Climate Change, Cities, Communities and Equity in Health

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R1 Report

Research on mitigation and adaptation strategies of climate change effects on human health in urban areas

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The Cli-CC.HE Project

The concepts of "urban health" and the role of urban design in the quality promotion of the cities' living spaces has been present in the international debate for some decades, but only since the publication of the "New Urban Agenda" (WHO 2016), health has been defined as "one of the most effective markers of any city's sustainable development". These aspects are beginning to be highly debated on a scientific level, but have not yet been introduced into university education. Moreover, the pandemic emergency we are experiencing imposes even more compelling reflection on the relationship between health and climate change, and on the role of university research and education to understand what the city of the future will and should be like. However, a gap between education, scientific research and professional practice hinders the achievement of a seamless collaboration among the different stakeholders involved in the urban regeneration of our cities.

CliCCHE, an Erasmus+ Project (Action Type KA220-HED - Cooperation partnerships in higher education) aims at developing and testing newer non-formal learning/teaching experiences that aim to stimulate students' motivation, enhance their engagement and amplify their contribution to generate a participative environment.

The CliCCHE educational methodology and tools will be developed seamlessly with the contribution and the involvement of representative groups of citizens, professionals and public administrations.

CliCCHE has been designed to achieve the following objectives:

- allowing students to evaluate climate change effects on urban health and equity and so to identify and design appropriate adaptation strategies;
- increasing the students' interest in the topic of urban regeneration through an innovative participatory process (urban simulation game);
- innovating the teaching activities by applying a transdisciplinary approach, and involving citizens through immersive virtual environments, simulation games and public art;
- promoting changes in the public administration (municipalities) and provide knowledge and tools, which could develop health-oriented, climate-proof urban plans and projects;
- raising citizens' awareness of climate change effects on health in urban context and strengthen their role as co-designers of urban spaces.

These non-formal learning tools will be adopted to identify and define climate change adaptation strategies at the urban scale. Since the produced educational methodology and tools will be finalized by an European consortium (University of Camerino; The Cyprus Institute; University Institute of Lisbon ISCTE; CNR IFT and UNIVERZITET U BEOGRADU) and integrated in its educational offer, it will be possible to transfer them in other EU countries.

Objectives of Result 1

Research on mitigation and adaptation strategies of climate change effects on human health in urban areas

This result is a catalogue of research and experiences that address the issue of health and climate change in urban areas. It incorporates both scientific research projects, and experiences carried on in cities at European and international level, including those developed by project partners, that link the topic of health to climate change and involve communities in designing/creating environments favourable to health. This catalogue focuses on:

- a transdisciplinary approach to urban health and climate change;
- design solutions for urban areas, aimed at adapting to climate change;
- design solutions that can be replicated in the various European cities that deal with the regeneration of the existing city.
- Professors and researches involved in the teachers training workshop (C1) have finalized it and will use it as a base for the development of upcoming studies. The collection will be the main element for professors in the local workshops to illustrate to students the effects of climate change on the built environment and the possible design solutions to protect urban health problems. Moreover, it will be spread out in the project website, Erasmus+ platform and other channels to make it available to interested stakeholders, and in particular to public administrations, universities and research groups at local, national and European level. As a result, its dissemination will:
- increase awareness among professors and researchers regarding the importance of a trans-disciplinary approach to urban health;
- increase students' ability to understand the importance of dealing with experiences developed in different contexts and in different disciplines;
- provide students with a sample of design solutions that can be used in their urban regeneration projects;
- enable the public administrations involved as associated partners to become aware of the experiences of other cities.

Contents

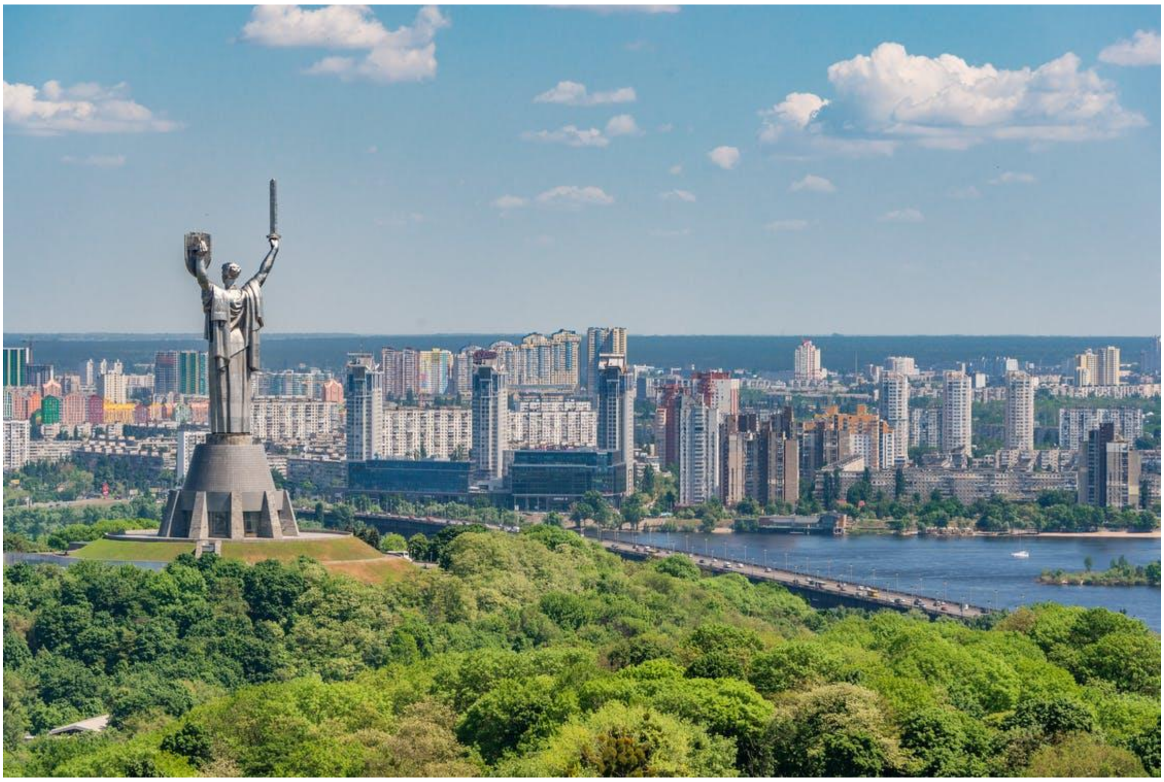
1. Climate change and its relation to urban health – a transdisciplinary issue

The recent past has been characterised by extended crises – economic crunches, social disruptions, national or international conflicts, public health shocks and constant climate anxiety. While some crises can be ameliorated and seem to have an expiration date, others are long-lasting. Climate change is such an affliction. It has been a research topic for decades, with each time period being marked by a different focus (Hou and Wang 2021). In the beginning, the physical aspects of the changing climate were observed in a context of naturally occurring planetary fluctuations (Lockyer 1910; "Astronomical Topics" 1932). Gradually, research interest extended to historical reflections related to migration patterns and the effects of a changing climate on living organisms (Brooks 1931; Buxton 1933; Regan and Richardson 1938; Teng and Heyer 1955), reflecting the fact that life on the planet was altered by prevailing environmental conditions and humans were becoming aware of it. It wasn't until the mid-20th century that scientists observed a relationship existed between carbon dioxide and surface atmospheric temperature (Plass 1956), and the role of anthropogenic emissions was only looked into years later (Benton 1970; Kopec 1971; Frisken 1971; Landsberg 1970). After the initial scientific findings on pollution and its impacts on the climate and human health, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and released its first report two years later. Initially, the IPCC reports employed extreme caution in describing climate change and the need to address it, often quoting high levels of uncertainty (IPCC 1992). Over the years and as research and technology have advanced, as well as the damage caused by anthropogenic climate change, the urgency to act emerged. Reports started mentioning high confidence levels for projections of extreme temperatures, increased exposure to frequent and intense hazards and loss of biodiversity (IPCC 2018). Global warming is now such a critical matter that the anthropic dimension is being examined alongside its scientific basis. The latest IPPC report highlights the impacts of climate change observed in many ecosystems and human systems worldwide. Notably, in an urban setting, observed climate change has caused impacts on human health, livelihoods and critical infrastructure. Hot extremes, including heatwaves, have intensified in cities, where they have also aggravated air pollution events and limited the functioning of critical infrastructure. Observed impacts are concentrated amongst the economically and socially marginalised urban residents, for example, in informal settlements. In this scenario, the magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions (IPCC 2022).

The changing climate is no longer a niche topic intended to be known only by experts; it is one of today's worst threats, and major efforts are being observed on a coordinated plan in order to avoid worst-case scenarios. The science of climate change is well understood, and the challenge for the near future is to assimilate this knowledge into policymaking, promoting major transitions in lifestyles and systems to a more sustainable living experience. The built environment plays a major role in this regard, with more than half of the world's population already living in urban centres in 2018 (UN 2019). The impacts of climate change within densely populated and travelled urban centres are manifested in many ways, from the built environment to the patterns of energy consumption and the health of humans or the natural ecosystems.

Box 1. Urban health

The term urban health generally refers to the development of pathways and tools for preventing and counteracting the effects of climate change on health with the aim of promoting conscious and sustainable processes of urban regeneration. Creating more sustainable built environments and developing actions that can positively influence human health and quality of life can promote healthier environments and lifestyles and create healthy environments and resilient cities and societies. Planning influences the way in which we use and access resources, land use models, urban form and urban space design, biodiversity and nature, and investment in transport, all of which may be important determinants of health and equity.



Due to increasing urbanization, there is a growing interest in identifying the environmental exposures characterizing urban contexts, such as air quality, traffic intensity, family density, natural and green spaces, high temperatures, floods. The positive health effects of many mitigation measures can help address global health priorities, reduce risk factors for chronic disease (e.g., ischemic heart disease, chronic respiratory disease and diabetes) and reduce respiratory and cardiovascular mortality in frail populations such as the elderly and children.

illnesses can be prevented by focusing our attention on designing, creating and managing the environments in which people live. For example, the promotion of green spaces improves air quality and mitigates the effects of climate change in cities. Green areas and gardens decorate urban spaces, and carry out important functions of thermoregulation of the city microclimate, improvement of humidity levels, air purification and reduction of pollution, thus contributing to the improvement of citizens' quality of life.

Designing and promoting interventions for the bioclimatic control of buildings, for the shading and control of solar radiation, for natural ventilation and cooling, and the improvement of thermal insulation with the use of innovative materials represent tools to prevent and mitigate the effects of climate change in cities and to create urban health.

Image source: (Vakhtbovych 2018)

However, investigating thoroughly from the scientific basis of climate change to its implication for our societies is a strongly transdisciplinary task, which requires multiple sectorial competencies and coordinated investigations. Therefore, this study aims to use a transdisciplinary approach to investigate those strategies adopted so far to mitigate the impacts of climate change on human health in urban areas, identifying the main trends as well as the overlooked opportunities.

1.1. Mitigation and adaptation strategies for a changing climate

In this study, we refer to the nomenclature established by the Intergovernmental Panel on Climate Change (IPCC) to examine the interactions between natural and human systems, as illustrated in Figure 1, with terminology elaborated upon in Glossary. Here, *climate change* is a phenomenon that implies a long-term alteration of the general state of the climate, including internal or extrinsic *climate variability*. Climate change may be attributable directly or indirectly to anthropogenic activity and differs from climate variability due to natural forcings observed over a comparable time. Natural and human systems are further affected in terms of *exposure* and *sensitivity*, experiencing *potential impacts* which may be dampened by *autonomous adaptation* offered by the specific system. The *residual impacts* influence the *vulnerability* of the given systems, which then determines *climate policy* responses; these essentially attempt to reduce overall system vulnerability through *planned adaptation* measures, which can reduce residual impacts and vulnerability, as well as *mitigation* measures, that are those anthropogenic interventions aiming to reduce the generation and enhance the sequestration from the atmosphere of greenhouse gasses (GHGs).

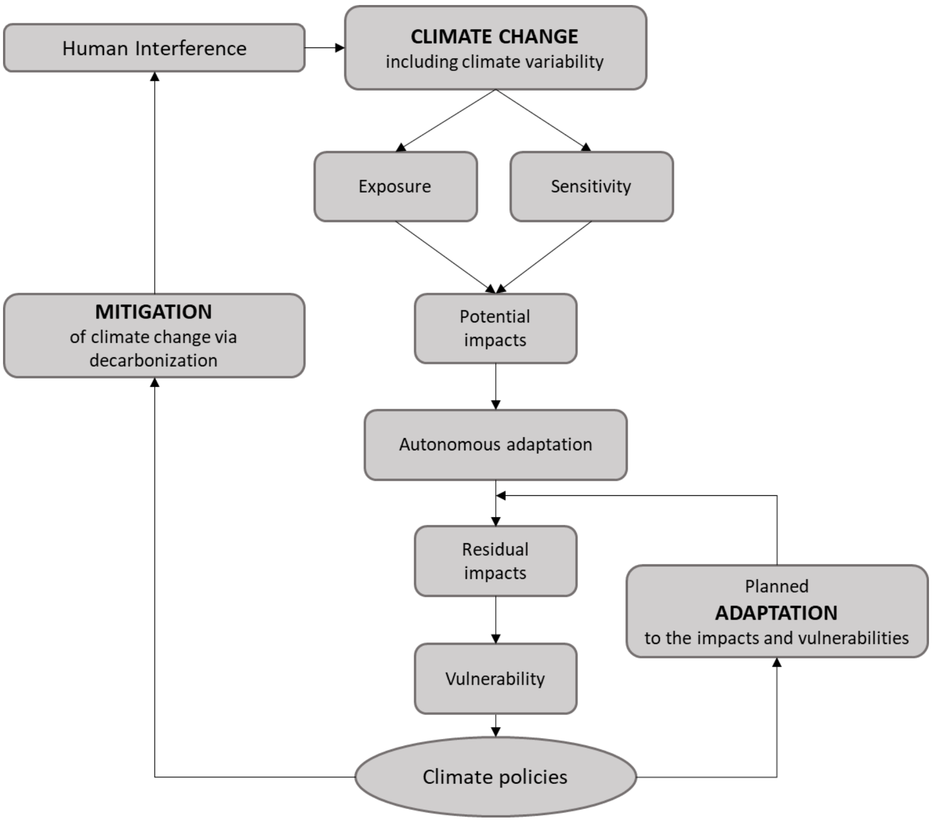


Figure 1. Relationship between the main aspects of natural and human systems and climate-change mitigation and adaptation. Modified from IPCC (2001a).

Implementing such measures alters the mode and degree of human interference in the fight to ameliorate climate change and its impacts. A number of strategies have already been deployed or are currently in planning stages, aiming to mitigate and/or adapt urban environments to climate change in Europe. The following sections summarise the main mitigation and adaptation strategies found in the scientific literature.

1.1.1. Measures, policies and economic instruments for the mitigation of climate change in the built environment

The final energy consumption attributable to the building sector globally has been increasing over the past decade (see Figure 2), possibly due to economic growth and social drivers. Also, the direct increase of carbon dioxide equivalent (CO_2-eq) emissions suggests that renewable energy and efficient electric technologies are not structurally replacing fossil fuel-powered systems. This seems in opposition to the gradual decrease of the energy density of the building stock, which is mainly due to stricter building regulations and technological enhancement (United Nations Environment Programme 2021). An explanation is in the demographic growth and urbanisation, which are characterising many countries in the world. The newly built floor area is increasing with a much faster growth rate than the reduction of the building stock energy intensity. Thus, optimising the use of space in buildings to reduce the need for new construction would reduce emissions by increasing the building occupancy's density and making more efficient use of the urban space besides reducing the related energy needs, GHG emissions and construction materials.

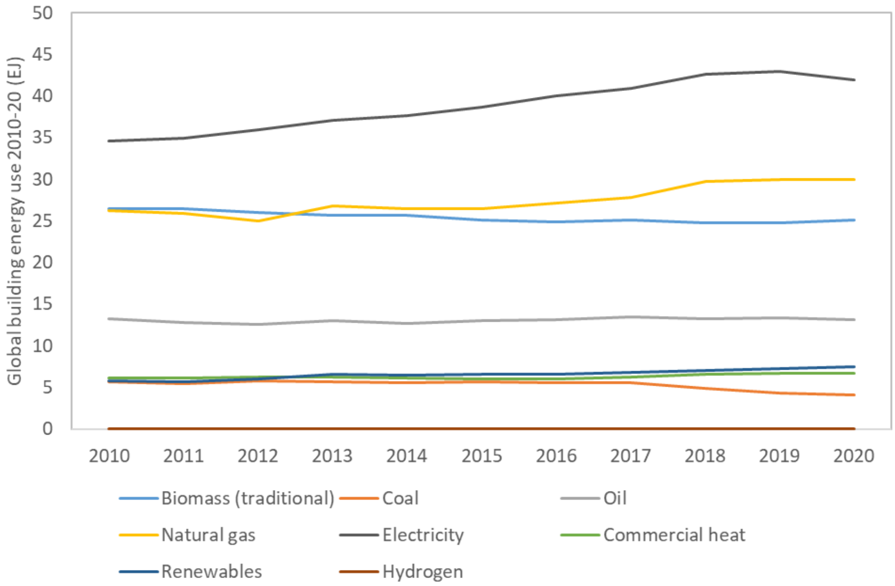


Figure 2. Global energy consumption of buildings per energy source.

Furthermore, the space heating and lighting energy consumption of buildings are in stark contrast to the need for space cooling, which has grown alarmingly in residential and commercial buildings in many regions of Europe, mostly in – but not limited to – central European and Mediterranean countries. For example, Cyprus presents the highest energy consumption for space cooling in Europe, with about 670 kWh per dwelling per year (Santamouris 2016). This can be attributed to several socio-economic and climatic drivers, such as an increase in noise and air pollution, higher atmospheric temperature and a significant decline in the price of air conditioning units, establishing mechanical ventilation as an attractive and affordable means of indoor cooling (Santamouris 2019b). Perhaps the most potent reason to seek mechanical ventilation in urban centres is the fact that in bigger settlements, pollution, noise and density make night ventilation a highly unattractive option. And although countries of the Mediterranean are somewhat adjusted to extreme summer heat and many buildings are equipped with cooling systems, the same cannot be said for central and northern Europe. In the past two decades, European countries unaccustomed to extremely high temperatures have experienced very high death tolls of primarily elderly populations as a result of inadequate cooling infrastructure in dwellings (Heaviside, Vardoulakis, and Cai 2016; Russo, Sillmann, and Fischer 2015; Thomson et al. 2019). For instance, traditionally cold countries of the Nordics, such as Finland, are now experiencing deadly heat waves, with their housing and welfare sectors being unprepared to withstand and address such hot conditions (Castaño-Rosa et al. 2022). Therefore, climate-induced phenomena, specifically the increase of the ambient temperature mean and the frequency and severity of heatwaves, will probably cause a surge of energy required for space cooling. Therefore, to achieve the Paris Agreement's objectives, concrete and effective mitigation actions are required to lessen the demand for energy of the building stock with energy conservation and energy efficiency measures, together with the decarbonisation of energy sources by a substantial shift toward renewable energy generation.

Low-energy, sustainable, and resilient buildings and neighbourhoods

The current central ambition in building science is to conceive affordable and high-performing buildings that use as little energy as possible and are capable of locally generating energy from renewable energy sources while remaining comfortable for their occupants and becoming resilient to climate changes. Technological innovation is a gateway to low-energy, sustainable and resilient buildings and neighbourhoods. While up to now, the main focus has been on the reduction of energy use for space and water heating, attention must be addressed to the predicted-to-significantly-increase cooling demands of indoor spaces. Buildings have to adjust to the new climate stresses while leaving as little an ecological footprint as possible. To develop such buildings with minimum energy consumption and greenhouse gas emissions, four main technological axes must be addressed:

- *Energy conservation measures* aim to optimise the building envelope to minimise thermal losses and maximise solar gains during the winter period, and conversely optimise solar inputs heat losses in summer, possibly with natural means;
- *Energy efficiency measures* aim to increase the average seasonal performances of HVAC systems in order to decrease the delivered energy required by a building;
- *Renewable energy measures* aim to facilitate the penetration and promotion of distributed renewable energy generation systems both integrated into building's fabrics and installed at the neighbourhood scale;
- *Smart control measures* aim to promote the installation of smart and intelligent technologies (smart controls, metering and appliances) for (i) improving the environmental conditions inside buildings through optimal management of technical building systems, (ii) contributing to energy

system flexibility by ensuring load reduction through energy efficiency, load shifting through demand-response, energy storage, and facilitation of smart charging of electric vehicles.

These measures shall also be financially affordable for developers and building owners and socially acceptable to occupants. A scale impact can be generated, coordinating and integrating different solutions beyond an individual building. At the neighbourhood scale, an excess of renewable energy generated locally can be effectively exchanged between different buildings connected through a smart grid, increasing the energy self-consumption at a communal level.

Energy conservation

Energy conservation is achieved when a building is constructed or refurbished so that heat is gained and prevented from leaking from the building envelope during the winter and expelled and prevented from penetrating the envelope during the summer. This can be achieved through multiple strategies and techniques, often in synergy with other technological axes (e.g., artificial intelligence or renewable resources) and innovative architectural concepts, urban and building morphology, building structure and materials (Dounis 2010; Chwieduk 2016). Energy conservation is a topic that has been examined under various lenses, but its essence remains the same: improving the building unit through an innovative holistic design, possibly integrating elements of traditional architecture and techniques proved suitable for the environment they are built in. Even in a warm climate like southern European countries, a high level of thermal insulation of the building envelope coupled with efficient control of solar radiation and an effective natural ventilative cooling has proved to be a successful strategy aiming to achieve a zero-energy target (Amirifard, Sharif, and Nasiri 2019; Santamouris 2019a). In this regard, it is required to establish a continuous building code improvement cycle to strengthen performance requirements every three to five years, to achieve zero-energy and, possibly, zero-emissions codes thanks to the solid implementation of energy conservation measures and the substantial integration of renewable energy into new constructions and existing buildings. In Europe, this is achieved through the Energy Performance of Buildings Directive (EPBD), which is regularly being updated with higher energy performance standards (European Commission 2021).

Energy efficiency

The goal of energy efficiency is to provide a given service by reducing the amount of required energy. In recent years, the performance of systems for the (space) heating, ventilation and air conditioning (HVAC) of buildings has substantially increased. Michel et al. (2010) have projected that the efficiency of split air conditioners in markets across America, Europe, Asia and Australia has improved by almost 3% per year over the last 15 years. This remarkable trend was possible thanks to the augmented efficiency of various components, gradually implemented in commercially available HVAC systems. It has been estimated that highly efficient compressors can improve the efficiency of room air conditioners by up to 19%, heat exchangers could improve it by up to 28%, the use of more efficient inverters by up to 25%, and more efficient thermostatic expansion valves can improve efficiency by up to 9% (Santamouris 2019a). Furthermore, the same study discusses an independent consulting work, projecting significant increases in energy efficiency ratios (EER) of various space cooling technologies typically installed in residential and commercial buildings (Table 1).

As the efficiency of this type of equipment increases, the International Energy Agency (IEA) estimates that the cost of cooling energy will significantly decrease by 2050. According to these predictions, achieving a carbon-neutral built environment between 2050 and 2070 may be technically and financially affordable, but, again, stricter regulations and codes are required.

Table 1. Current and future performance of various cooling technologies. Reproduced from (Santamouris 2019a).

Air conditioning (AC) type		**2013**		**2020**		**2030**		**2040**	
		Typical	**High**	**Typical**	**High**	**Typical**	**High**	**Typical**	**High**
Residential AC	EER	10.80	11.50	10.90	11.90	10.90	12.90	11.10	12.90
Residential air source heat pumps	SEER	14.00	22.00	14.50	23.00	15.50	24.00	16.00	25.00
Residential ground source heat pumps	EER	14.20	25.00	17.10	36.00	21.00	42.00	24.00	46.00
Residential gas heat pumps	COP	0.60		0.70		0.70		0.70	
Commercial Chillers									
Gas-fired absorption	COP	1.10		1.20		1.30		1.40	
Gas-fired engine driven	COP	1.70		1.80		1.80		1.80	
Centrifugal	COP,(F.L)	6.10	7.80	6.50	8.00	6.80	8.20	7.00	8.40
Reciprocating	COP,(F.L)	2.81	3.52	3.06	3.52	3.06	3.52	3.06	3.52
Screw	COP,(F.L)	2.84	3.46	3.10	3.55	3.20	3.66	3.26	3.74
Scroll	COP,(F.L)	3.02	3.17	3.08	3.23	3.17	3.29	3.23	3.32
Commercial Roof Top									
Air conditioners	EER	11.20	13.90	11.50	13.90	11.50	13.90	11.50	13.90
Gas-fired engine driven	COP	1.10		1.10		1.10		1.10	
Heat pumps	EER	11.00	12.00	11.00	12.00	11.00	12.00	11.00	12.00
Ground source heat pumps	EER	17.10	20.60	18.00	22.00	20.00	24.00	22.00	26.00

However, efficient governance of the sustainable transition is needed to ensure equity and increase the acceptability of energy-efficiency measures by all populations without penalising the poorer segments of society. European countries have already implemented either prescriptive and performance-based requirements on the minimum energy efficiency of technical building systems for space heating and cooling, domestic hot water production, appliance use, and lighting in their building codes.

Renewable energy

Effective exploitation of renewable energy sources is invaluable to substantiate a transition towards a sustainable built environment. In southern Europe and the greater Mediterranean area, with clear skies for the longest part of the year, many countries have embraced solar-powered technologies on a large scale. In fact, according to IEA statistics, solar photovoltaic (PV) generation has been steadily increasing since 2008 across Europe (IEA 2020). Electricity generation from solar PV exploded from approximately 7,485 GWh in 2008 to more than 139,200 GWh in 2019 (IRENA, n.d.). Nevertheless, these trends are not necessarily consistent with renewables integrated into buildings but also include larger-scale photovoltaic (PV) parks.

At the building level, renewable systems may include different types of solar applications (PV, solar thermal, solar water heating), geothermal, wind and bioenergy, with solar technologies being the frontrunner (Hayter, Kandt, and Kandt 2011; Chel and Kaushik 2018). Integration of renewable technologies in the building is ensured by the implementation of the EPBD, but in any case, solar-rich countries tend to incorporate solar water heater technologies, whether that concerns existing or new buildings, exploiting the huge potential of solar energy due to the region's geographic location and climate (IEA Solar Heating & Cooling Programme 2021). Asim et al. (Asim et al. 2017) showed that solar domestic hot water systems can be used not only for hot water used in households but also to generate pure drinking water.

As for renewable energy systems at the community level, several countries have implemented such projects and are already gaining momentum. For instance, in Greece, the concept of energy communities has been legislated, and several projects have either been launched or are being planned. Energy communities are by definition "open and voluntary", led by citizens, local authorities, or small businesses not otherwise involved in the energy sector and aim at generating socially and environmentally responsible electricity. Any type of renewable energy is considered to participate in the scheme. Although up to August 2020, 409 energy communities were established in Greece, less than 10% were generating energy at the time (Electra Energy 2020) due mainly to implementation shortcomings that require research support to be overcome.

Smart control

Smart technologies and services have penetrated virtually every aspect of the modern lifestyle, from transforming government services into smart services to integrating smart technologies in buildings. These technologies are not only restricted to newly built facilities but are also getting available for existing buildings thanks to substantial research support (see, e.g., European Commission (2020)). On the building level, smart-enabled systems allow for better management of indoor environments, higher thermal comfort, healthier environmental conditions, and increased overall building energy performance. Scaling up from the building to the neighbourhood scale, the installation of smart meters and smart grid offers the possibility of distributing excess renewable energy with an increase in the neighbourhood's self-consumption and optimising the neighbourhood's load with the implementation of demand-response control logic. In general, smart technologies, such as smart controls, smart metering and smart appliances, saw a global explosion of interest between 2009 and 2012, while the market for advanced green IT technologies is exhibiting similar trends (Singh 2012; Santamouris 2019a). Often, the concept of "smart cities", according to which existing urban centres need to transition to more sustainable versions, has been implemented in various regions of the world. New cities are being planned or are currently being developed in a bid to create new urban environments that are already smart, green and efficient. For instance, in Kuwait, the Middle East's first green and smart addition is under development in the South Saad Al Abdullah smart city, and the United Arab Emirates (UAE) planned Masdar city in 2006, aiming to establish it as an archetype of renewable-based energy solutions, free from oil (Foster+Partners 2021; Hub 2017). Recently, a new $500 billion megacity was announced by Saudi Arabia, largely funded by the country's Public

Investment Fund. Neom is described as a living laboratory for hub and innovation and a sustainable ecosystem for living and working, integrating cutting-edge technologies and attracting sustainable tourism (NEOM 2020). Although these cutting-edge advancements embody depictions of what the future might look like, a question remains whether they will be truly sustainable. Equity in society is one of the three pillars of sustainability, and these smart new cities may not be inclusive of all population groups.

The growing body of research has a common goal: to develop systems able to effectively and resource-efficiently manage the needs of inhabitants at the building and the neighbourhood level.

Circular economy

A circular economy model is based on the principles of reducing waste, keeping products and materials in use, and regenerating natural systems. In the building sector, this concept includes closing water, energy, and material cycles while deploying decarbonisation strategies accounting for the building's whole lifecycle. In this respect, three main aspects are examined:

- *Material efficiency measures* aim to reduce material use;
- *Low-carbon materials measures* aim to foster the development and use of innovative low-carbon, durable, and affordable construction materials;
- *Carbon capture measures* aim to promote carbon capture and utilisation in construction materials.

If these sets of measures are tackled together, the construction sector can become a low-waste, low carbon-emitting realm, producing affordable and long-lasting structures with minimum carbon footprints throughout their lifecycle.

Material efficiency

In the building sector, the most carbon-intense materials are steel and concrete, which are often overused to assure higher standards in structural resistance and stability. This "over specification" also occurs when labour costs for designing more material-efficient designs need to be reduced, resulting in denser buildings with more material than needed. In order to reduce material and the accompanying greenhouse emissions (embedded and generated during construction), leaner designs are required. For example, it has been shown that buildings could be designed with up to 46% less steel without putting at risk their structural integrity (Moynihan and Allwood 2014; Dunant et al. 2018). Furthermore, current building designs could reduce concrete use by up to 10% (Group 2020). To apply these material-efficient practices in real-world conditions, building standards need to be revised, and the use of the computer-assisted design of leaner buildings should be enforced. Another approach is reusing, into new buildings, materials such as disassembled steel and concrete components from existing buildings, thereby reducing the need for new products. Currently, very little material is being reused in the construction industry; however, the wide implementation of this practice holds great environmental benefits. This is because the processing of demolished buildings and regenerating materials are very energy-intensive. In contrast, if new standards were in place to ensure more convenient disassembly and reuse, vast amounts of energy and material could be salvaged. It has been estimated that under a circular economy model, up to 90% of building materials can be disassembled and reused (Guldager Jensen, Sommer, and 3XN 2016). Adopting universal standards that allow design-for-disassembly practices would be a success story, facilitating "urban mining" and extraction of material from cities for cities. Complimenting actions would be needed to succeed in this, for example, creating databases and material banks so that there would be available information on where to find the materials or components needed for new construction. A third approach is the use of optimisation protocols in the design of the structure of the building. For instance, topology optimisation methods offer the possibility to compute the distribution of the material in the structure in such ways that it reduces the amount of material in use by up to 7% (Junk, Fleig, and Fink 2017).

Low-carbon materials

Aside from redefining the design procedure, the materials used in constructions require energy-intensive processes to be produced and, therefore, typically have high carbon footprints due to their embodied energy. New materials, such as different cement types, are considered climate-friendly and low-carbon, while their durability and affordability are not jeopardised. Studies have shown that cement made from locally available minerals and industrial wastes could substitute conventional cement, mitigating large amounts of CO_2 that would otherwise be released into the atmosphere during the manufacturing stage (Naqi and Jang 2019). There are numerous innovative products, such as bio-cement, each of which has its benefits and disadvantages (Hasanbeigi 2012; Madani Hosseini, Shao, and Whalen 2011). Large-scale utilisation of these products is difficult at the moment, not only due to a lack of modernised standards but also due to a lack (1) of policy incentives on price, (2) of information about the composition of the materials used in existing buildings, and (3) of demand for climate-friendly alternatives, and the long delay between the implementation of actions in a building and their effect on waste management that manifests itself several decades later (European Environmental Agency 2020).

Carbon capture

The technique of carbon capture and storage has been implemented in oil-rich countries such as Saudi Arabia, where existing fossil fuel plants are adopting this measure to sequester large amounts of CO_2 while enhancing their own oil recovery methods by maintaining high pressure in the reservoir (Aramco 2020). Moreover, the UAE aims to drastically reduce greenhouse gas emissions by implementing carbon capture technologies to produce blue hydrogen (Di Paola 2021). Even the building sector can become, to a given degree, a carbon sink. It is, therefore, possible to capture carbon in building materials and components. An interesting example is the adoption of timber as the structural material in buildings, replacing concrete and steel. Wood absorbs CO_2 from the atmosphere as it grows, and its use as a building material implies a store of carbon in the building fabric, making buildings themselves carbon sinks. Another interesting approach is the recycling of cement from demolition waste using efficient recycling processes. Waste concrete can be crushed, and the extracted cement can be reused in new buildings. These operations can be performed on the construction site since concrete recycling technologies already exist, and would incorporate existing material (with its own embodied energy) into the new building components and would tremendously reduce the need to transport materials on-site. Zooming out from the materials to the interventions and whenever possible, deep renovation of existing buildings should be preferred to their demolition and subsequent reconstruction. Currently, only 1% of the old building stock is being renovated in the EU. However, the benefits of deep energy refurbishment extend beyond the structure's energy performance into an extended lifetime and a significantly lower carbon footprint. In the EU, the Renovation Wave is expected to improve the meagre renovation rate, and other countries of the world may benefit from the new design and renovation practices that will be established to meet this target.

Urban design, land-use planning and reduction of the UHI

Urban design is fundamental for healthy cities and the well-being of their citizens, but simultaneously, when poorly developed, it can be the cause of non-functional spaces, trapped heat and pollution and even increased CO_2 emissions. Local urban warming and the phenomenon of Urban Heat Island (UHI) are frequently blamed for increased morbidity and mortality (Wong, Paddon, and Jimenez 2013). In southern Europe, where summer heat has always been near the extreme, poor urban development can be the deciding factor for human behaviour; for example, deciding to drive a car instead of walking a short distance. Intense urbanisation and uncontrollable land-use change are also factors impacting the shapes of cities, usually negatively because land-use changes are not holistically considered, resulting in a vast amount of people and vehicles densely concentrated in relatively small areas. The need for an appropriate and adapted urban design becomes even more urgent under the threat of more frequent and more extreme heat events due to global warming, which sums up to UHIs, already observed in almost all countries of the Mediterranean region (Santamouris, Cartalis, and Synnefa 2015; Potchter and Itzhak Ben-Shalom 2013; Moghbel and Shamsipour 2019). UHI can lead to heat stress, imposing physiological and psychological health impacts on urban dwellers. Mitigation strategies of UHIs include an array of technological solutions, such as cool roofs and pavement materials, green roofs, urban greenery, and water use to dissipate heat (Santamouris 2020). Of course, in arid regions, the use of vegetation and water resources should be carefully considered jointly with the water scarcity issue, for example, by taking advantage of recycled wastewater.

As an example, Riyadh, Saudi Arabia's capital, is one of the warmest cities in the world, and, during the summertime, the temperatures exceed by far comfortable levels. This is due to several factors, like its proximity to the desert, the limited urban vegetation and greenery due to water scarcity, and the vast use of conventional materials characterised by low-albedo, like black asphalt and concrete constituting the urban surfaces. To face the current and future challenges posed by climate change, it has commissioned an ambitious and technologically-advanced mitigation plan to alleviate overheating, reduce the temperatures in the urban spaces, and make the city a more liveable and sustainable place for its inhabitants (Henwood 2020).

Sustainable mobility

Urban transportation systems are the backbone of modern lifestyles, whether that concerns urban dwellers or professionals commuting daily between their out-of-town homes and their workplaces. Sustainable mobility essentially transfers the principles of sustainable development onto the transport sector, aiming to create systems that "[…] *meet society's economic, social and environmental needs whilst minimising their undesirable impacts on the economy, society and the environment*" (Council of European Union 2006).

Modal shift, shared mobility, mobility services, traffic optimisation

One of the primary modes of transport in Europe is passenger cars, with some exceptions where public transportation systems have successfully moderated urban traffic. Even in such cases, the transition hasn't been completely successful. In Athens, Greece, for example, although extensive bus and metro networks exist, traffic congestion, noise pollution and vehicle emissions are still very high (Golias 2002; Sotiropoulou et al. 2020). Urban transportation systems alone cannot effectively create a modal shift, and a suite of policies and incentives is also needed. For example, research has proposed technical solutions to improve "soft mobility", which is the option to walk or cycle instead of using automotive transportation (Gallo and Marinelli 2020). Technological innovations and the growing ecological awareness of young generations also facilitate the use of shared public and private mobility, such as micro-mobility and car-sharing. In parallel, satellite services and smart vehicles also provide live feeds of traffic patterns so that traffic may be optimised by the users themselves.

High-efficient, low-emission, smaller vehicles

Other than traffic moderation and the modal shift, sustainable mobility also requires improving the main mode of transportation, the passenger car. Vehicle designs are constantly improving aerodynamically, and their engines are becoming more efficient and smaller, essentially consuming less fuel but offering a high power output (Mueller and DeLaurier 2003). Moreover, low-emission vehicles, such as hybrid and electric cars, which have gained a high technology readiness level and hit some markets, are becoming viable alternatives (Boretti 2019). However, these non-conventional mobility options are disruptive to the current global industrial, transport, and energy systems and their effective penetration in the automotive markets has not yet been as profusely accepted as conventional ones in many parts of the world. Even when electric vehicles are endorsed by consumers, and although their mechanical efficiency is higher than internal combustion cars, their overall GHG footprints greatly depend on the energy mix used to produce electricity. Furthermore, a car with a lower weight can offer greater offsets of emissions, whether conventional or not, relative to those saved by incentivising a fast transition to electric vehicles, unless the electricity grid is extremely decarbonised. Lighter vehicles offer immediate savings on the road and do not depend on the rates of decarbonisation of the electricity grid (Serrenho, Norman, and Allwood 2017).

1.1.2. Measures, policy and economic instruments for the adaptation of the built environment to the climate change

There are many ways to classify adaptation strategies for the urban environment. In this document, we follow the approach proposed by Rosenzweig et al. (Rosenzweig et al. 2018), which foresees four categories: (1) technology-based strategies, (2) ecosystem-based strategies, (3) community-based strategies, and (4) policy-based strategies.

Although classified in distinct categories for a more straightforward description of their main features, it is important to stress that interplay between these strategies must be encouraged in order to amplify the effects of individual measures. If, for example, a technological measure is not adequately supported by the community- or policy-based strategies, then its adoption will never reach desirable or even expected outcomes.

Technology-based strategies

This category of measures relies on the potentiality and efficiency of technological devices and systems to mitigable locally the impacts of climate-induced phenomena.

Resilient energy installations

Ensuring energy security and resilience under climate change is a critical challenge due to extreme weather events making cities more vulnerable to loss of electrical power and damage to essential infrastructure. If the supply of electricity is lost, a cascade of additional problems is created: potable water supply, food production, transportation, sanitation, communication and health care systems, to name a few, can be disrupted. To deal with these hazards, infrastructure delivering energy to cities must be upgraded and maintained to ensure resilient energy installations. Increased redundancy levels and flexibility will be required from distributed generation systems so that they are able to cope with service disruptions or city-wide blackouts. Zhang et al. (Zhang et al. 2017) have reviewed the developments in energy interconnections in the Middle East, noting that renewable energy deployment has increased manifold in the last decade, including large-scale hydro, wind and solar (both photovoltaic and concentrated solar power) projects. In fact, measures such as feed-in tariffs and net metering are used to promote renewable energy among consumers. However, the authors note that concurrent improvements in grid infrastructure are required to achieve better uptake of renewable technologies. More local solutions to such design or service deficiencies could be provided through community-scaled renewable projects, which could deliver essential services such as potable water or emergency healthcare equipment, at least until the outage is resolved. These small-scale renewable stations can even electrify remote areas of developing countries, where main grids have not reached yet or increase local capacity.

Water and wastewater adaptive management

Climate change imposes risks on urban water systems in several dimensions. The increasing temperatures are responsible for higher evaporation rates affecting watering demand, availability, and freshwater quality; current precipitation patterns are expected to shift, and cities will also have to deal with surface-water and groundwater availability and conditions. Water as a resource in hot arid cities of Europe has been at risk for some time, and that danger is now even greater. Adaptation strategies will have to address this risk in two dimensions: ensuring there are adequate quantities to sustain livelihoods and ecosystems and reconsidering what is adequate, identifying different water needs for different uses. Specific options addressing the first dimension, meeting the demand, include desalination, increasing reservoir capacities, promoting green infrastructure, and improving existing systems' efficiency. One of the most prominent adaptive options is reusing water and integrating wastewater (or greywater) in households. This has been a topic of multiple research studies in regions with prevailing arid climatic conditions (Fatta et al. 2004; Shomar and Dare 2015; Al-Ismaili et al. 2017). For example, Batisha (2020) estimated that, in Egypt, from 4.15 to 8.30 billion cubic meters of greywater can be added to the country's water resources; an opportunity that can facilitate a sustainable transition to mega urban projects.

Pluvial and coastal flood protection

Historically, the sea and rivers attracted settlers due to having water resources nearby, and so many cities have developed near the coastline and major rivers. As a result of rising sea levels, numerous European cities are located within potential floodplains. The intensity of flooding from heavy precipitation is intensified in urban areas due to the development of floodplains, removal of minor river channels (channel straightening, which leads to concentrated flow in the main river) and the very high share of impermeable surfaces (e.g., concrete, asphalt), which convert incoming precipitation into runoff (Gharbia et al. 2016). For example, soil sealing in the EU has been increasing for decades; land cover surveys conducted for the years 1990-2006 revealed that more than 1 000 km^2 of land was taken annually, half of which is estimated to have resulted in soil sealing. To put this into perspective, the overall amount of sealed surface area in 2006 was estimated at around 100 000 km^2, representing 2,3% of EU territory. This was associated with an increase in urban areas in the EU, calling for more rigorous assessments of the dangers of surface sealing in city centres. A lack of suitable water management strategies in urban centres could incur substantial losses if flooded, possibly affecting vulnerable populations disproportionately. Rapid urbanisation means increasing housing demand, which is often met by unsuitable construction sites, for example, over water runoff land, therefore obstructing proper stormwater drainage in powerful waterfalls. Moreover, a separation between stormwater and wastewater networks is required in urban centres to manage fluctuating water volumes more efficiently and prevent health risks associated with flooding events. This separation should come with downstream treatment using wetlands, ponds, filtration, or other suitable systems (particularly to control substances washed from pavements by rainwater). Research efforts on this topic have focused on modelling techniques for the development of strategies for urban flood management (Radmehr and Araghinejad 2014); for instance, rainwater harvesting based on precipitation rates has been suggested in Tehran, Iran, as an effective approach to adapt to urban flooding events (Hossein, Mehrabadi, and Motevalli 2012). Moreover, a continental-scale European Flood Awareness System (EFAS) was established at the end of the 20th century, aiming to “support preparatory measures before major flood events strike, particularly in the large trans-national river basins and throughout Europe in general” (Copernicus 2022).

Climate-proof transportation and infrastructure

Climate hazards that can disrupt transportation systems in cities include extreme precipitation, flooding due to sea-level rise or land subsidence, coastal storms and extreme heatwaves. On the flip side, urban transportation accounts for large amounts of greenhouse gases, further contributing to urban warming and pollution and continuing the cycle of impact and cause with climate change. Adaptation strategies in the transport sector may have a double effect: reducing climate change impacts on urban transport and reducing subsequent consequences (Mehrotra et al. 2018). Providing climate-proof transportation and infrastructure means that adaptation solutions are needed to face the different climatic hazards. For instance, public transportation is reinforced in areas where extreme heat is often encountered, either by means of mechanical ventilation, artificial shelters or natural canopies of vegetation (Moretti and Loprencipe 2018; Lanza and Durand 2021). Moreover, flooding could be addressed by implementing early warning systems to prepare populations and traveller information systems which help to incorporate flexibility into the transportation network, shift to alternative transportation modalities, but also by adjusting the infrastructure and updating land use regulations limiting the development of the transportation network in vulnerable areas, using pumps where appropriate, creating dikes and barriers, enhancing the performance of drainage systems and having the option to re-channel water. Similarly, behavioural and structural options can be combined to mitigate the impacts of storms. In addition to early warning systems, appropriate parking facilities to securely store vehicles temporarily and allow for modal shift, adherence to emergency evacuation plans can be employed, as well as the development of contingency plans for increasing preparedness of equipment and material for rapid repair and rebuild of damaged facilities. Finally, as a response to rising temperatures and rain flushes, the selection of materials should be further considered to increase the soil's permeability, increase albedo for reducing the heat absorbed in infrastructure, and select heat-resistant materials for better and climate-proof transportation infrastructure.

Ecosystem-based strategies

Ecosystem-based adaptation strategies encompass a broad set of nature-based measures harnessing biodiversity and ecosystem properties to enhance urban systems and communities' resilience against climate change (International Union for Conservation of Nature 2017). Restoring ecosystems in urban environments can reduce vulnerability, increase resilience, and reinforce urban populations' well-being by integrating nature into the urban texture. This section will look at three types of ecosystem-based strategies: (1) green roofs and walls, (2) green spaces, and (3) river restoration in urban areas.

Green roofs and walls

These technological solutions allow for building elements to support living vegetation, which benefits the building’s services and improves its environmental quality. For instance, green roofs have been proven to reduce indoor fungal aerosol concentrations, and they are also associated with carbon sequestration, rainwater retention and energy conservation (Karteris et al. 2016; Pyrri et al. 2020). It has been shown that intensive green roof systems can use up to 70% less energy compared to buildings with black roofs in Mediterranean climates (Silva, Gomes, and Silva 2016), while some of the benefits of green roofs are difficult to monetize since they have wide-ranging implications, such as enhanced biodiversity and stormwater retention resulting in urban flood protection (Ziogou et al. 2018).

Green spaces

Intense and rapid urbanisation has resulted in large-scale land-use change, urban sprawl and prioritisation of economic development rather than human well-being. In many parts of the world, living in urban centres means having little access to nature and its benefits. Some of the most substantial urban hazards, such as extreme heat and air and noise pollution, could be mitigated through urban design that promotes greenery pockets in the urban textile (WHO regional office for Europe 2017). Green aeration corridors can alleviate the adverse effects of UHI, improving outdoor thermal comfort and conserving energy in adjacent buildings. Vegetation further enhances carbon removal from urban environments and enhances water retention, improving cities’ resilience to flooding and providing viable stormwater management options. Green spaces in cities also afford urban dwellers the ability to exercise more regularly increasing their mental and physical health and stimulating socialising and life-enriching experiences, something which is often lost in megacity habitats (Rostami et al. 2014; Akpinar 2016). The role of urban green spaces offering shaded areas has also been associated with more diverse and frequent daytime activities in environments otherwise too harsh due to intense solar radiation while also being avoided at night due to safety concerns (Bahriny and Bell 2020).

River restoration in urban areas

As populations traditionally settle near rivers, the development of settlements into urban centres comes at a cost for the rivers. Rivers now enable industrial development, supply drinking water and discharge urban waste, but these practices often lead to major environmental degradation of the rivers themselves. The physical structure of water bodies is altered due to land-use change and to create transportation infrastructure; even water quality and quantity are negatively affected, and the biodiversity of their ecosystems is threatened no longer being able to sustain multiple species of wildlife (ECRR 2020). Restoration of urban rivers can be achieved by reducing the share of impermeable surfaces and returning rivers to their natural states. Further actions improving sustainable drainage in urban environments have been shown to enhance river restoration, including green roofs and micro reservoirs to allow for localised storage of rainfall volume (Veról et al. 2020). Among the benefits observed in the physical environment surrounding urban rivers, Giannakis et al. (Giannakis et al. 2016) have shown that thermal comfort can be improved significantly, therefore boosting urban dwellers' well-being.

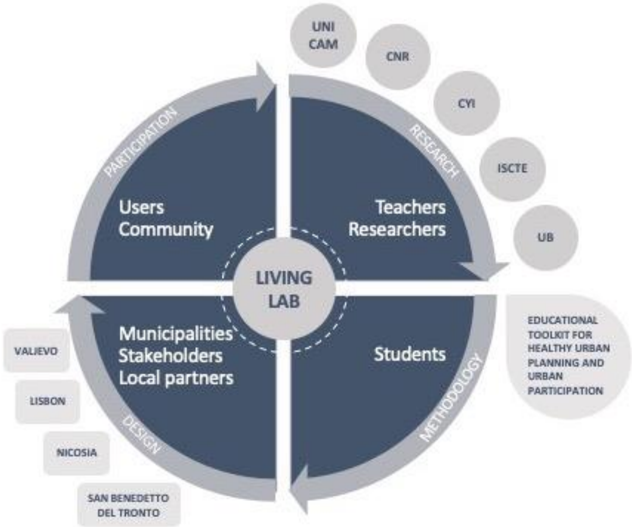
Community-based strategies

Stakeholder engagement in urban adaptation

As in any endeavour, stakeholder engagement is vital to apply adaptive measures in the urban environment successfully. Indeed, stakeholders represent individuals or groups capable of affecting policy development and implementation or otherwise could be affected by it (Bryson 2004). Obtaining stakeholder support influences the perceived legitimacy of policy options and their political feasibility and raises the adaptive capacity of society to cope with climate changes. This effect is amplified under the cooperation of public and private bodies (Mees, Crabbé, and Driessen 2017). For instance, in flood risk management, the involvement of local stakeholders is seen as a valuable complement to the capacity of the local authorities (Begg 2018). Particularly, when it comes to the local level, engagement of public stakeholders is highly effective because it allows insight into the needs of communities and can offer tailored solutions. In this respect, it is also essential to ensure that vulnerable groups or minorities are adequately represented and have good reason to participate in the co-design and decision-making process of adaptive actions. Therefore, community-based adaptation is an important locally-oriented part of managing climate change impacts with the capacity to address the limitations or inadequacies of central governmental intervention.

Box 2: Living labs, co-participation and co-design

Living labs are almost synonymous with co-participation, either within co-design experiences or within co-implication. It implies an actual participation of the people involved in projects, beyond researchers or other project executors (from the academy, state institutions or private institutions).



They usually combine different methods – interdisciplinary is welcome. But, more than a method, it is a project approach applied by researchers and requires the collaboration of public and private partners drive innovation with co-creative approaches in real-life settings. This allows for a participatory and democratic framework of policy and governance, something required in the bid to sustainable urban development.

Since living labs imply a real participation, they also include users in the evaluation process. To be part of all project phases is a living lab requirement and, in the end, users feel more attached to the whole process. A number of Living labs use toolkits as a specific methodological tool, which can be expanded to public administration (education, health, housing).

Living lab are sometimes synonymous to urban labs or other similar terms, based on open science and the involvement of community at the early stage of research. The central idea is to give "Power to people", that was the title of the speech held by Creative Commons CEO Catherine Stihler during the annual United Nations Climate Change Conference (COP26), she "discusses how open access to research and data, and the ability to widely share context-specific approaches, are key to unlocking sustainable solutions for every facet of climate change and preservation of biodiversity". At the moment, there are various existing platforms and projects, as well as a European network of Living labs
Sources: (Dekker, Franco Contreras, and Meijer 2020; Jennie Rose Halperin 2016; Stihler 2021; Public Lab 2022; European Network of Living Labs 2022)

Education and capacity building

The United Nations Framework Convention on Climate Change addressed the need for education, training and public awareness of climate change and its effects in 1992, calling for public participation. Since then, the key role of education in climate change mitigation and adaptation has been highlighted many times, especially at the community level. Knowledge sharing and skill-building allow individuals and communities to make informed decisions on the realistically best ways to adapt against climate change in a local context. The concern of sustainability in urban environments, that is, creating urban habitats that can support healthy lifestyles for upcoming generations, should be integrated into educational curricula through formal and non-formal educational channels. A mixture of participatory, experiential, critical and inclusive education is considered crucial for children and adults alike (Mitchell and Borchard 2014). Sufficiently educated individuals can then interact with their local environments and establish a symbiotic relationship where their actions improve local conditions. They, in turn, benefit in case of extreme events. For instance, individuals with higher education were linked with less vulnerability to drought and higher appreciation for adaptation measures (Lasage et al. 2015).

Health and livelihoods

Now more than ever, community-based adaptation strategies are pivotal in strengthening and improving public health and livelihoods and in limiting the detrimental impact of shocks (like the current global pandemic) on society and the economy at large. For example, many reviewed studies have investigated the role of community-based approaches in adaptations to vector-borne diseases in the changing climate. One such example is the role of community participation in the case of malaria, where community engagement and local prioritisation were found to be significant factors in disease control. In other cases, projects engaging indigenous communities reported significant contributions to health behaviours such as boiling water or raising awareness on health and vulnerability issues (Ford et al. 2018). Finally, climate change impacts such as floods are very often destructive to the livelihoods of farmers and populations dependent on agriculture; therefore, local adaptive action is one of the most effective ways to reduce vulnerabilities, for instance, through capacity building of local communities (Shaw 2006).

Policy-based strategies

Emergency risk reduction

In the last decades, catastrophic events have become more frequent, with the World Health Organisation (WHO) estimating 800 major events per year worldwide. In order to deal with such emergencies, an “All-Hazard/Whole-Health” approach is suggested to adequately prepare for any hazard scenario (natural, biological, technological or societal) and under a unified emergency preparedness and response unit (WHO 2007). For the region of Europe, such national and international strategies are most relevant because of the increased frequency of natural disasters such as dust storms, heat waves or extreme rainfall, political instability or the most recent public health crisis. The mandate provided by WHO calls its member states to:

- “engage actively in the collective measures to establish global and regional preparedness plans that integrate risk-reduction planning into the health sector and build-up capacity to respond to health-related crises” (WHO 2007);
- “formulate […] national emergency-preparedness plans that give due attention to public health, including health infrastructure […]” (WHO 2007).

Thus, each nation’s responsibility is to provide detailed emergency action plans on risk reduction and coordinate at the global level under WHO guidelines. European countries could further coordinate regionally to ensure equitable protection and support to the most vulnerable populations or minorities often excluded from healthcare. Such action plans should be part of long-term commitments to building up the capacity of health sectors, with the responsibility lying with all national actors, public or private, and across multiple sectors.

In Europe, disaster risk reduction is mainly addressed through the "EU Strategy for Supporting Disaster Risk Reduction in Developing Countries" and the Communication on a "Community Approach on the Prevention of Natural and Man-Made Disasters", which is governed by similar principles of cooperation among national and international actors with emphasis on vulnerable groups. This strategy tackles natural and technological hazards and outlines the sub-sectors needed to be addressed by each member state (DG ECHO 2013). For instance, local disaster management components include local capacity building and training (e.g., civil defence programs), early warning systems, and mapping and digitalisation of relevant processes and events. Other sub-sectors encompass establishing institutional linkages and advocacy, raising public awareness through information, education and communication activities, developing small-scale infrastructure and services, creating banks of emergency and relief items and protecting livelihoods and economic assets.

Insurance

A strategy to increase the resiliency of urban centres should include insurance when dealing with the consequences of climate change and extreme events. Insurance may act as financial compensation for losses so that those affected can recover faster following a severe weather event, or as an incentive to reduce risk, through added requirements in the insurance agreements (e.g., the insured should take action to reduce risk, or their pay-out will be lower) or through price signalling (e.g., an insured owner who has renovated a facility strengthening its envelope will be paying a lower premium) (European Commission 2018). Promotion of risk awareness and reduction and public-private partnerships and collaboration across different domains of organisations can boost the efficiency and effectiveness of insurance schemes related to private property or agriculture. Moreover, cities may also play a role in improving vulnerability assessments of municipal infrastructure and transparently sharing risk, hazard and impact data with relevant stakeholders, increasing capacity building with regard to insurance and climate resiliency. It has even been suggested that multiple cities could collaborate, pooling their insurance and spreading their risk (European Commission 2018).

Urban planning and zoning regulation

Land-use change is often associated with increased risks of climate change impacts, such as flooding, landslides, heat stress or water scarcity. Therefore, integrated land-use planning strategies in urban areas are essential in order to prevent extensive damage. To achieve this, urban planners need to anticipate climate change impacts in the local context, adjusting a city's plan accordingly. For example, urban planning considering in advance the city's water balance could address flooding and improve local water resources simultaneously through modifications in permeable surface areas, reforestation for improved water retention via root systems, and water channel redistribution. Moreover, extreme heat can be mitigated by integrating green corridors and open spaces in the urban fabric or using heat-reflecting materials. Zoning regulation is another tool that is already used to reduce exposure to risks, for example, by prohibiting development in high-risk areas for flooding or imposing restrictions on the building design. However, zoning regulation may require periodic revision to reflect local changes better and ensure higher urban resilience in case of danger. These principles may be applied against extreme events such as flooding, landslides or fire hazards that are critical in many European cities.

Design guidelines

Aside from allowing building construction in suitable sites, measures should be taken to safeguard the integrity of buildings and their surroundings. In the case of zoning restrictions, this translates to restrictions that improve resiliency against extreme events, as mentioned above. Nevertheless, urban centres remotely at risk of extreme events should also adhere to design standards, such as minimum floor heights and maximum amounts of floors, seismic adaptation, waterproofing, and evacuation pathways. For new buildings, such design guidelines should be implemented at inception, but guidelines should also apply to existing buildings, considering and protecting the most vulnerable population groups. In the EU, standardised construction guidelines have been integrated with climate change adaptation measures since 2014, fostered by European Standardisation Organisations CEN and European Committee for Electrotechnical Standardization (CENELEC) (Climate-ADAPT 2021).

1.2. Cities reimagined

The future of cities has been explored in many settings and from new perspectives, especially after the pandemic, which started in 2020. This section introduces the case of the 'CCUHRE–Climate Change & Urban Resilience' research project, which has dealt with two different approaches to the future city; envisioning what an urban centre will feel like in terms of thermal stress (Cocci Grifoni, Caprari, and Marchesani 2022) and what it should feel like in terms of continuity of open and common spaces and services (D'Onofrio and Trusiani 2022). Both studies are based on the city of Ascoli Piceno in Italy, and specifically the public neighbourhood of Monticelli. While on the one hand, the case of an urban centre at risk is presented, on the other hand, the potential for a higher level of spaces and services is explored.

The first part of the project employed a multidisciplinary approach combining geographic information systems (GIS) and computational fluid dynamics (CFD) tools to identify hotspots of urban heat and simulate the effects of climate change in a neighbourhood of an Italian city (Cocci Grifoni, Caprari, and Marchesani 2022). The researchers conducted fieldwork through remote sensing to describe urban heat island effects, incorporated a mapping approach and included 'moments of listening' in their work, collecting the views of the community and further detecting critical aspects of living in the area, risks, opportunities, and desires. Two maps were created; the Green Atlas and the Risk Map. The former describes greenery at the vertical and horizontal planes, whereas the latter incorporates demographic data, detailed analysis in a CFD environment and the insights of the participatory process describing the collective intangible heritage. This work revealed an area at risk, characterised by intensive buildings and impervious or vacant areas, where vulnerable groups are concentrated in the central study area, which is more susceptible to the effects of climate change. In developing urban risk maps and identifying the social demands of the neighbourhood, the municipal urban agenda can be reconfigured to respond to the present and future needs of the area and its residents. The main results of this study are presented below; once the morphological/climate indicators were finalised, the macro-scale study turned to the creation of two main cartographic drawings: the Green Atlas and the Risk Map. The former was produced by geospatially relating the DSM and Surface Atlas (Figure 3).

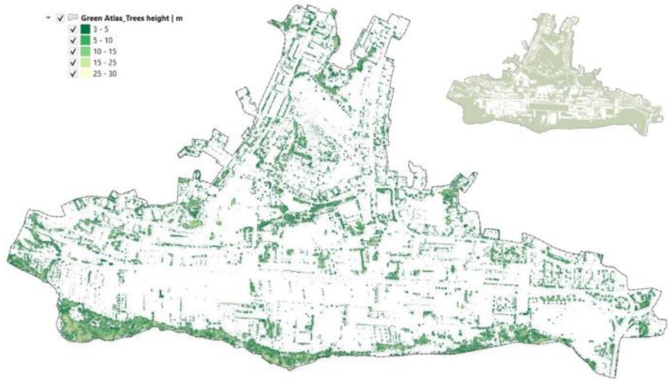


Figure 3. Green Atlas of Monticelli. In the centre, the digital census of trees (SAVI + DSM); at the top right, the 'horizontal' green is identified by the SAVI index (Cocci Grifoni, Caprari, and Marchesani 2022).

The last step, the final map (Figure 4), combines and returns all qualitative and quantitative information considered to be above the 'critical threshold' on the neighbourhood scale for awareness of the population at risk; climate data (GR, DSR, LST) and urban morphology (SVF, Green and Surface Atlases).

Figure 4. The combined GIScience-CFD simulations approach: from the Urban Risk Map investigation to the CFD micro in-depth analysis simulations. Base map source: Google Maps (Cocci Grifoni, Caprari, and Marchesani 2022).

With reference to the areas of investigation identified above, the results of the CFD simulation processes concerning the total bioclimate comfort and the various competing variables are reported below (Figure 5). The values of potential temperature range from about 20°C in open areas to 28.6°C in urban areas. Surface temperatures peak at 50.4° C on surfaces with a low albedo (e.g., asphalt) and are lowest on natural surfaces. The average radiant temperature is only moderated in trees, where the minimum value is around 33°C; elsewhere, it rises to around 64°C. Relative humidity are also related to greenery, where it reaches almost 66% while it drops to 46.6% in urbanised areas. The wind field has maximum values of 3.2 m/s in the most exposed areas (in line with the initial data), and, in the presence of buildings, there is a calm wind. Lastly, the UTCI comfort index, which summarizes the above values, ranges from a minimum of 23.8°C to 37.1°C.

Figure 5. *ENVI-met results for area A (up) and B (down) at 14:00* (Cocci Grifoni, Caprari, and Marchesani 2022).

Regarding the analysis of the data obtained during the simulation phase, it is clear how the differences in surface temperature are correlated with the characteristics of the materials distributed on the ground (Figure *5*). The highest temperatures are recorded for impermeable surfaces, about 8°C higher than permeable surfaces at the hottest times. In areas where tall vegetation is present, there is a particular cooling effect on surface temperatures, where the temperature is up to 12°C less than on asphalted surfaces. Despite some approximations, the research allowed for experimentation with an integrated workflow involving various disciplines to objectively characterize the territory using a scientific, transcalar, and multidisciplinary approach.

The future developments of this and other research will be able to evaluate the efficiency of the proposed solutions through pre-figurative-alternative scenarios. These evolutionary scenarios will measure thermo-regulatory actions related to energy efficiency or greening strategies (e.g., desealing, micro-forestation, rain gardens, green roofs, cool and high albedo/reflectance materials, etc.). On the other hand, they will be completed with aesthetic-perceptive and socio-recreational analyses through an integrated, technological-traditional approach as developed in CCUHRE project.

While the previous work in this Italian urban centre looked into the current vulnerabilities, the subsequent study considered the future needs of the city, taking into consideration the limitations imposed by the pandemic and envisioning a city with higher liveability (D'Onofrio and Trusiani 2022). This research takes on the matter of the "relational" aspect of urban proximity, indicating that cities have needs beyond design solutions and physical infrastructure; the reconfigurations and reuse of spaces should aspire to a higher quality and community life. In response to the pandemic, Italian cities expedited urban regeneration projects to offer public spaces and services to improve the – at the time bleak – quality of life for residents. Although performed in a state of urgency, such examples illustrate how the focus should shift from economy-driven to people-driven urban spaces. Moreover, this work highlights how large-scale urban regeneration in Italy post-fascism, starting from 1949, has been marked by incompleteness, leaving vacant and derelict spaces woven into the urban fabric. Transforming unused spaces into habitable ones is a challenge of the post-Covid era, and it should be treated along the lines of institutional goals regarding society, climate and health in a safe and inclusive treatment. Moreover, the four axes of walkability (attractiveness, comfort, safety and ease of walking or cycling) should be taken into account in relation to the specificities of the region. This work combined qualitative and quantitative methodologies, including a questionnaire used to capture aspects of daily family life, focus groups, mapping of the area indicating built spaces and services, mobility options and vulnerability.

The urban planning investigation entailed a critical reading of the neighbourhood. Monticelli is a neighbourhood of 7500 residents where half the population is older than 50 years old, and children and teenagers represent only 14%. The main results in this regard indicated some emerging problems regarding the distribution of services and mobility. The same can be said of the green areas. Moreover, while there is good and perhaps excessive parking, cycling paths are mainly concentrated only in a part of the district. In terms of the Neighbourhood Health and Well-Being Profile, both questionnaires were administered prior to the pandemic. Therefore, the answers would probably be different today. Nevertheless, this is what emerged and was confirmed in both interviews: a good state of health, both physical and mental; general satisfaction with the social climate; good accessibility to services and commercial activities. Despite these positive aspects, other aspects also emerged: Cars are indispensable for normal daily activities such as going to school or shopping; neighbourhood residents do little physical activity, and there is a lack of awareness of its importance: there is low or mild physical activity for 65% of people, and just 4% of the population goes by bike or on foot to work or school or for daily Movements. Another critical issue is the safety of walking at night. Sixty-six *per cent* of people say they do not feel safe on the street at night. The sense of insecurity is due to the lack of public lighting (for 50% of people), a lack of law enforcement (40%), and the intensity and speed of vehicular traffic (just 30%). The results of these questionnaires led to a more in-depth investigation through focus groups with citizens.

Moving on to the Climate Profile, risk maps were created using remote sensing techniques, spatial data, and satellite images. The maps were designed to assess the growing impacts of climate change on urban infrastructure, health, and well-being, especially with regard to heat waves. In the GIS environment, it was possible to relate information about the population's awareness of climate risks (children, elderly people, large families, etc.) to climate data and the urban morphology, identifying the most vulnerable areas. The analysis evidenced a vulnerable system scattered in multiple parts of the neighbourhood (red zones). Widespread impermeability in parking areas, the absence or lack of trees in parks, and the presence of large sun-drenched open spaces are the biggest problems.

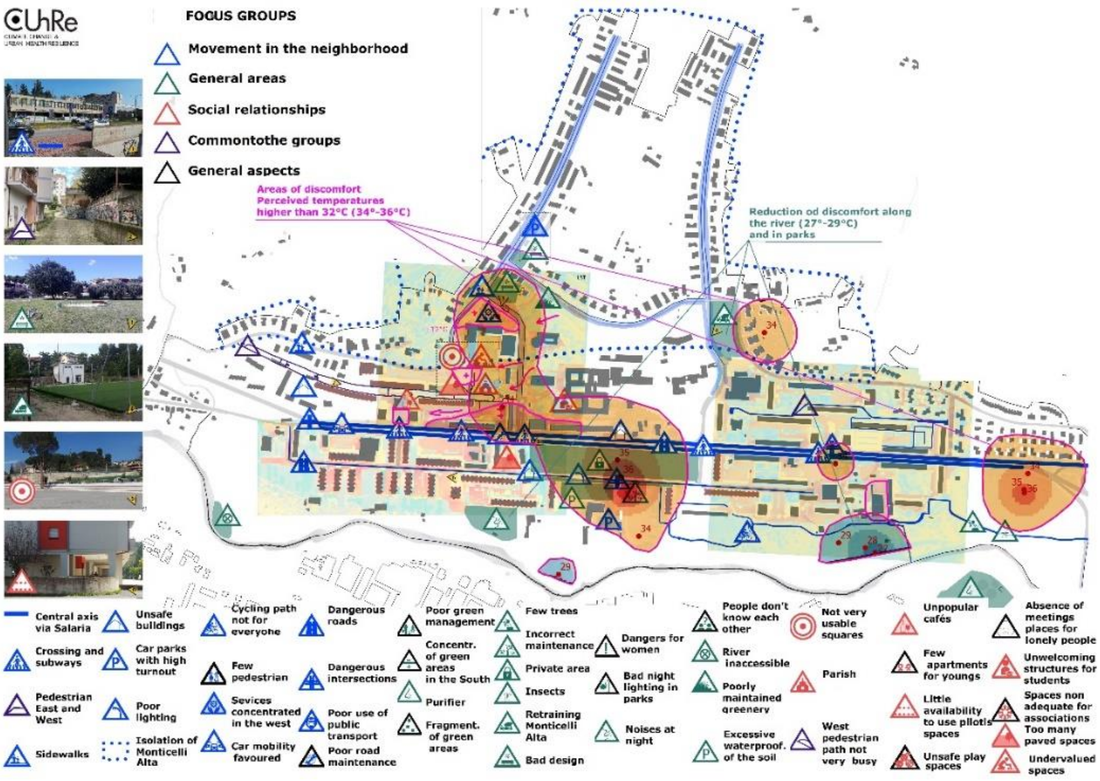


Figure 6. Criticalities and risks map from D'Onofrio and Trusiani (D'Onofrio and Trusiani 2022).

As for the Participatory Process with Citizens and the focus groups employed, it was necessary to investigate the critical functional and spatial aspects of the neighbourhood with the local population in order to understand, for example, the low level of walking in the neighbourhood. The focus groups during the lockdown influenced the responses from citizens regarding, for example, their satisfaction and dissatisfaction with slow mobility and the provisions in gathering spaces. The citizens often referenced the change in lifestyle during the lockdown and the growing value given to the presence of green areas and movement on foot and bicycle as conditions to ensure and implement in the future of the neighbourhood (Figure 6). The focus groups thus identified a number of priority areas for action to regenerate the neighbourhood: the river park and connections with the neighbourhood; the urban road, the Via Salaria and the creation of public services and spaces for socialization for all ages. Finally, on the Climate and Health Actions and Design Concept for 2050, a repertoire of climate and health design actions was produced. About 70 actions were identified, divided with reference to two main topics—public spaces and mobility— and four subtopics—squares and open spaces; green and blue spaces; paths and pavements, active transport networks, and home-school routes. The selected actions were used to build design scenarios up to 2050, which can guide future urban regeneration projects. The identification of these design actions enabled the construction of a Project Concept that selected the actions and groups of actions that give more guarantees in terms of inclusiveness, safety, and comfort with reference to the areas of interest. All these actions guide the configuration of possible design alternatives to be verified through pilot projects (Figure 7).

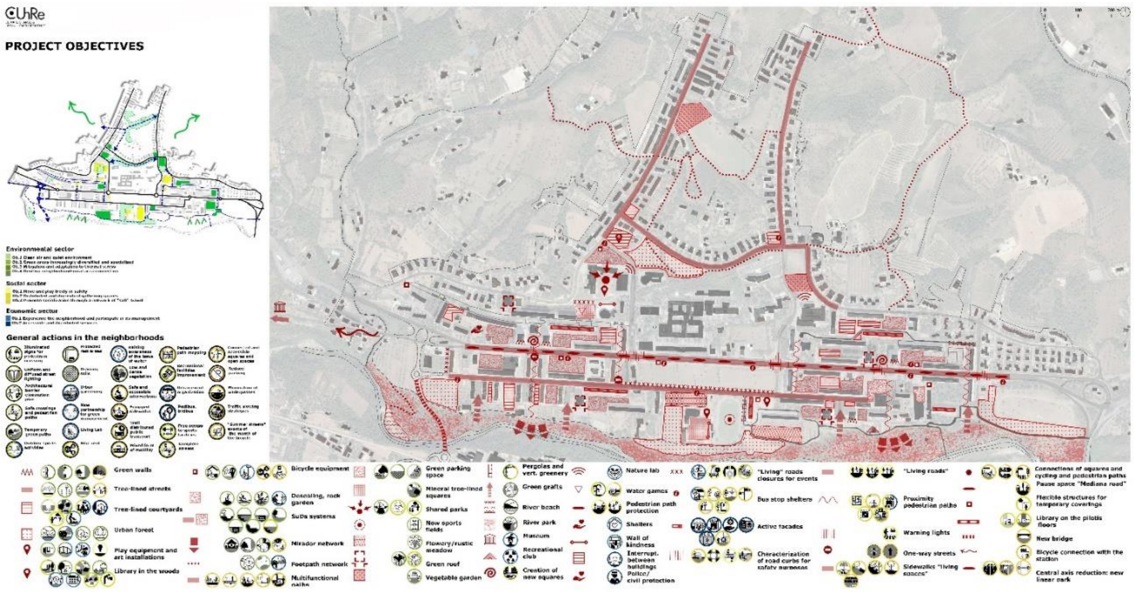


Figure 7. Concept Plan. Representation of project actions from D'Onofrio and Trusiani (D'Onofrio and Trusiani 2022).

2. Approach to knowledge investigation

To investigate the body of available knowledge and data, a systematic literature review is used. It helps to identify in a structured, replicable and transparent manner the documents published on a given topic and available in specified scientific databases. These documents are then studied, analysed and synthesize to provide an updated state-of-the-art on the given topic. Once collected documents from scientific databases, a data-driven bibliometric analysis has recently been used with large datasets in need of quantitative analysis of the identified documents (Donthu et al. 2021). It is used to qualitatively assess manageable datasets, supporting the evaluation and interpretations of findings. Although such guidelines seem clear and concise, it is often the case that a considerable number of publications need to be reviewed under a qualitative lens, which is nevertheless facilitated through quantitative approaches. The favourable method is, therefore, often a mixed methodology adjusted to the specific needs of a topic, with diverse fields of research already exploring such methodologies (Radzi, Osman, and Mohd Said 2022; Abdelmagid, Checchi, and Roberts 2022; Gamage, Ayres, and Behrend 2022).

The objective of this study is to analyse mitigation and adaptation strategies to climate change effects to protect human health in urban areas. Although this establishes a niche topic, literature is not scarce. To analyse the identified studies, a Strength-Weaknesses-Opportunities-Threats (SWOT) analysis is adopted. It is a tool often used in participatory approaches or the development of business models, but it has proven to be useful in identifying specific major problematic areas, as well as those with the highest potential for improvement. Nevertheless, this still remains a tool, and its findings are as sound as the knowledge it analyses (Terrados, Almonacid, and Hontoria 2007).

Therefore, in this study, a quantitative and bibliometric perspective is used to assess prevailing patterns, trends and possible gaps, and mixed review methods are employed to examine the specificities of urban health in relation to mitigation and adaptation strategies.

2.1. Systematic investigation of available knowledge

In the last decades, several studies have dealt with the conditions related to global warming and the linked impacts caused by climate change. In order to study the implications of climate change's impact on urban health, a systematic literature review was performed. For this purpose, the Preferred Reporting Items for Systematic Reviews and Meta-Analyse (PRISMA) scheme and the Context-Intervention-Mechanisms-Outcomes (CIMO) logic are used in tandem to explore existing knowledge in this theme. According to the most recent PRISMA scheme, three main steps are advised in the selection of documents: Identification, Screening and Inclusion (Page et al. 2021). In the first step, identification, the CIMO logic is applied to define the research question and the exact queries to be run in accessible databases of scientific publications. For the purposes of this study, the Scopus and the PubMed databases are investigated, representing the former primarily natural sciences- and engineering-oriented sources and the latter primarily health and medical sources (Falagas et al. 2008; Mongeon and Paul-Hus 2016). Iteration and review of keywords were crucial steps in the Identification phase in order to finalise the exact queries. Following the CIMO logic, the research question investigated in this work is: "*How can mitigation and adaptation strategies (M) mitigate climate change effects (I) to improve health (O) in urban contexts (C)?*"

Based on the formulated research question, a set of keywords was identified for each component of the CIMO logic. They are presented in Figure 8. The keywords are connected with proper Boolean operators: OR within each of the four CIMO categories and AND between the four CIMO categories. Therefore, it is possible to build a search query. Then, exclusion criteria are applied throughout the PRISMA process, including the removal of generic keywords and duplicate studies selecting specific document types and language. The process of query building and exclusion criteria is adjusted to the two databases used. A manual search of specific articles compliments the query search (lastly accessed on 14/3/2022), and the ultimate pool of research documents included 110 contributions.

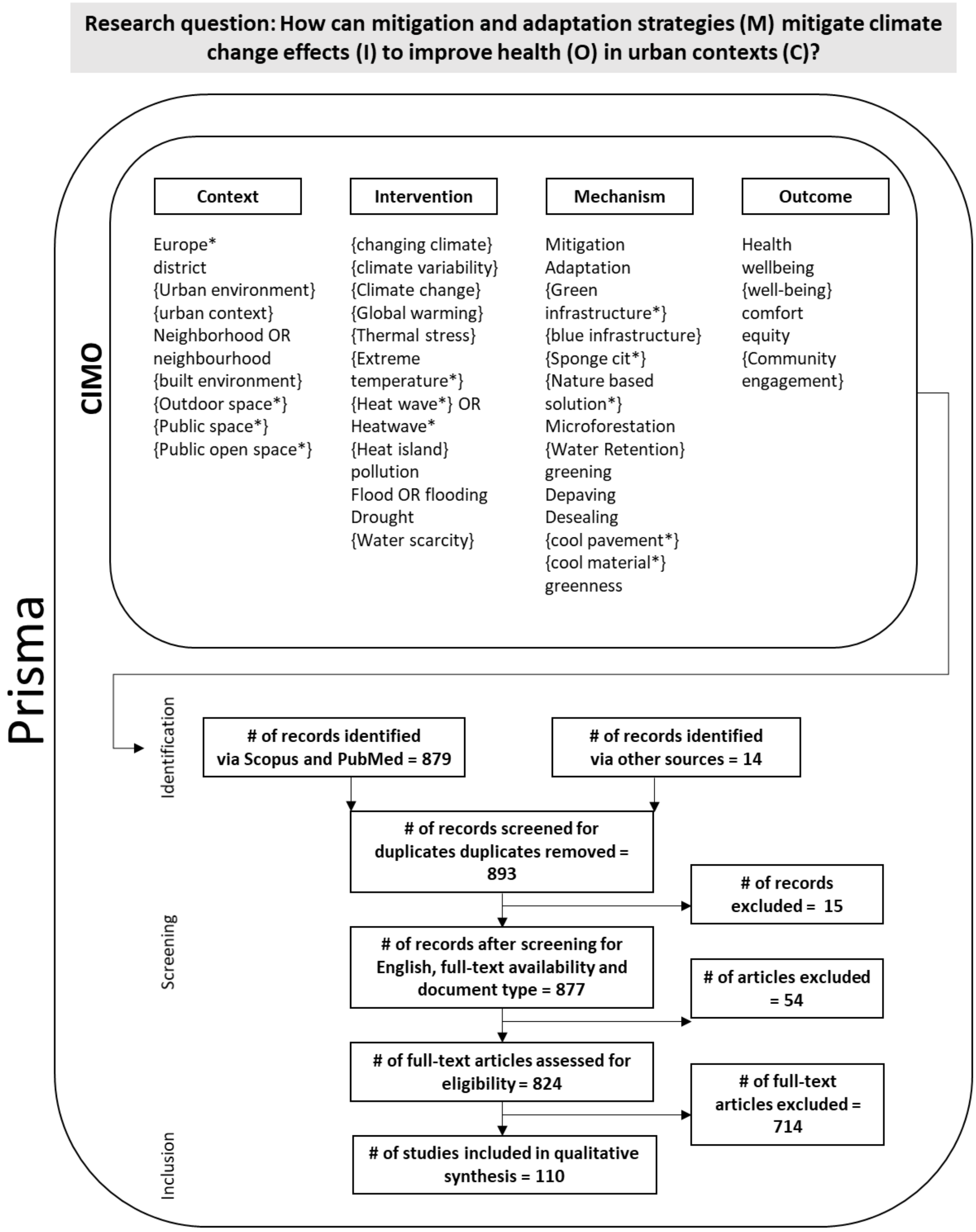


Figure 8. Systematic literature review based on the CIMO logic and organised according to the PRISMA schemes.

2.2. Data-driven analysis of identified bibliometric data

Bibliometrics are explored through the free software VOSviewer 1.6.18 to analyse key bibliometric and meta-analysis features and visualize scientific landscapes, in line with similar hybrid studies that have followed a systematic literature review approach (Camarasa et al. 2019; Carlucci et al. 2020; Gamage, Ayres, and Behrend 2022). Co-occurrence analysis detects the simultaneous occurrence of specific words, whether that refers to author or index keywords, institutions or thematic areas, helping in the identification of research hotspots and trends in a field of literature (Hou and Wang 2021). In this study, co-occurrence analysis is conducted for author and index keywords.

3. Scientific landscape and emerging themes

In this section, numerical findings and bibliometric indicators are analysed. The systematic literature review results are presented in subsections, illustrating the key features of bibliometric analysis, the CIMO components and the SWOT analysis. These are discussed in a qualitative approach in the subsequent section. No time limits were imposed on the literature search, with the resulting timeline of publications spanning from 1996 to 2022, although only one publication fitting the search criteria was published between 1996-2007 (Figure 9). The observed increment in publications, approximately over the last decade, may serve as a reflection of the increased focus of international alliances on the urgency of climate change mitigation and urbanisation; something which has also been observed in other bibliometric studies (Allam et al. 2022; Fu and Waltman 2022; Wimbadi and Djalante 2020). The research query, hence, successfully echoes the physical and the social dimensions related to the adaptation and mitigation of climate change and health in cities. Still, it is notable that half of the publications responding to the research question posed were published from 2018 onwards, with a remarkably low number of papers reaching the publication stage in 2019 and a corresponding increase in 2020.

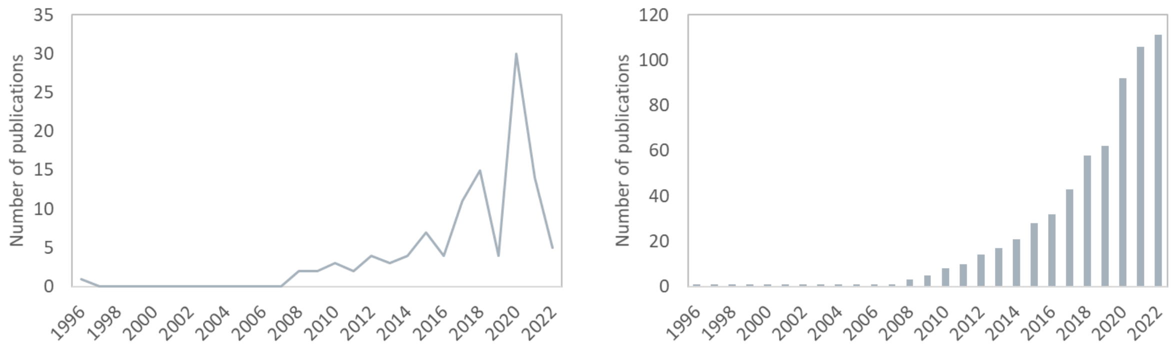


Figure 9. Timeline of publications per year (left) and cumulative publications (right).

As for the co-occurrence analysis, Figure 10 presents the density visualisation indicating that climate change is the most frequently cited keyword. The most frequent keywords also include human(s), urban heat island(s), urban design, thermal comfort and adaptive management, illustrating the priorities of research so far. Moreover, health, mortality and vulnerability are highlighted, as well as policy, adaptation and decision making.

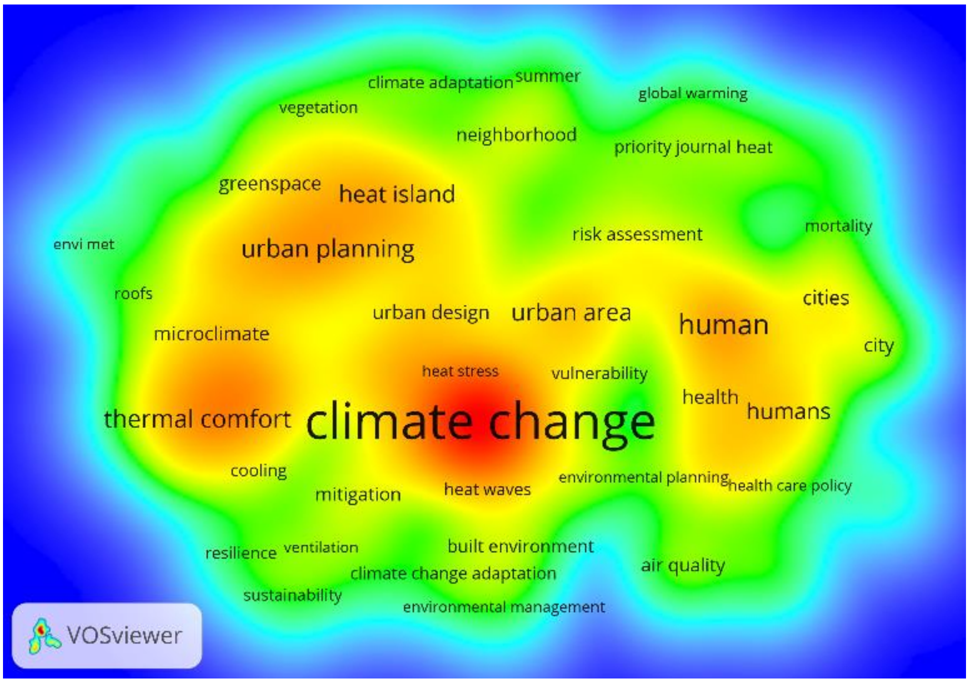


Figure 10. Co-occurrence of all keywords, with a minimum number of 5 occurrences. Source: own work via VOSviewer.

Each component of the CIMO logic was further partitioned into sub-categories, presented throughout Figure 11-Figure 15. The Context (Figure 11) where the intervention is embedded refers to the physical boundaries of cities, ranging from the scale of a single building to the higher level of territories overarching multiple cities. The most frequently examined spatial plane is the city level, although neighbourhoods, districts and clusters are also commonly examined. Singular buildings or overarching territories are less frequent but not rare. On the other hand, in the other two sub-categories of the Context component, open spaces are by far more regularly studied in relation to closed ones, and the most common type of climate is related to locations with temperate humid subtropical or oceanic conditions.

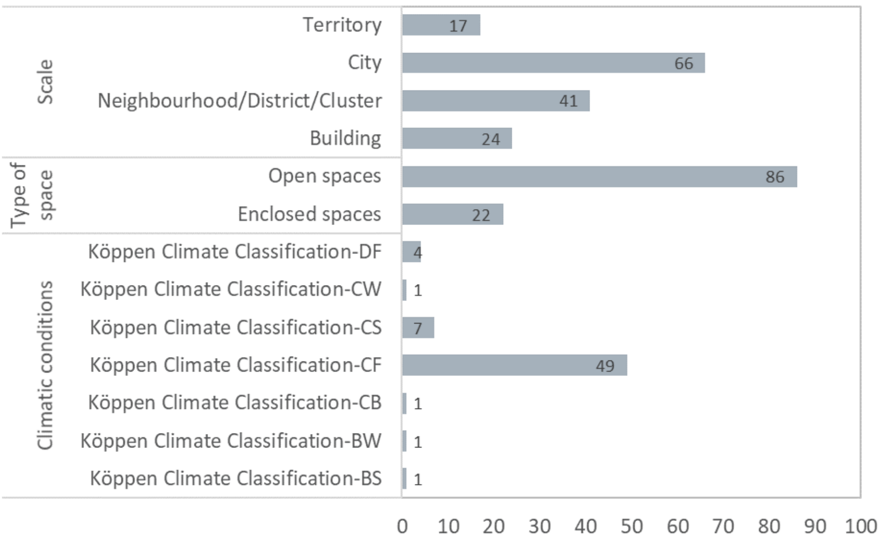


Figure 11. Sub-categories of the Context component of CIMO.

Under Intervention (Figure 12), only two sub-categories exist: anthropogenic and natural climate change-induced hazards. The first category refers to hazards that have developed due to human activity, while the second refers to naturally-occurring phenomena without linking human interference. In both sub-categories, heat is the most commonly studied hazard, whether that relates to heat stress due to global warming or the urban heat island effects. Under anthropogenic-induced hazards, the second highest occurrence relates to issues of pollution, whereas shortage of energy or other resources comes last. In terms of naturally occurring catastrophes, the subject most frequently studied following heat stress is related to flooding. Droughts and disease outbreaks are not so common, whereas dust storms are non-existent in this specific research field, something possibly owed to the European focus; such dust events are a major hindrance in other parts of the world, such as the Eastern Mediterranean and the Gulf Cooperation Council area (Kyprianou, Serghides, and Carlucci 2022).

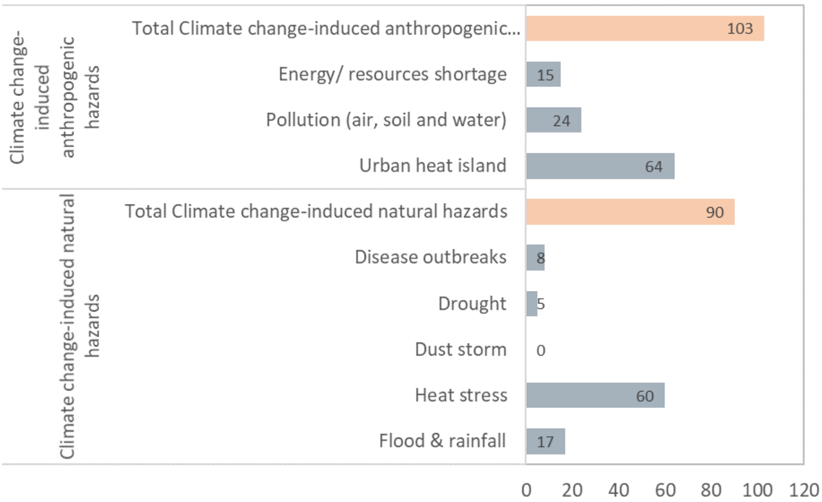


Figure 12. Sub-categories of the Intervention component of CIMO.

The Mechanism component of CIMO logic contains two major sub-categories, Mitigation and Adaptation strategies, each comprising multiple further subdivisions according to the classifications presented in Chapter 1. Findings on the mitigation strategies detected in the literature are shown in Figure 13. Urban design and land-use planning seem to be a preferred study subject, while investigations on circular economy issues such as carbon capture, low-carbon materials and material efficiency are the least common topic. As for the Low-energy, sustainable and resilient buildings and neighbourhood subdivision, it is mostly represented by the energy efficiency element, followed by energy conservation. Innovative and renewable energy technologies are under-represented in the literature. The same can be said for the entire class of sustainable mobility, which is, however, uniformly represented in the subdivisions of modal shift, shared mobility, mobility services, traffic optimisation and smaller vehicles with high efficiency and low emissions.

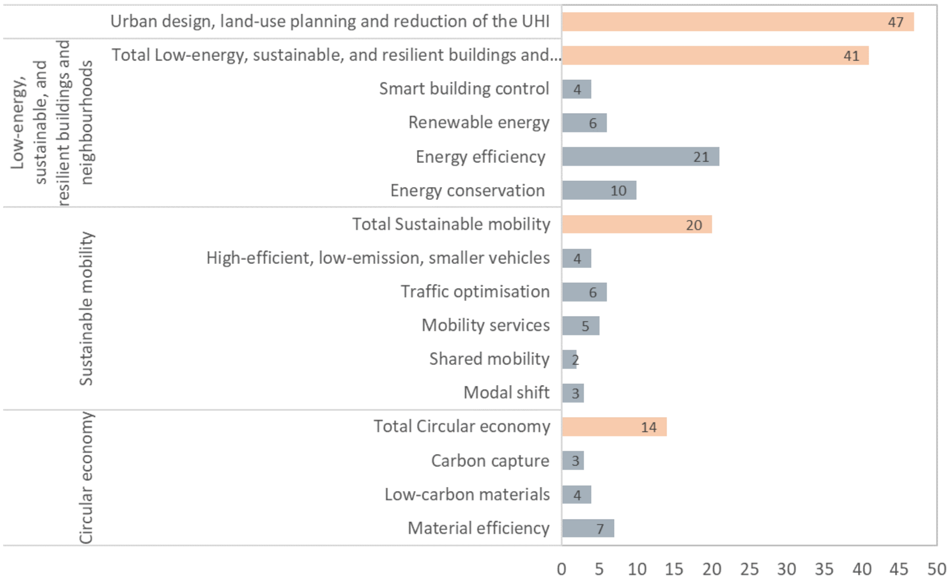


Figure 13.Sub-categories of the mitigation strategies for the Mechanism component of CIMO.

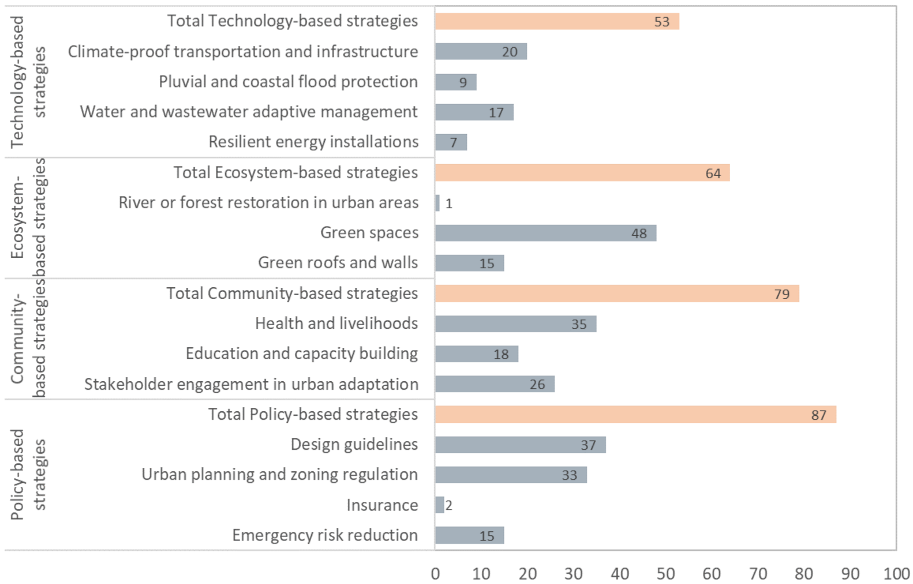


Figure 14. Sub-categories of the adaptation strategies for the Mechanism component of CIMO.

In Adaptation strategies (Figure 14), there is no significantly overshadowed component analogous to sustainable mobility; all sub-categories are well embodied in research. Policy forms the strongest element, almost equally represented by design guidelines and urban planning and zoning regulation. Although emergency risk reduction is far less echoed in literature, insurance-related policy strategies are almost absent. The category most closely following policy-based strategies is related to community-driven adaptive measures. The three divisions featured here, health and livelihoods, education and capacity building and stakeholder engagement, are well reflected in the research. In ecosystem-based strategies, one subdivision overpowers the rest, and another is poorly mirrored. Green spaces are the most significant aspect of ecosystem-driven approaches, possibly reflecting the importance of urban design, and urban rivers or forests are not a hotspot of research at the moment, with green roofs and walls being moderately studied in relation to other topics. The final category under adaptation is focused on technology-based strategies, mostly comprised of climate-proof transportation and infrastructure, as well as management of urban water resources. Pluvial and coastal flood protection and resilient energy installations have received little to moderate attention in this field of research. The last component of the CIMO logic is Output (Figure 15), defined here by two categories: human health and urban environmental health. The lion's share is taken up by comfort, under human health, without however diminishing the attention paid to other subdivisions. Under this main category, disease, fitness and mental health are uniformly investigated, unlike equity issues, which nevertheless are moderately reflected in relation to other elements. Under environmental health, improved urban ecosystems and resource use efficiency are well-illustrated, with improved carbon footprints and reduced emissions being moderately examined.

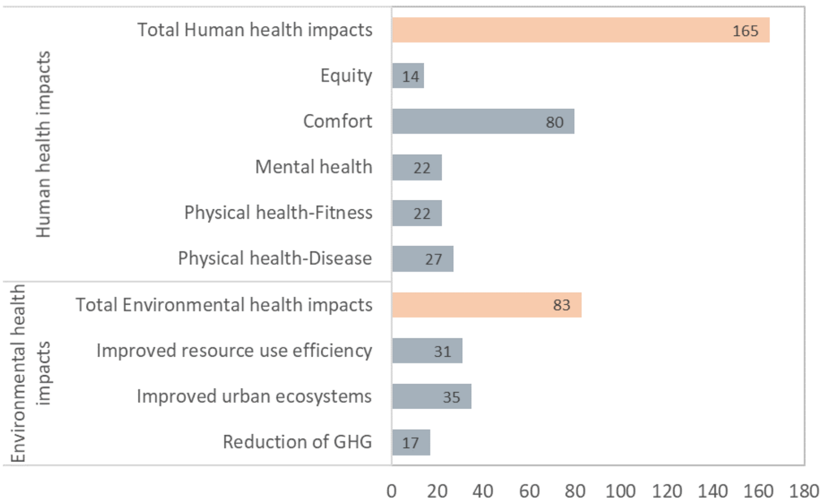


Figure 15. Sub-categories of the Output component of CIMO.

A clear distinction is observed in the reported number of each element of the SWOT analysis, with a considerably higher amount of strengths and opportunities being identified relative to the number of weaknesses and threats. The number of strengths and opportunities identified in this systematic literature review is more than twice the number of weaknesses and threats; this may be due to the focus of the query search, aiming to detect adaptation and mitigation designs instead of simply the adverse impacts of cities on health (Figure 16).

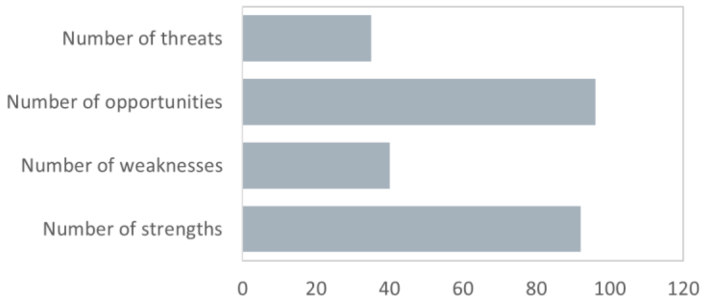
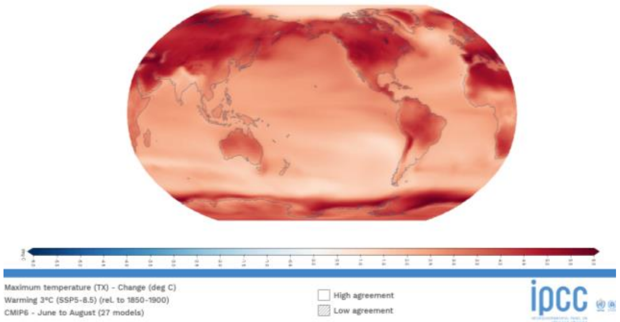


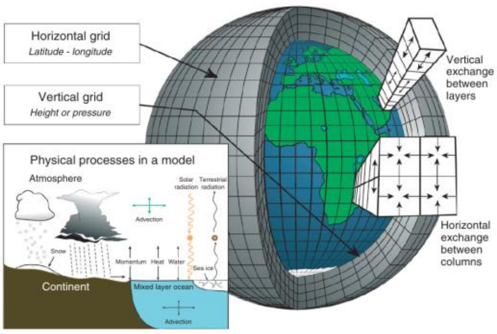
Figure 16. Metrics of the SWOT analysis.

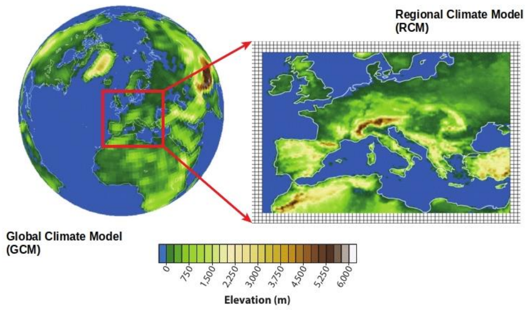
Box 3: Climate modelling: from global to local

The development of climate models for numerical simulation of the atmosphere and oceans was one of the great scientific triumphs of the twentieth century. These models are mathematical constructions representing climate processes, written in code that run in powerful computer systems in order to simulate the Earth's climate system and help understand past and future climate change. Temperature change projections under anthropogenic climate change such as the one depicted below (Illustration 1) are based on results from global climate model (GCM) simulations.



GCMs' operation is based on fundamental physical laws (such as Newton's laws of motion), which are subjected to physical approximations appropriate for the large-scale climate system, and then approximated through mathematical equations solved for discrete space grids and time steps ("discretization" as in Illustration 2). Computational constraints restrict the resolution that is possible in the discretised equations, and some representation of the large-scale impacts of unresolved processes is required ("parametrization").





The spatial resolution of the GCM output is of the order of 100 km which is too coarse for actionable climate change information at the local scale. The need for regionalisation is served by dynamical downscaling, where a regional climate model (RCM) is forced at its boundaries by meteorological fields from a GCM and applied over a limited area of the globe (Image 3). By this we obtain climate output at higher spatial resolution (now days typically between 10-20 km) and more appropriate for climate change impact studies at the national and local level.

Cities are experiencing the "urban heat island" effect, where temperatures in the city centres are higher compared to their rural surroundings. This urban heat is added to the large-scale warming due to climate change. Increasing urbanization, evolving urban landscapes, and growing populations require an accurate representation of urban areas and urban processes. Advancing urban-resolving climate modelling by bridging the regional with the city scale, will take us closer to capabilities that can truly capture natural and human components and address the challenges for human comfort and health induced by urban overheating and climate change.

Image sources: (Gutiérrez et al. 2021; Edwards 2011; Giorgi and Gutowski 2015)

4. Detecting trends, patterns and gaps

Adaptation and mitigation interventions that cities will be able to implement in the coming decades represent an essential factor in the fight against climate change. The integration of different skills and the involvement of different stakeholders is a process that develops interdisciplinary paths and tools for the preventive assessment of the health impacts of environmental changes, with the aim of creating more sustainable built environments and developing tools for a global assessment of the interconnections between climate and health, social, environmental, and economic vulnerabilities, and the quality of urban spaces. Cities are at the forefront of the fight against climate change and must play a leading role in strategies for identifying adaptation and mitigation interventions. This section explores the subjective aspects of the analysis carried out and highlights trends and gaps in the literature.

4.1. Potentiality of mitigation and adaptation measures against climate change

An array of strategies has been identified holding the potential to improve urban centres for their residents, benefitting humans and the local environment simultaneously. Urban geometry and vegetation have been the most effective strategies that contributed to reducing substantially human thermal discomfort in outdoor spaces (Salman and Saleem 2021; Bochenek and Klemm 2021; Almeida-Silva et al. 2020; Ketterer and Matzarakis 2014). Urban green interventions, such as road trees, public and private gardens, parks, green roofs and walls, and urban gardens, contribute significantly to climate adaptation, the reduction of heat waves, to the improvement of surface runoff and absorption of water (Ottelé et al. 2011; Claessens et al. 2014; Mutani and Todeschi 2020; Gatto et al. 2021). Humans also benefit from urban greenery as they mitigate the effects of urban heat islands and contribute to air filtration, noise reduction, rainwater drainage and wastewater treatment (Cârlan et al. 2020). When residents of urban centres have access to public green spaces with options of different active travel modes (e.g. walking, cycling), physical health benefits are observed (Mahmoudi Farahani, Maller, and Phelan 2018). Gardening also has physical health benefits and is considered a moderate to rigorous form of physical activity but is typically limited to private gardens (Therese Fallast et al. 2021; Mahmoudi Farahani, Maller, and Phelan 2018).

Pocket parks have been shown to be useful in mitigating heat stress in dense urban areas and providing refreshment to pedestrians, locals and tourists, even if they cannot improve the physical microclimate (5). Moreover, the implementation of climate-responsive, multifunctional street gardens has promoted the improvement of urban climate, mental and physical health, and biodiversity, providing direct and indirect economic benefits (Therese Fallast et al. 2021). The widespread installation of green roofs can help improving the microclimate at a neighbourhood scale; in fact, the cooling effects of these systems are not limited to the roofs, but they extend to the ground (Peng and Jim 2013).

Urban interventions may represent effective tools for preventing and mitigating the effects of climate change in cities. The design and promotion of interventions for the bioclimatic control of buildings, also with the use of innovative materials, can help improving thermal insulation, shading solar radiation, and increasing natural ventilation and cooling (Rosso et al. 2017; Karakounos, Dimoudi, and

Zoras 2018; Trimmel et al. 2021). Solar reflective pavements have been shown to be simple and cost-effective solutions to reduce surface temperature. Less understood is the effect of solar reflective coatings on radiant heat, which may affect human thermal exposure and comfort (Middel et al. 2020). Nevertheless, reflective coatings of cool roofs may be useful to limit the absorbed solar energy, leading to a decrease in the temperature of surfaces, air, and, thus, the surrounding environment. Indeed, reduced overheating periods have been observed as a result of the reduced values of the heat quantities (Kaboré et al. 2018).

Another key thematic area identified is the role of a participatory approach and active citizens. Engaging in ongoing research projects has allowed citizens to better understand the links in their daily lives related to urban infrastructure and land-use planning (Meyer et al. 2018). Community-based strategies allow for tailored solutions in relation to local contexts and needs, establishing new habits that can contribute to improved urban health (Krebs, Holzhauer, and Ernst 2013; Newell and Picketts 2020). Moreover, 'citizen-inclusive policy making' is viewed as an important focus point for future policy plans aiming to improve air quality and health benefits (Oliveira et al. 2022a).

The evaluation of the impact of mitigation strategies is an emerging topic in the relevant literature. In particular, such evaluation concerns the impact of mitigation strategies of the urban heat island effect, in terms of improvements in the health outcomes of the resident population, particularly in the most susceptible subgroups (Sun et al. 2021; Yao and Fricker 2021; Synnefa et al. 2020). One of the main challenges is identifying cross-sectoral climate change mitigation policies with immediate, medium and long-term health benefits (Kazak 2018). Climate adaptation plans and projects must contribute to improving the environmental quality of the city, improve biodiversity, implement important urban regeneration plans, lead to a better understanding of ecosystem services, create climate-sensitive multifunctional street gardens, and minimize energy consumption (Badura et al. 2021; Schmid et al. 2019; Boeri et al. 2017; D'Ambrosio and Leone 2015; Orsetti et al. 2022).

Little research has been carried out for the evaluation of the multiple benefits of green residential structures based on empirical data (Schmidt and Walz 2021). Particular attention should be paid to health risks and the implementation of an innovative approach to the study of health benefits as a motivator for climate action. Moreover, there is a growing need for new and innovative methods that could be able to raise awareness of urban residents and stakeholders about the potential impacts of climate change, to provide easily understandable scientific information on future impacts and appropriate adaptation options, and to promote the collaboration of cities within climate-related networks (Rohat, Goyette, and Flacke 2018).

4.2. Barriers to healthy urban centres

Although potentiality exists, often there are hidden and obvious barriers to the proper implementation of adaptation and mitigation measures. For instance, insufficient knowledge of climate change and its impacts may create situations where, although the political will exists, practical actions are not taken due to a lack of suitable expertise. Furthermore, institutional hurdles, mismatches between local and national governments, lack engagement of stakeholders from the public and private domains and limited resources to promote green infrastructure works are some of the concealed fences found at the policy level. The selected articles highlight specific tangible barriers related to temperature rising, as well as air, water, and soil quality worsening, which constitute the main impacts of climate change in the urban environment on people's health. Moreover, the issue of inadequate standards for urban design practices is something that troubles many parts of Europe and the world, whether those concern developed or developing countries.

The main trends identified for the thematic area of rising temperatures are focused on the need to investigate the objective and subjective dimensions of climate impacts on health (Rosso, Pioppi, and Pisello 2022; Lenzholzer 2012; Müller, Kuttler, and Barlag 2014), taking into account the spatial perception, in addition to the quantitative data of physical impacts. Moreover, negative impacts of urban heat can be investigated through scenario hypotheses for climate changes and design hypotheses through satellite maps, numerical simulation software, prognostic models based on fluid dynamics and thermodynamics; multi-criteria methodologies (Lassandro and Di Turi 2019), often integrated and involving citizens, decision-makers, local planners and interested parties (Oliveira et al. 2022b). The identified mitigation and adaptation measures related to this topic involve project solutions such as small-scale green measures and pocket parks (Sun et al. 2021) and vegetation and cool materials (Venter, Krog, and Barton 2020). In addition to small-scale interventions, urban heat can be tackled at the policy level through guidelines for local authorities on where to focus the most sustainable actions (Kazak 2018), policies to improve the shading function of roads (Middel et al. 2020) and to use a transdisciplinary approach for the joint framing of problems and solutions with the aim of developing shared design solutions (Foshag et al. 2020). Nevertheless, only a few studies analyse the effects of heat weaves on socio-demographic factors at the urban and neighbourhood scale (López-Bueno et al. 2020); there is a lack of relationships between the computational models for forecasting urban microclimate and liveability and people's perceptions (Pigliautile, Pisello, and Bou-Zeid 2020), as well as a need to give greater importance to the aspects of information and dissemination is detected (Mücke and Litvinovitch 2020).

Another recurring theme of identified weaknesses of urban systems concerns water scarcity and impacts of flood risks on health, socio-economic and systemic systems, infrastructures and peoples' safety (Truu et al. 2021; Assmuth, Dubrovin, and Lyytimäki 2020), as well as the storage and drainage capacity of soil and vegetation (Claessens et al. 2014) and water as a limited resource, using performance indicators to assess sustainability in water management (Van Leeuwen, Koop, and Sjerps 2016). Adaptation and mitigation measures discussed in this context refer to the construction of planning support systems to enable decision-makers and identify the possible effects of extreme weather events (Truu et al. 2021) and selection of appropriate strategies and recommendations for water supply, sanitation and climate adaptation to be developed with technological and non-technological options (Assmuth, Dubrovin, and Lyytimäki 2020). Moreover, the use of green spaces and permeable soils favour water storage capacity, affecting the cooling ability of urban areas (Claessens et al. 2014); and the identification of the local urban level as a relevant scale for the governance and management of the water cycle has been explored. The need for a multi-level and long-term bottom-up approach promoting collaboration between cities and regions has also been highlighted (Van Leeuwen, Koop, and Sjerps 2016). Regarding gaps identified, there is a need to investigate qualitative aspects, such as the social dimension (perception of risk, the importance of communication), indirect factors and macroeconomic consequences of floods, general prevention, risk management, integration of climate policies and adaptive governance, underestimation of the "soil" topic and an interdisciplinary investigation involving heuristic methods and flexible management procedures.

Finally, air pollution is another thematic area related to a multitude of negative health impacts in the urban environment. It has been linked to human mortality and morbidity (Almeida-Silva et al. 2020), especially related to pedestrians (Daghistani 2021). In response to the detrimental effect of pollution in cities and the well-being of residents, adaptive and mitigating topics emerging from the literature include mixed methods that consider the role of citizen behaviour in creating future scenarios with the aim of improving urban environments (Oliveira et al. 2022b), including innovative approaches to investigate health benefits as a motivator for climate action (Herrmann et al. 2018). Moreover, evaluation models have been used to internalize health costs related to air pollution, as well as models that efficiently integrate environmental monitoring data and scenario modelling (Schmid et al. 2019). In addition, researchers have elaborated planning strategies and guidelines to control road traffic emissions by implementing policies to reduce circulation and facilitate traffic flow, avoiding congestion (Sofia et al. 2020) and new technologies to move and disperse polluted air (Daghistani 2021). Research could be further explored in the study of computational models for traffic management and urban planning, as well as in understanding pollution dispersion models within road canyons (Almeida-Silva et al. 2020). Moreover, interdisciplinary factors in the assessment of citizens' preferences for mitigation measures that may have practical implications for public health and climate policies are another underexplored topic (Herrmann et al. 2018).

All of these thematic areas are linked to certain common denominators relating to urban design and land use practices, as well as design guidelines. For instance, Barbosa et al. (2015) frame the issue of thermal comfort in terms of vulnerability and suggest retrofit options that can be integrated into urban development standards to reduce thermal discomfort, shedding light on the existing weaknesses of the existing building stock and related efficiency requirements. Moreover, Ryńska and Solarek (2018) discuss the issue of pollution in dense, industrialised cities, reviving a century-old proposition of creating urban air corridors within urban masterplans to counteract the effects of deteriorating urban air quality.

4.3. Taking steps towards healthy urban societies

As previously mentioned, the literature search detected more opportunities in relation to weaknesses and threats. This can be partly attributed to the fact that the project's research question is designed to capture design solutions used to address certain issues in cities, such as overheating, water management and ambient pollution. Therefore, under this thematic area, six additional classes of domains that constitute opportunities for environmental and human health improvement can be found: Green spaces and nature-based solutions; Built environment structures and elements; Technological improvements; Public participation and consideration of specific social issues; Planning and strategy development and Knowledge – new theoretical and methodological approaches.

Green spaces are widely recognised as a key issue for urban health, and the content of analysed papers reflects that fact. Research results reveal various opportunities that integration of different forms of green spaces and the use of specific nature-based solutions may provide in dealing with overheating and air pollution, but also identify constraints in implementing them in a specific context. The main trends and/or patterns in research, recognising opportunities are related to the benefits of greenery in specific spaces (streets and public spaces (Sun et al. 2021; Foshag et al. 2020), residential courtyards (Schmidt and Walz 2021; Mahmoudi Farahani, Maller, and Phelan 2018), pocket parks (Rosso, Pioppi, and Pisello 2022), leftover spaces (Kaloustian et al. 2018), green elements such as urban canopies (Jiang, Larsen, and Sullivan 2020; Speak et al. 2020; Salman and Saleem 2021), green roofs (Venter, Krog, and Barton 2020; Peng and Jim 2013), green facades (Ottelé et al. 2011), small-scale interventions (Yao and Fricker 2021), specific tree species (Teixeira, Fernandes, and Ahern 2022; Gatto et al. 2021) and combinations of greening with other measures (Trimmel et al. 2021). Moreover, greenery is also considered in the context of water management, for example, by considering adequate supply (Müller, Kuttler, and Barlag 2014), while identification and quantification of the environmental benefits of NBS (Epelde et al. 2022) and the co-benefits of urban green structures (Schmidt and Walz 2021) are also considered. Some emerging topics in relation to adaptation and mitigation in this respect include the development of an "anti-gentrification" urban greening strategy through greening with the vertical system (Ling et al. 2020) and the Inclusion of psychological and social aspects in the research and implementation of NBS measures (Mosca et al. 2021).

Moving on to the built environment, the spatial scales and the focus of research vary. Knowledge in this domain is important for guiding urban planning and design principles and interventions. In terms of overheating management, the availability of breezeway/wind paths in the built environments (Wai, Xiao, and Tan 2021) and passive building design in an urban context (Kaboré et al. 2018) are examined, including a study on the spatial configuration types which can be read as microclimate cues (Lenzholzer 2012). Additionally, the effects of green roofs (Mutani and Todeschi 2020; Peng and Jim 2013) and the use of cool materials (Rosso et al. 2017) are evaluated, as well as smart management of air conditioning (AC) urban cooling systems can help alleviate UHIs and mortality (Tremeac et al. 2012). Besides urban heat, applications of different types of green wall modifications when constructing or refurbishing buildings are examined (Ottelé et al. 2011). A recent study found that increasing the provision, access, and accessibility of a network of public spaces can generate multiple co-benefits for health (Orsetti et al. 2022), while building design and configuration and occupant scenarios were found to have beneficial impacts on thermal comfort, energy consumption and emissions (Roetzel et al. 2010). For instance, Bienvenido-Huertas et al. (2020) found that according to adaptive thermal comfort conditions applied to new buildings, energy savings greater than 1000kWh/year can be achieved, Attia and Carlucci estimated energy savings between while William et al. (2020) estimated energy savings up to 67% through energy refurbishment and sizing the HVAC system correctly. Moreover, CFD approaches are proposed to improve microclimates, linking green solutions to building energy savings while examining the individual building and the neighbourhood levels (Castaldo et al. 2018; Kubilay et al. 2020).

Opportunities relating to novel technological improvements can be found across the problems of overheating, water management and air pollution. The use of blue technology – water spraying system in urban canyons (Wai, Xiao, and Tan 2021), using photovoltaic pavements (Efthymiou et al. 2016) and the approach of combining passive and active cooling for the outdoor built environment are used to address urban heat, while water management is studied through research on the effect of irrigation on suburban areas during heatwave conditions (Broadbent et al. 2018) and the design of rainwater harvesting systems to adaptation to climate changes (Sadowski 2008). Moreover, built chimney systems are examined in their capacity to remove polluted air from the pedestrian-level of the streets while generating clean electricity (Daghistani 2021), and an open-source tool titled Urban Multiscale Environmental Predictor (UMEP) is introduced for city-based climate services (Lindberg et al. 2018).

Stepping away from the technical aspects of urban improvements, the social dimension of opportunities for the environment and health improvement has been recognised as important in several papers. Two groups of papers can be recognised in this domain: (a) research that focuses on the importance of public participation in different phases of the research and planning process and (b) research that highlights the importance of taking into account differences in how people are affected by climate change. The matter of linking knowledge on thermal factors with neighbourhood social factors is examined with respect to the efficient allocation of limited resources (Sun et al. 2021), and understanding the impacts of urban heat vulnerable groups and with attention to certain socio-demographic factors is a recurring topic (Synnefa et al. 2020; López-Bueno et al. 2020; Herrmann et al. 2018). Moreover, engaging stakeholders from both the top-down and the bottom-up to better understand local-level vulnerability and existing adaptation is another aspect investigated in this thematic area (Wilhelmi and Hayden 2010), as well as in water management. Here, ambitious leaders and an active civil society are recognised as essential factors in variability in the sustainability of urban water cycle services among cities (Van Leeuwen, Koop, and Sjerps 2016). In different avenues of investigation, lifestyle changes have been linked to measures reducing GHG emissions (Herrmann, Sauerborn, and Nilsson 2020) and mapping urban vulnerabilities has been shown to be important in the preparation of Local Adaptation Plans (D'Ambrosio and Leone 2015). Topics not usually looked into have also been probed, for instance, the ethical differences concerning the perception of effort and heat, information on how to deal with it (Messeri et al. 2019) and the role of resident engagement in the assessment and monitoring of the performance of storm-water infrastructure, in creating resilience plans (Meyer et al. 2018).

At the systemic level, opportunities for improvement of human health in urban areas rely not only on the knowledge that guides climate-related urban interventions and policies, but also on factors that enable and support their implementation. For instance, few studies researched the effects of extreme heat events as a basis for preparing heat health action plans (Mücke and Litvinovitch 2020), and climate studies of reasonable planning alternatives in relation to bioclimatic effects and impacts on mortality (Othmer, Schmitt, and Greiving 2020; Huber et al. 2020), and strategies to increase the resilience of the built environment using codes and standards (Gangolells and Casals 2012) and incorporating microclimate parameters in the revitalisation of cities (Cortesão et al. 2009). In relation to urban heat and thermal comfort, Kleerekoper et al. (2015) show how policymakers can simulate measures aiming to improve the climate design of neighbourhoods. Moreover, synergies between different policy areas regarding the soil-water system have been studied as the basis for a climate-proof and healthy urban environment (Claessens et al. 2014), whereas strategic planning is also needed for multi-pollutant emission reductions and overall air pollution-related risk (Sofia et al. 2020). Planning and strategy development is also encountered in studies of developing systematic procedures for implementing green interventions in the urban public realm (Therese Fallast et al. 2021) and combining measures in heat stress reduction/thermal comfort such as (a) vegetation, street orientation and aspect ratio (Ketterer and Matzarakis 2014), or (b) green areas, shadow zones of large buildings and the maintenance of ''street canyon ventilation" (Goldberg, Kurbjuhn, and Bernhofer

2013). In the area of low carbon societies, Boyko et al. (2015) detail selected measures that can be implemented to create decarbonised futures while improving urban design practices.

Box 4: Public Art and Public Space (PaPs)

Public art has diverse meanings but one relation always exists: public art occupies public space and therefore- public art is intended to be physically and freely accessible to the public. Public art is often site specific or audience specific and relates to the context in which it is sited. It can be both permanent and temporary, internal and external, and large or small scale. Public art can embrace all art forms and its parameters are continually expanding.

Public art is widely understood to have many benefits to urban quality:

- in helping to improve the quality of an environment and as a vehicle for involving the community in environmental improvements,
- in helping to create a sense of identity, uniqueness, and civic pride,
- as a way of celebrating place, historical heritage or of highlighting particular characteristics which relate to a specific site.

Nevertheless, relation between public and art could be completely different than genesis, creation, perception and art reception, felted by public. There are a number of expected roles of an artwork placed in public space. To name just a few: adding visual quality to a built environment, demonstrating certain urban planning and urban design strategy, promoting higher level of integration between art, architecture, and the landscape through artists' collaboration with architects, landscape architects, city planners, urban designers, and city administrators, increasing cultural awareness, making works of contemporary art more easily reachable for general public, providing new jobs for free-lance artists by public commissions, attracting tourists, visually marking a site of communal importance, generating a sense of pride and belonging to groups that are using it, by memorizing an event from their collective history, or providing a communal image.

PaPs Methodology

Hierarchy of disciplines disappears!

Public art is often used to energize urban design - to comment on sites in order to help one see and experience them in new ways. Artists often collaborate with architects, landscape designers, urban designers and engineers in realization of their projects.

Participation of local community in projects in the civic realm. Design professionals ask the general public how they use or experience a place, what their memories and sensibilities are about an urban space and what they would like to see there. This communication informs designers' perspective and helps him/her design a new site or redesign an old one, without destroying its tradition or histories associated.

Sources: (University of Belgrade / Faculty of Architecture 2022; ShonEjai 2018)

The last thematic area focuses on the larger scale of knowledge and the introduction of new theoretical and methodological approaches. The development of the latest theoretical models and methodological approaches has been recognised as necessary for guiding planning and design solutions as well as for developing climate change and health-related strategies. The development of a human-centric model assessing thermal comfort (Pigliautile, Pisello, and Bou-Zeid 2020) and integral performance assessment methodologies for use under different scenarios of future climate have been explored with regard to urban heat and climate model projections of future summer conditions were developed based on the seasonal cycle of surface hydrology (Selten et al. 2020). Some emerging adaptive and mitigating research explorations are found in a multi-criteria and multiscale assessment of building envelope responsibility (Lassandro and Di Turi 2019) and in biomimetic design, a practice which aims at the thorough understanding of biology and ecology integrated into the architectural design for climate adaptation and mitigation (Zari 2010). Besides individual domains, it has been recognised that specific opportunities lie in combining different mitigation and adaptation measures (Trimmel et al. 2021) and domains of action (Ketterer and Matzarakis 2014), as well as in developing approaches that enable co-benefits (Luber and Prudent 2009; Mavrogianni et al. 2015; Newell and Picketts 2020; Orsetti et al. 2022).

Gaps in the literature related to opportunities to improve human health in cities exist and refer to several issues. Starting from climate-change-related aspects, these are not equally covered in the analysed literature. Almost half of the papers refer to overheating problem, and, thus, it is possible to identify a greater variety of opportunities in this domain. Moreover, although water-related health problems are significant for urban living – the analysed literature does not reflect it and consequently does not offer opportunities to overcome these problems. Several gaps in knowledge and recommendations for further research have been recognised in analysed literature as well, such as the need to investigate low-cost solutions for a more straightforward and more accessible implementation in disadvantaged locations and countries (Rosso, Pioppi, and Pisello 2022) and the need for more specific research, such as the impact of different materials (Salman and Saleem 2021) and specific configurations of greenery (Bochenek and Klemm 2021).

Cities exploiting individual or combinations of measures such as the ones discussed here create healthy and sustainable living conditions, boosting local economies and the green jobs sectors while reducing unemployment and promoting mindful consumption and lifestyles. Urban health equity can benefit from cohesive urban planning, which includes strategies for workplace health and safety (Friel et al. 2011). Moreover, environmental quality is improved through the promotion of sustainable mobility, reduced air and noise pollution from traffic and green areas, which in fact serve both as carbon sinks and as catalysts for the better mental health of urban dwellers (Sarigiannis et al. 2017; Therese Fallast et al. 2021; Schmid et al. 2019).

4.4. Risking human health in cities

The threats found in the papers are related to many aspects of urban health risks. Perhaps the most common one is related to overheating, including UHI (Urban Heat Islands) and heatwaves (Habitzreuter, Smith, and Keeling 2020; Steeneveld et al. 2018; Rosso, Pioppi, and Pisello 2022; Kaloustian et al. 2018; D'Ambrosio and Leone 2015), extreme temperatures and future warming (Wai, Xiao, and Tan 2021; Luber and Prudent 2009) and heat stress (Ketterer and Matzarakis 2014; Foshag et al. 2020). Heat stress and air quality in a high-density urban environment have also been examined (Wai, Xiao, and Tan 2021), as well as the impact of increased demand for domestic electricity in socio-spatially gentrified neighbourhoods due to urban heat (Ling et al. 2020). The role of building overheating (Botti and Ramos 2017), thermal discomfort in relation to high sky view factors (Karakounos, Dimoudi, and Zoras 2018; Goldberg, Kurbjuhn, and Bernhofer 2013) and temperature-related mortality (Huber et al. 2020) are some further threats identified for cities in literature. In the future, heatwaves will be more intense, frequent, and prolonged due to climate modifications (Rosso, Pioppi, and Pisello 2022), while air emissions and the quality of air are also serious problems for health, with premature deaths predicted to be increased (Oliveira et al. 2022b). Even if low temperatures currently contribute stronger to overall excess mortality, this pattern could be reversed if the global mean temperature (GMTs) rises more than 3 °C with respect to pre-industrial levels (Huber et al. 2020). The human-induced climate change has increased the frequency and severity of hazardous events such as heat waves and affects more vulnerable groups (Messeri et al. 2019).

Atmospheric emissions and air quality (Oliveira et al. 2022b; Daghistani 2021; Ryńska and Solarek 2018), pollution (Monforti-Ferrario et al. 2018; Steeneveld et al. 2018), exposure to allergens and the emission of biogenic volatile organic compounds (Appolloni et al. 2020) are also frequent research subjects. Moreover, the impact of massive urbanization and human development (Teotónio, Silva, and Cruz 2018; Appolloni et al. 2020), the increased risks encountered by vulnerable groups (Messeri et al. 2019; Goldberg, Kurbjuhn, and Bernhofer 2013), urban floods (Albano, Mancusi, and Abbate 2017; D'Ambrosio and Leone 2015), business activities in the centre leading to higher urban housing needs the exponential increase of the need for cooling energy (Gangolells and Casals 2012) and problems derived from AC cooling systems (Tremeac et al. 2012) are some of the topics reflecting the threats lived by urban residents and travellers. A less tangible but equally critical threat is that of the equity chasm. The impacts of climate change are already experienced differently among different population classes and global locations, something which is predicted to progress over time. Climate change will aggravate any existing underlying social inequities and possibly create new ones, with direct and indirect repercussions on urban health (Friel et al. 2011).

Attention is paid to the education and involvement of citizens that are concerned about heatwaves and climate change (Badura et al. 2021) and also to "citizen-inclusive policymaking", namely the importance of citizens participating in city decision-making (Oliveira et al. 2022b). Nevertheless, it is not only necessary to make cities interesting and attractive; they must mitigate climate change as well (Therese Fallast et al. 2021) and for this task, it is necessary to foster a co-design approach for climate change adaptation (Foshag et al. 2020). When introducing novel approaches, even if the environmental advantage of the proposed methods is evident, the economics, maintenance and management costs of the system to reduce human exposure to polluted air need to be studied further (Daghistani 2021). Moreover, specificities of suburban and industrialised zones can prove to be threatening to the health of urban populations due to polluting infrastructure and aeration practices of cities (Ryńska and Solarek 2018). Similarly, materials aiming to improve the urban fabric can prove to be worsening the situation if a series of conditions is not met. For instance, a study found that areas with high sky view factors do not benefit from the application of cool paving materials but instead suffer worse thermal comfort conditions in the daytime (Karakounos, Dimoudi, and Zoras 2018). Heat stress in a high-density urban environment is, therefore, a potent threat (Wai, Xiao, and Tan 2021).

Some of the emerging topics identified in relation to adaptation and mitigation are linked to NBS, including small urban or pocket parks in dense urban areas (Rosso, Pioppi, and Pisello 2022), multi-species in public spaces (Badura et al. 2021), climate-responsive street gardens in the streetscape (Therese Fallast et al. 2021), green gentrification and vertical green system (Ling et al. 2020), green roofs (Teotónio, Silva, and Cruz 2018), and a range of cooling systems (Montazeri et al. 2017; Botti and Ramos 2017) are seen as design solutions able to mitigate adverse effects of climate change in cities. However, green spaces can lead to health risks, mainly associated with exposure to allergens such as plants and the emission of biogenic volatile organic compounds, which can act as air ozone precursors (Appolloni et al. 2020), fertile conditions for bacterial growth (Montazeri et al. 2017) but also for often chronic diseases such as cancer, heart disease, mental illness, chronic respiratory disease, allergies, diabetes and obesity, especially present in the Global North (Barron et al. 2019). High temperatures due to global warming are estimated to have an influence on the start and duration of plant pollen production, suggesting that climate change, through high temperatures, is already affecting season timing and duration, thereby increasing pollen amounts in the Northern hemisphere. Interestingly, with regard to the interaction between air pollution and aeroallergens, some studies demonstrated that pollen grains could absorb heavy metals but, also, nitrate and sulphur, while others showed that particles could agglomerate on the surface of pollen grains. This pollen-particle interaction may modulate the allergen release and the absorption of pollen proteins to airborne particles, finally contributing to the increase in pollen allergies and asthma in highly polluted areas (Di Cicco et al. 2020). The green assessment of adaptation measures should be carefully planned at particular locations because excessive use of trees might even cause an increase in temperature (Geletič, Lehnert, and Jurek 2020). In relation to massive urbanization and human development, especially in areas with “uncontrolled” (illegal or irregular) urbanization, a major threat is observed because of an increased risk of unplanned urban slums to landslides and flooding, also due to the excessive reduction of natural wooded areas (Appolloni et al. 2020). Additionally, building design seems to be another potential threat if not properly considered, with overheating risk shown to vary between flats and rooms in flats. A greater frequency of overheating instances is noted in specific orientations, calling for proper bioclimatic design to be incorporated into architectural practice (Habitzreuter, Smith, and Keeling 2020). Also, although planning has an important role in promoting health, the latter is not sufficiently considered in the public space planning process and therefore requires more attention (Orsetti et al. 2022).

As for gaps in the literature, the evaluation of the European project Nature4 Cities shows that European cities do not share the same planning strategies; therefore, it is challenging to offer the same assessment across different spatial and geographical scales (Bouzouidja et al. 2021). What is more, current literature elucidates a definite knowledge gap, as the focus solely illustrates Western cities’ perspective and lacks a broader global consideration (Ling et al. 2020), also largely missing socio-cultural considerations, for instance, in relation to vulnerable population groups such as outdoor workers (Messeri et al. 2019). Another gap in the reviewed literature is that a need for more awareness is mentioned, but the researchers don’t consider the ways awareness can be implemented (Pisello et al. 2017). This vagueness is also reflected in the fact that many articles refer to general and specific effects on human health, but it is unclear at what measure specific/practical answers to mitigate these effects are presented. Finally, dissemination strategies of design solutions are severely under-developed, resulting in low visibility of project and research outcomes (Villalbí and Ventayol 2016).

One of the biggest risks cities and policymakers face are lock-ins created by the asynchronous implementation of adaptation and mitigation measures. It has been estimated that while there is an energy conservation potential of over 70% for the building sector of western Europe, the unrealised energy gains, reflecting the lock-in risk, is around 45% (Santamouris 2016). The result of such situations is often legacy infrastructure and carbon-intensive technologies that persist over long periods, which de facto hinder the reduction of energy intensity and the penetration of low-carbon technological alternatives (Seto et al. 2016). On the other hand, focusing on isolated measure implementation could either lead to amplify results or substantially reduce the overall impact (Ürge-Vorsatz et al. 2018). It is therefore vital for urban planners to acknowledge their limitations in predicting the exact future needs of cities and rather focus on the strategic development of a malleable urban design that avoids future negative lock-ins and enhances positive ones.

5. Challenges and prospects for urban health in the changing climate

Living in and moving around urban hubs can be both a privilege and a risk; a user-friendly and sustainable city has the capacity to offer shelter, livelihood and high-quality services to its residents, maintaining its present and future integrity. Nevertheless, the lived reality of most urban centres is far from this utopian outlook, featuring high levels of air, soil, water and noise pollution, intense thermal discomfort, unaffordability issues and limited mobility options, reminiscent of a lengthy hurdles race where participants find it impossible to uphold their balance. This project aims to bring forth existing design solutions that allow urban dwellers to adapt to the new realities and mitigate the negative impacts of climate change, bridging the concepts of urban design and urban health. To this end, the following research question was posed and addressed through a systematic literature review and a SWOT analysis: "*How can mitigation and adaptation strategies mitigate climate change effects to improve health in urban contexts*?"

The methodological approach followed highlighted that the vast majority of research output studying all the elements of our research question was only published over the past four years (since 2018). This increase in research interest most likely reflects the urgency of making cities liveable and enjoyable, especially after the space and movement restrictions imposed on residents of dense centres due to the pandemic. The co-occurrence bibliometric analysis indicates that research focus is on climate change, human health and comfort and urban design, and although policy and decision making are also indicated as most frequent among all the papers reviewed, topics relating to social aspects, such as community or participatory processes, are not listed as top keywords. It would be expected that an increase in the socio-economic dimensions of climate change and urban health should be observed in the coming years, accounting also for the preference for studying open public spaces and their utility in urban centres. Nevertheless, it would be a mistake to assume that the prominence of social sciences will overcome that of physical actions towards addressing urban challenges.

Findings of this work indicate that although the emphasis is given to climate change-induced anthropogenic hazards such as urban heat islands and pollution, the frequency and severity of naturally occurring hazards, including heat stress and flooding, are also prominent in the literature. This suggests an awareness of the naturally changing climate as well as the acceleration caused by human action. In terms of mitigation strategies most frequently examined, those are related to the circular economy and especially urban design and land-use planning, with low-energy, sustainable and resilient buildings and neighbourhoods also being adequately investigated. The same cannot be said for sustainable mobility, where very few studies have attempted to tackle this matter and propose resolutions. As for the favoured adaptation strategies in literature, these concern policy- and community-based approaches. However, a specific element under ecosystem-based strategies emerges as the most talked among the solutions: green spaces. Within the adaptation strategies identified, the negligible contributions towards river or forest restoration in urban areas and matters of insurance should be pointed out, suggesting their suitability for possible future investigation avenues. Regarding the health outcomes of research, studies on impacts on human health outweigh those on environmental health, with one championing topic: thermal comfort in the city. When considering the most popular elements of each subcategory under the mitigation and adaptation classes, it can be observed that the limelight falls on the use of urban spaces to improve climatic conditions for optimal human comfort, aiming mostly at mitigating urban heat through appropriate land-use planning and nature-based responses (Figure 17).

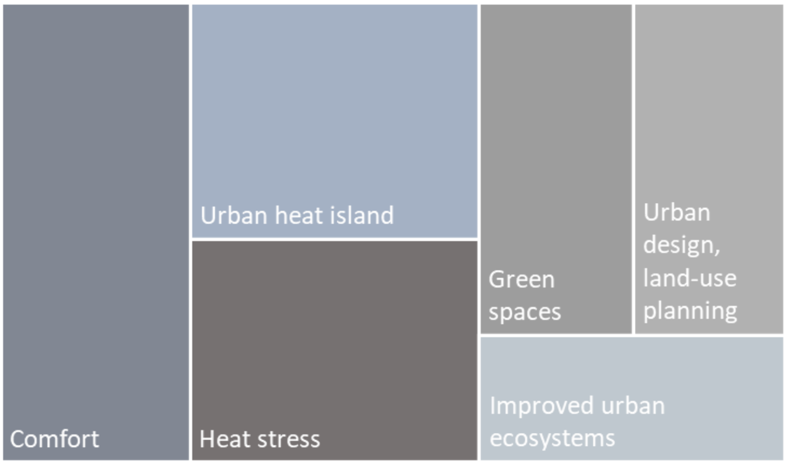


Figure 17. Specific keywords most frequently observed in each sub-category of mitigation and adaptation strategies.

The second type of analysis performed, based on identifying potentialities, limiting factors, opportunities and risks in the adoption of adaptation and mitigation actions with respect to climate change impacts, highlighted different perspectives of common denominators. For example, pollution comes up in discussions relating to barriers and risks, as would be expected, but it is also mentioned in relation to potentialities in the context of abatement and the prospect of cleaner urban environments. Likewise, highly discussed subjects such as urban heat and green spaces are addressed under positive and negative lenses, exposing both the benefits and the risks of specific design options.

For instance, while greenery and urban vegetation are predominantly related to the higher thermal comfort of microclimates and decreased energy consumption, this also means that local water resources must be appropriately managed, and care must be taken to avoid bacterial growth and high exposure to allergens. Identifying both sides of the coin for specific measures is a requirement for the development of appropriate and effective solutions, indicating a holistic approach in the entirety of the reviewed literature.

Aside from the usual suspects, some emerging research paths have also been detected. One such, possibly under-represented topic is that of a participatory approach and citizen action. Community-based adaptation and co-participation are important components of managing climate change regionally. This mode of operation has a higher capacity for local action, making up for the limitations or inadequacies of central government intervention in a democratic governance framework. Research has shown that a participatory process can be used to describe the collective intangible heritage and allows citizens to engage and have a voice in the decision-making process. Moreover, it emerges that urban planning should consider health issues as experienced by local habitants, whether that concerns pollution mitigation, improved comfort or higher relational proximity. Regeneration of cities should therefore aim at improved physical designs able to reinforce the efficiency of the built environment while promoting stronger, more cohesive social structures. In this regard, it can be said that the focus of research on green urban spaces reflects the multiple facets of urban health, in a nexus of human physical and psychological well-being as well as that of the urban environment.

6. Glossary

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC 2021)

Autonomous adaptation: Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural s y stems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation (IPCC 2001b)

Planned adaptation: Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC 2001b)

Adaptive capacity

The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC 2021)

Air pollution

Degradation of air quality with negative effects on human health or the natural or built environment due to the introduction, by natural processes or human activity, into the atmosphere of substances (gases, aerosol) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect (IPCC 2021)

Climate change

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/ or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC 2021)

Climate variability

Deviations of climate variables from a given mean state (including the occurrence of extremes, etc.) at all spatial and temporal scales beyond that of individual weather events. Variability may be intrinsic, due to fluctuations of processes internal to the climate system (internal variability), or extrinsic, due to variations in natural or anthropogenic external forcing (forced variability) (IPCC 2021)

Co-benefit

The term "Co-benefits" refers to simultaneously meeting several interests or objectives resulting from a political intervention, private sector investment or a mix thereof. Co-beneficial approaches to climate change mitigation are those that also promote positive outcomes in other areas, such as air quality and health, economic prosperity and resource efficiency or more general in terms of Sustainable Development (SD) Benefit (UNFCC 2015)

Exposure

The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC 2021)

Hazard

The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC 2021)

Health

Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (WHO 1946)

Health equity

Health equity is the absence of systematic inequalities in health between groups with different levels of social advantage / disadvantage. The Report Healthy, prosperous lives for all: the European Health Equity Status Report, from the WHO Regional Office for Europe in 2019, identifies five essential conditions necessary to create and maintain a healthy life: good quality and accessible health services; income security, and social protection; decent living conditions; social and human capital and decent working and employment conditions. These conditions refer not only to the conditions put in place by health programs, but to all those resources, policies and programs that play an important role in shaping health, many of which are beyond the immediate control of the health sector. Climate change that affects the quality of land, water, and air can cause health problems even if it did not previously, or it can increase the severity or frequency of health threats. Low-income communities are often more exposed to climate risks and less likely to have the resources to address the health impacts of the cumulative effects of climate change (White-Newsome, Meadows, and Kabel 2018; Watts et al. 2021; WHO 2019)

Healthy lifestyle

Healthy lifestyle is a way of living that lowers the risk of being seriously ill or dying early. Not all diseases are preventable, but a large proportion of deaths, particularly those from coronary heart disease and lung cancer, can be avoided (WHO 1999)

Heat stress

A range of conditions in, for example, terrestrial or aquatic organisms when the body absorbs excess heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water-breathing animals, hypoxia and acidification can exacerbate vulnerability to heat. Heat stress in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity and low wind speeds, causing regulation of body temperature to fail (IPCC 2021)

Heatwaves

A period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves, or heat and hot weather that can last for several days, can have a significant impact on society, including a rise in heat-related deaths. Heatwaves are among the most dangerous of natural hazards, but rarely receive adequate attention because their death tolls and destruction are not always immediately obvious (WHO 2022a; IPCC 2021)

(Climate) Impacts

The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial (IPCC 2021)

*Potential Impacts: A*ll impacts that may occur given a projected change in climate, without considering adaptation (IPCC 2001b)

Residual Impacts: The impacts of climate change that would occur after adaptation (IPCC 2001b)

Mental Health

Mental health is a state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community. Mental health is more than the absence of mental disorders. It exists on a complex continuum, which is experienced differently from one person to the next, with varying degrees of difficulty and distress and potentially very different social and clinical outcomes (WHO 2022b)

(Climate change) Mitigation

A human intervention to reduce emissions or enhance the sinks of greenhouse gases (IPCC 2021)

Nature based solutions

Nature based Solutions are a series of actions inspired, supported, or literally copied by nature. It is a relatively recent concept used by the European Commission to identify nature-based strategies, actions, interventions that provide capable environmental services and socio-economic benefits, if carried out in an urban context, to increase the resilience of cities and improve people's health. Nature based Solutions essentially consist of the increase, improvement, and enhancement of green areas, in order to generate a series of ecosystem benefits and services such as, for example, improvement of air quality (by intercepting dust and other atmospheric pollutants), regulation of the urban microclimate, containment of the heat island in the city, regulation of meteoric water flows, provision of leisure/recreation opportunities, improvement of the quality of life, conservation of biodiversity, absorption of greenhouse gases and much more (European Commission 2015)

Physical Activity

WHO defines physical activity as any bodily movement produced by skeletal muscles that requires energy expenditure. Physical activity refers to all movement including during leisure time, for transport to get to and from places, or as part of a person’s work. Both moderate- and vigorous-intensity physical activity improve health (WHO 2020)

Physical fitness

The ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and respond to emergencies. Physical fitness includes several components: cardiorespiratory fitness (endurance or aerobic power), musculoskeletal fitness, flexibility, balance, and speed of movement (U.S. Department of Health and Human Services 2018)

Quality of Life

WHO defines Quality of Life as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns (WHO 2012b)

Resilience

The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/ or transformation (IPCC 2021)

Sensitivity

Urban agglomeration

the city or town proper and also the suburban fringe or thickly is the predominant source of employment, it might be advisable settled territory lying outside, but adjacent to, its boundaries (United Nations 1998)

Urban design

Urban design concerns the design of cities based on the vision contained in urban plans including public space, infrastructure, transport, landscape, and housing for the community. By definition, it is the "design of the characteristics of the city". It is about creating connections between people and places, movement and urban form, nature and built fabric. Urban design brings together the many strands of place-making, environmental protection, social equity, and economic feasibility in the creation of places, beauty and identity. Urban design is derived but transcends from planning, transportation policy, architectural

design, development economics, engineering, and landscape. Urban design is defined by many as part of the practice of urban planning, it shares the same objectives, interests and purposes, and they are two faces of the same object, which is the physical being of the city (Cuthbert 2010; Patsy 2010; Raven et al. 2018)

Urban health

The change in the surface temperature in response to a change in the atmospheric carbon dioxide concentration or other radiative forcing (IPCC 2021)

Sustainable development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs and balances social, economic and environmental concerns (Keeble 1988; IPCC 2019)

Urban health is a term used to investigate the intersectional lived experiences of urban dwellers. It focuses on the unique influence urbanisation has on our biological systems through exposure to environmental and psychosocial stressors-working definition (The Urban Health Council 2021)

Urban Planning

Urban planning concerns the design and regulation of space uses in order to satisfy the needs of the people who live there; it focuses on the physical shape, economic functions, social impacts of the urban environment, and the location of different activities in space. It is the act of "planning the strategies, structures and policies of the city". It is a field of practice that helps to transform into a reality of sustainable development, to use space as a key resource for development and the involvement of a wide variety of subjects in the process. In general, it takes place on the scale of the city or of a metropolitan region; it formulates medium and long-term objectives that reconcile a collective vision with the organization of the resources necessary to achieve it. It aims to make the most of the budget of the entities by investing in infrastructures and services, balancing requests with the need to protect the environment; urban planning ideally distributes economic development within a given urban area to achieve a broader social dimension. It requires careful evaluation and planning so that community needs such as housing, environmental protection, health care and other infrastructure can be incorporated. It makes use of building codes and regulations (UN Habitat 2013)

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2021)

Well-being

Well-being exists in two dimensions, subjective and objective. It comprises an individual's experience of their life as well as a comparison of life circumstances with social norms and values (WHO 2012a)

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