recirculating rainwater	●	●	●	●	●	●	●	●	●
		Shading of public spaces			●						
		Wetlands	●		●	●	●				●
		Tree planting and/or creation of green areas	●	●	●	●	●	●	●	●	●
		Infrastructure maintenance/repair							●	●	
		Design and construction of hazard-resistant infrastructure				●		●	●	●	
		Flood defenses		●		●			●	●	●
Transportation		*Separate bicycle and pedestrian paths*		●				●			
		Bike and car sharing		●	●	●	●	●	●	●	●
		Efficiency of public transportation		●	●	●					
		Telecommuting spaces		●		●					
Resources	water	*Diversification of water supply*						●			
		Technologies for storing, filtering, and recirculating rainwater	●	●	●	●	●	●	●	●	●
		Maintenance/repair of water systems						●			●
	MSW	*Waste prevention initiatives*		●	●	●	●	●			
		Construction sites with low environmental impact				●					
		Secondary raw material recovery processes		●	●	●	●	●	●	●	●
		Collection systems integrated with pretreatment technologies.		●		●		●			
	Food	*Urban agriculture*	●	●	●	●	●	●	●	●	
		Productive green roofs			●						
		Km0 agricultural markets			●	●	●		●		
		Educational urban farms				●					

Detailed Executive Plan and Local Strategic Plan – which regulate urban functions and transformations. Links to other local Plans are not always visible in the Plans reviewed. However, the Italian ones especially emphasize the importance of initiating climate adaptation solutions in the historic city, which is the densest urban area.

The urban fabric of Turin is primarily historical. Therefore, modifying and adapting to new needs is problematic because it is densely urbanized. In close coordination with the Green Infrastructure Plan, the climate strategy calls for a neighborhood-level plan of multifunctional green micro-areas to reduce the load on the urban drainage network, produce shade, and provide other ecosystem services in the urban environment. The opportunity to implement these greening micro-interventions is provided by the transition to the door-to-door garbage collection system, which has vacated some public areas previously destined for street garbage collection (Image 1).

The Bologna Plan includes the redevelopment and enhancement of the city's network of historic canals, primarily eliminating substandard sewage discharges and rehabilitating and enhancing artifacts of historical and testimonial importance, including creating public itineraries. A few greening operations are planned within the redevelopment of ten public buildings and urban spaces in the historic center, possibly using some of these as community gardens. In the historic Bolognina neighborhood, major transformations are underway to expand the system of metropolitan and functional services (construction of a new research center). Specific sustainable urban drainage systems (SUDS), such as rain gardens and filter trenches, will be used along with greenery. The assessments reported by the Bologna Plan show that historic buildings are the most affected by worsening weather conditions, which challenge their maintenance deficiencies. Within the Municipality's heritage, this is worse for buildings that house works of art, such as frescoes or museum collections. One possible solution is installing monitoring systems at cultural sites to capture information on measurable or controllable environmental conditions and report detected anomalies. Scheduled monitoring allows appropriate maintenance activities to intervene where critical situations are found. As part of the "Climate City Contract" project recently launched by the city administration, work is underway to rehabilitate the Cavaticcio hydroelectric power plant. Its 1 MW power will make it the largest plant in a historic center. The Cavaticcio is one of the canals that characterized the historic center of Bologna for centuries. However, between the 1930s and 1960s, it was completely buried. Its 15-meter elevation drop allows for enough electricity to power a significant part of the urban center (Image 2).

The intervention priority that the City of Savona has undertaken in its urban center falls within the "infrastructure interventions." It is carried out by improving drainage capacity and containment of stormwater runoff. For this objective, in the CAP, the City proposes the construction of draining and permeable paving within the urban area on which a hydraulic basin collects whitewater from the coastal part of the city of Savona. Due to the conformation of the basin, which is totally urbanized and highly waterproofed, the area is often subject to flooding. Savona also stands out for the energy policy of its urban center, a key strategy for the LEED certification of cities and communities. The policy action takes a cue from the virtuous model of the University of Genoa, Savona University Campus, which has developed a "smart" energy microgrid (Smart Microgrid Polygeneration) to power electric and thermal utilities on the university campus. This system can efficiently manage the energy produced in buildings by balancing generation and loads, resulting in economic savings and reducing the environmental impact of CO_2 emissions.

Among European CAPs, Dublin emphasizes the built environment, starting with the risks entangled by climate phenomena to its integrity. Expected increases in temperature, wind speed, cold snaps, precipitation, sea level, and overtopping waves will test the resilience of critical infrastructure (such as power and communication networks) and urban settlements, especially those built along the coast or the Liffey River in the heart of Dublin. The CAP points out that proposals to improve thermal performance or incorporate renewable energy technologies in historic buildings will be carried out only if they respect traditional construction methods and do not require the removal of historic elements such as original windows, doors, and floors. The national guidelines for appropriate interventions are represented by the Department of Environment, Heritage and Local Government's publication "Advice Series: Energy Efficiency in Traditional Buildings" (2010).

Protecting the river and city walls requires a mix of solutions. For example, where it is necessary to maintain access (pedestrian walkways), Dutch dikes are planned to be incorporated within the floodwalls at these crossings. These demountable defenses can be manually closed when one of the operational flood forecasting systems predicts a flood risk. Further upstream, soft solutions are implemented, such as increasing the buffer distance from the river edge, urban drainage systems (e.g., rain gardens and permeable pavements), and green infrastructure to improve the city's resilience to flooding.

The PACs of London, Oslo, and Barcelona do not distinguish between actions in the city's most historic area, the rest of the urban environment, and, for example, the peri-urban belt; all the actions listed in the previous paragraph are addressed to the entire city. However, during implementation, there will clearly be a reference to conservation laws for heritage preservation. The London City Resilience Strategy 2020 plan specifies that, due to the morphology and density of the built environment in the historic area, green roofs and walls, street trees, and the addition of vegetation are the most appropriate interventions.

Several actions are already in place to improve climate resilience in the historic urban centers of these major European cities. Some regeneration operations and changes in the intended use of residential complexes have recently been completed in the urban center of Barcelona. They include green roofs and walls and innovative photocatalytic facade surfaces, with catalysts to absorb pollutants in the atmosphere when irradiated with light of appropriate wavelength.

1a. Urban acupuncture in the Barriera di Milano neighborhood in Turin, Italy

1b. Green roof bocciodromo "La Tesorina" in Corso Moncalieri in Turin

1c. Draining paving in Porta Palatina, Turin

Image 1. Turin climate resilience plan. Implementation of multifunctional green micro-areas.
Source: Climate Resilience Plan of Turin (Città di Torino, 2020).

1a. Cavaticcio hydroelectric power plant, Bologna 1b. Eco-boulevard Lazzaretto district, Bologna

Image 2. Adaptation Plan of the city of Bologna. “Climate City Contract” project and sustainable urban drainage techniques.
Source: https://www.comune.bologna.it.

The Parc de Joan Raventós in Barcelona is an innovative and sustainable drainage system: it collects rainwater through various types of draining surfaces, filtering the water and purifying it to eventually reach the subsoil. In heavy rain, water flows in the retention zone or specially created anti-flooding areas. Also, in Barcelona, during the renovation of Plaça del Centre, a pergola placed over the children's play area uses solar energy to generate electricity in addition to providing shade (Image 3).

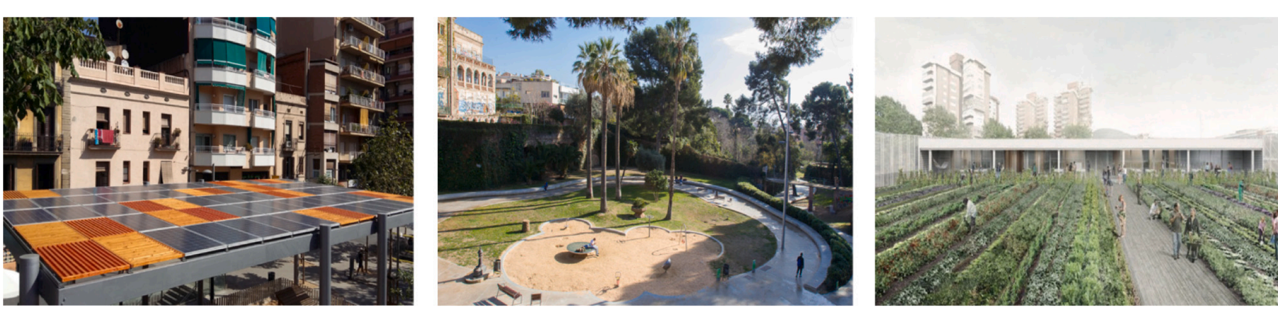
Slow mobility interventions in the historic urban center are growing: Barcelona ensures a bicycle path within 300 m from home for at least 95 % of the city's population. Oslo's “Car-Free Livability Program,” introduced in 2015 and still in force, has gradually removed on-street parking in the downtown area for alternative uses. Oslo initiated the “Action Plan for increased City Life 2018-2027” and the “Zoning plan for streets and urban spaces in the city center.” In the city center, traffic routes were closed to vehicles, except for goods delivery and disabled people's parking, and the City Council invited stakeholders to develop and implement an annual calendar of activities and events to be held in the new pedestrian areas. Various temporary and permanent interventions have replaced on-street parking lots (e.g., new bike lanes, wider sidewalks, street furniture, parklets, art displays, lighting, and flowers). This Program is one reason Oslo received the designation of European Green Capital 2019 and has contributed positively to attracting visitors to the city center and businesses (Hagen and Tennøy, 2021).

Among the CAPs reviewed, the one in Paris proposes a greater thematic diversification of actions in the downtown area, highlighting some good practices already in place or underway as examples to be repeated. In 2016, the Paris Council adopted a vast project to redevelop iconic squares in central Paris to decongest them, facilitating access only for pedestrians, cyclists, and public transport. This resulted in creating welcoming green spaces where people can stop to admire the architectural and historical heritage and engage in cultural and sports activities. The administration aims to preserve the historical heritage while adapting to major climate change. In collaboration with the Paris Convention and Visitors Bureau, tourism professionals will be supported in developing and promoting responsible cultural and tourism offerings compatible with the Tourism and Leisure Development Plan and the Charter for Sustainable Accommodation in Paris.

The CAP proposes to use the opportunity associated with high building density in the urban center to rethink the use of rooftops as sites for solar energy production, possibly in conjunction with other uses such as green roofs and urban agriculture. Since 80 % of the building stock was built before the first thermal standards were introduced in 1974, sustainable building renovation remains a key issue in efforts to achieve carbon neutrality in Paris. In compliance with heritage protection requirements, urban greening interventions in the built environment will be preferred: green roofs and walls, planted areas on slabs or in open ground, etc. The city of Paris will create new ponds, urban canals, and rain gardens: breathing spaces that combine biodiversity conservation, alternative areas for rainwater management, and areas with cooler temperatures. Following the Paris Biodiversity Plan, a network of wetlands and phytoremediation basins will be created and restored. This will help with stormwater management by treating some types of contaminated water that can then be used to water crops (Image 4).

4.3. *Toolkit of “soft” climate change adaptation and mitigation actions to be integrated into an urban space in the urban historic fabric*

By comparing the best practices from the state of the art, the paper aims to outline a synthetic toolkit highlighting the most usual design actions in climate adaptation and mitigation in dense urban centers with high historical-artistic value to foster their replication in similar contexts. The actions described here accomplish both adaptation and mitigation. Thus, while supporting the urban landscape's adaptive capacity, they influence the determinants of climate change to which it is exposed.



1a. Photovoltaic pergola over a children's play area in Barcelona's Plaça del Centre 1b. Parc de Joan Raventós, a green area that absorbs rainwater 1c. Agriculturally productive green roof at the Vall d'Hebron-Teixonera market

Image 3. Barcelona Climate Plan. Some actions on Transforming communal spaces:
Renewables in public areas, water retention surfaces, recovering terrace roofs.
Source: Barcelona Climate Plan (Ajuntament de Barcelona, 2018).

1a. Green roof in a historical building in Paris center.

1b. Solar energy system in Paris center. Source: https://www.apur.org

1c. Patrick Blanc's vertical garden on the corner of rue des Petits Carreaux

Image 4. Paris Climate Action Plan. Some actions on buildings: Végétalisons Paris Programme, renewable-energy.
Source: Paris Climate Action Plan (City of Paris, *2018*).

The historic urban centers of the European cities examined have long been involved in organizing comfortable buildings and urban spaces. Their history has characterized urban livability and functional and symbolic quality for centuries. It is set on simple planning rules, initially focusing on the context's geo-morphology and the prevailing climatic conditions. Over time, some of these urban spaces have become detached from their original intentions due to various factors (intensification of urban density, excessive sealing of surfaces, minimization of slow use, etc.) that have contributed to discomfort and danger to the enjoyment and safety of places. Adapting and mitigating the urban center also means enhancing the livability of these places and benefiting the environment; improving microclimate provides comfortable conditions. Thus, one first consideration is that planning actions in these places should start from their observation, as they often constitute open-air manuals; respect for their nature and urban design comes from conscious choices that a good technician can bring to the surface.

Governance and engineers can consider the actions listed in the table below, planned or in place in the surveyed historical centers, as a compendium for design. They are soft actions with dual functions: improving the quality of use and resilience to climate change. Out of the actions identified in Table 3, the table below (Table 4) describes those addressed to urban spaces in plans (see Table 3, Built Landscape- Urban infrastructure and landscapes), focusing on the ones that have also been used for the historical urban center. The actions are divided by the design scale between the urban area and the urban space. Some actions are multi-scalar, as they can be realized for a single urban area or the whole urban center. Naturally, a larger scale is associated with an increasing effect of the established goals (emission reduction, urban cooling, etc.)

Some actions are for mitigation (M) as they reduce climate change impacts by preventing or reducing greenhouse gas emissions into the atmosphere. Others adapt the urban environment (A) by preparing it for the adverse effects of climate change to prevent or minimize the possible damage. In many cases, some actions have a double value, such as urban greening, which improves air quality (adaption measure) by absorbing CO_2 (mitigation measure). At the same time, urban green areas serve as permeable layers, leading to a better response to heavy rain and reducing the heat-island effect and extremely hot temperatures through evapotranspiration processes. Sometimes, the adaption effect is not direct, but the results of mitigation actions produce a long-term adaption benefit: for example, slow mobility planning guarantees immediate greenhouse gas emissions while helping to reduce the heat-island effect by decongesting urban traffic.

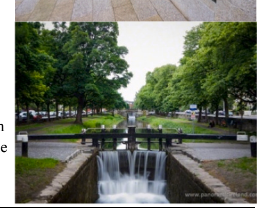
5. Conclusions

The paper investigates preliminary actions for drafting a CAP in historical urban contexts. Implementing low-impact actions – the basic principle of a vision that aims to counteract the emission of CO_2 into the environment – is tied to the viability requirements of urban spaces and, for historic centers, to the preservation of qualitative characters. The technical assessment phase of the first GST identifies some general solutions to be enacted in urban areas, such as urban cooling by greening, water retention areas, retrofitting, and infrastructure redesign according to permafrost degradation. Apart from the GST – which only indicates a few actions with precision, without reference to real practices – no documents collect and describe in detail the virtuous actions implemented by cities in their urban centers. However, the GST stresses that international cooperation can help share experiences to realize opportunities and overcome obstacles and challenges in implementing adaptation plans and promote learning of good practices in various contexts.

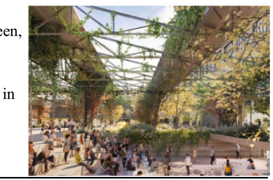
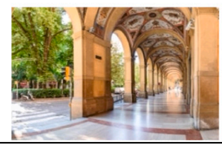
All the examined Plans start from the typically urban risk vulnerability and then define strategic lines and related actions. Although the planning policies respond to global political ambitions and goals, the Plans' impact is still limited to local risks. Moreover, their possible contribution to the global process of climate change mitigation is difficult to estimate. This is also due to the lack of clarity on the difference between climate change mitigation. Moreover, though their prediction is understandably difficult, no estimation is provided on the single actions' greenhouse gas emissions mitigation capacity (rarely, for actions that directly lead to greenhouse gas emissions reduction; never, for adaption actions that could limit urban center pollution in the long term).

The observed interventions also converge in the perspective of urban regeneration since historic urban contexts, like the cases studied, are particularly vulnerable to various climatic threats that jeopardize their preservation. This issue is largely addressed in Bologna's CAP. It is also the focus of the World Heritage Center, as discussed in the City Lab Historic Cities, Climate Change, Water, and Energy (Hein, 2021), an event organized as part of the 10th anniversary of the HUL Recommendation to respond to the 2030 Agenda for Sustainable Development by complying with the 1972 Convention concerning the Protection of the World Cultural and Natural Heritage. The challenge is to reconcile the need for climate adaptation with design solutions that can strengthen the quality of the existing landscape. Thus, the paper focuses on these and shows how they can be integrated into the historic built landscape with a few targeted interventions already in place in virtuous practices in Europe, the latter drawn from a detailed literature review. Given that each urban and spatial context requires specific and tailored solutions, the need-performance approach is common to all the studied cases. Starting from users' demands, it helps identify the design objectives and requirements to propose solutions at various scales. All the reviewed plans start from the city's typical risk vulnerability and establish strategic lines and related consequent actions. The toolkit proposed here is based on these actions: it is a guiding tool, collecting soft actions that engineers and governance can include when planning climate mitigation and adaptation actions in dense historic urban landscapes.

Table 4
Climate actions that could integrate into the dense historic urban landscape.

MULTI-SCALE DESIGN ACTIONS WITH PREVALENCE IN URBAN AREAS	**M/A - Urban Greening** *(Image: Paris - Place de la République, Source: https://www.urbangreenbluegrids.com)* Flowerbeds, trees, gardens, green walls, green roofs, and urban forests and parks greatly catalyze urban space. Vegetation has an environmental function that helps limit climate change and adapt to its effects. Some examples are punctual and widespread interventions of transforming interstitial urban spaces to green for enlivening areas that are little used by the population and making them attractive; collectively managed shared spaces (e.g., urban gardens); sunken flowerbeds capable of intercepting rainwater from roofs, streets, parking lots, and squares; rooftop greenery on building roofs; vertical gardens in building facades; ornamental greenery in urban parks; tree-lined urban spaces with tree species capable of shading in summer and letting sunshine filter in colder periods. Plants can change wind direction and speed, decrease the possibility of heat island formation, reduce high temperatures, trigger urban breezes, and capture pollutant gases and dust.	
	M - Aids for slow mobility *(Image: Oslo - Bike Parking, Source: https://ecf.com)* Connecting height differences by means of ramps, stairs, curbs, and elevators, safely differentiating the vehicular route from pedestrian to soft-mobility routes (even with simple flowerbeds or light bollard elements) encourage less and less use of combustion vehicles and could change urban space. Planning should encourage active mobility, such as walking and cycling, as well as low-cost, zero-emission forms of mobility, which can also provide health co-benefits associated with more active lifestyles. This also aims to trigger a new consideration of the new forms of micro-mobility (scooters, hoverboards, electric bikes, and scooters), inevitably leading to more vulnerable road users on city streets due to present immaturity regarding road safety awareness and education. Concerning urban vehicular mobility, it is preferable to encourage the use of small, eco-friendly electric vehicles for public transport services and provide suitable charging stations and parking areas.	
	M/A - Permeable areas *(Image: Barcelona - Passeig de St Joan, Source: https://landscapearchitecturebuilt.com)* The subtraction of impervious surfaces (e.g., asphalt) in favor of permeable (e.g., beaten earth, grassed gravel, stabilized gravel, marble grit or crushed stone, porous concrete, brick, soil) and vegetated surfaces improves soil eco-system services in terms of filtering and decontamination of stormwater; absorbs carbon; and contributes to bioclimatic comfort conditions (moisture reduction and cooling). The most suitable spaces for replacing impermeable surfaces are parking lots, squares, and streets in urban areas built with little attention to quality. Attention should be paid to the attitude to frostbite when choosing materials.	
	M – Innovative socio-technical solutions for separate MSW collection *(Image: London -Smart Bin, Source: https://tech.gnius.it)* Good circular resource management is a requirement for the ongoing decarbonization process. MSW collection strongly affects the quality of urban space, especially regarding aesthetics, smell, and sound concerning vehicular collection vehicles. The collection phase should impact the built environment as little as possible. Some expedients could limit the incidence of the service, e.g., the use of small electric vehicles, non-visible ecological islands underground, or integrated into the ground floors of buildings. Technical multi-function systems allow anticipating the treatment stage when delivering waste; some examples are micro-compacters, composters, integrated bins with systems for scanning the type of waste delivered, separation, screening, crushing, or shredding. This allows for more accurate sorting at the delivery stage and a possibility of abatement of the volumes of delivered material. Moreover, electronic systems could work autonomously if powered by RES.	
MULTI-SCALE DESIGN ACTION WITH PREVALENCE IN URBAN SPACE	**M - Efficient lighting** *(Image: Turin - Piazza San Carlo, Source: Antonella Mamì)* Street lighting can be upgraded with new technologies (e.g., LEDs and luminous flux controllers), including RES power systems (e.g., PV). These technologies enable functional self-sufficiency, significant reduction in environmental impact, overall annual savings, and better performance in terms of brightness and durability. Energy efficiency in urban public facilities provides indirect benefits, such as reducing traffic accidents through effective lighting to optimize the sense of safety and urban regeneration by enhancing the architectural heritage.	
	M/A - Regeneration of historical solutions and technologies *(Image: Bologna -Canal delle Moline, Source: https://www.bolognawelcome.com)* Regeneration and enhancement of existing devices and existing solutions that anticipated the need for climate adaptation in historical centers, e.g., fountains, canals, vegetated ditches and canals, draining trenches, green courts, gardens, and villas, underground cisterns, above-ground reservoirs, underground water regulation systems, arcades, reduced street sections for shading, underground (cave-like) solutions, cryptoporticus, etc. In these cases, it is necessary to interpret and preserve, restoring the efficiency of the original solutions and their technical-constructive configurations.	
	A - Maintenance and reinforcement of technological elements *(Imagine: Dublin - Liffey flood defenses Source: https://www.newcivilengineer.com)* The development of technical solutions for conservation, restoration, retrofit, and maintenance interventions as strategies for building and urban regeneration and precautionary measures induce the improvement of the resilience of the built landscape, decreasing the city's vulnerability to adverse disaster events. Examples include preserving or restoring all water catchment areas and strengthening critical infrastructure, such as coastal defenses and flood control functions of existing dams and agricultural basins.	
	M/A - Elements for water resources collection and storage *(Image: Dublin -Grand Canal, Source: https://panoramicireland.com)* Canals, fountains, pools, natural and artificial basins, vertical blades, horizontal jets, and vaporizers could act as storage reservoirs and, in some cases, even filter rainwater and cool the microclimate while becoming characteristic urban elements. A 25-30 cm thick water mass has four times the thermal capacity of building materials and up to 80 percent solar radiation absorption capacity. Evaporating water requires energy that is transferred from the air, which in turn cools; therefore, the presence of water in an urban space contributes to improving thermal comfort conditions. The phenomenon is more pronounced if water jets are inserted into canals and fountains. Compared with the horizontal surface, cooling due to water flow on a vertical surface is higher.	

DESIGN ACTIONS IN THE URBAN SPACE

A- Enhancing the favorable climatic conditions of urban space *(Image: London - Richmond Riverside, Source: https://www.visitrichmond.co.uk/)* The key is to observe urban space in the physical and geo-morphological conformation of the natural and built environment to avoid the generation of urban heat islands. For example, for slopes or terraces characterizing an urban space, allocating a function for users to stop in the most advected position is more favorable. This considers air's natural fluid dynamics (warm air moves from the bottom to the top) and the possible protection the depression can provide against prevailing winds. However, in other cases, triggering convective motions (e.g., with overhangs, niches, and light walls that originate a Venturi effect) may be preferable. It should also be remembered that the microclimate can change considerably on the coast or in the presence of a river or waterway. Depending on the case, some functions currently allocated in more densely built and trafficked areas could be moved to the vicinity of these wetter areas.	
A - Shading systems *(Image: Barcelona - Cooling-shelters project, Source: https://www.barcelona.cat)* Systems such as sunshades, awnings, pergolas, verandas, or porches create a shaded filter zone that acts as a sunscreen, adapting urban space to very hot climate conditions. If shading systems face south, the shading function is more effective because they intercept the sun's rays at more times of the day. In design, it is important to study the sun's zenith angle according to the climatic context and exposure to determine the size of the shading so that it will shade in summer and be permeable to sunlight in winter. In cold climates, transparent roofs are one of the most effective solutions for harnessing and storing solar energy and containing heat through their waterproof and weatherproof characteristics. Canopies define and protect the parking areas of urban squares.	
A - Transitional spaces *(Image: Bologna - Via D'Azeglio Porch, Source: https://www.comune.bologna.it)* Transitional spaces provide a "soft" transition between the private and public spheres. These courtyards, porches, verandas, etc., can change the microclimate both externally and internally; therefore, they can be considered a strategy to affect an urban space's environmental performance. This transition should also be considered regarding transit from one urban space to another and weather protection (rain, sun, wind).	
M/A - Multifunctional spaces *(Image: Bologna - Multifunctional spaces Via Milano, Source: https://www.comune.bologna.it)* A multifunctional space avoids the consumption of additional land, encourages the accommodation of different functions, and includes equipment to carry out different activities throughout the day. Therefore, it must be both equipped and well-lit. Markets and urban squares can be outfitted with pergolas, canopies, shading structures, and seating to accommodate events, including temporary ones.	
A - Cold Surfaces *(Image: Turin - Historic Coatings, Source: Antonella Mamì)* They are characterized by high solar reflectance, achieved with light shades or darker colors treated with special near-infrared reflective pigments. They reduce thermal load and are used in facade cladding, roofing, and outdoor spaces, applying them to portions of pedestrian and bicycle paths. The energy balance of the built environment is affected primarily by its density and can be improved by reducing thermal gains in the urban environment. Cool surfaces include porous ceramics, self-locking cementitious screeds, and draining cementitious pavements for applications designated for pedestrian traffic, bicycle paths, and parking lots. The recommended characteristics are high long-wave emissivity, porosity, and high heat capacity. Porosity allows water to rise by capillarity, reducing the floor's surface temperature and evaporating, cooling the room.	
M - Photocatalytic surfaces *(Imagine: Barcelona - Sant Jordi Street photocatalytic pavement, Source: https://www.breinco.com/de/airclean/)* This exploits the natural phenomenon in which a substance, called a photocatalyst, activates a strong oxidative process upon capturing light, leading to the decomposition of organic and inorganic pollutants in the atmosphere that come into contact with them. One example is segmental concrete pavements integrated with photocatalytic activators, which are particularly suitable for redeveloping courtyard areas. Thanks to their anti-pollution properties, they are effective in heavily trafficked streets. The typically used photocatalyst substance is titanium dioxide (Ti_{O2}).	

Most of the actions in the plans are concerned with cooling the dense area, pursuing this with the help of two natural elements: greenery and water. This is a return to the natural environment, a crucial element in the fight against pollution and the abatement of fine particulate matter, and fundamental to making cities attractive and comfortable. It can be considered that, over history, vegetation and water have always been used to make urban microclimate comfortable; maybe, when working in a historic urban center, it is implied that the history of urban morphology should guide engineers' design. The main action is observe the city, shedding light on the ancient solutions designed in its very genesis to meet climatic needs: fountains, canals, green courts, gardens and villas, underground water regulation systems, vegetated ditches, arcades, reduced street sections for shading, cave-like solutions, etc. The built space, in its various morphological, typological, technical, material and historical discriminants, provides the answer to the design choices. Although each context demands its own design action, in similar contexts, revisiting cities' Climate Action Plans, in observing of the most virtuous and repeatable practices, can help technicians and city administrations to address the tension between heritage preservation and climate action.

Acronyms

CAP Climate Action Plan
SEAP Sustainable Energy Action Plan
SECAP Sustainable Energy and Climate Action Plan

CRediT authorship contribution statement

Elvira Nicolini: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

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Data availability

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

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