Urban planning, design and management approaches to building resilience – an evidence review

First report on protecting environments and health by building urban resilience

World Health Organization
European Region

The WHO European Centre for Environment and Health, now located in Bonn, Germany, was established in 1989 by the First European Conference on Environment and Health and is an integral part of the WHO Regional Office for Europe. The Centre provides technical and scientific expertise on the impacts of the environment on health. It delivers policy advice and tools to inform and support decision-making in the areas of air quality; access to safe drinking-water, sanitation and hygiene; minimizing the adverse effects of chemicals; adaptation to and mitigation of climate change; environmental sustainability of health systems; urban health planning, including transport and mobility; and violence and injury prevention. It works with partners to develop collaborative initiatives addressing environment-related diseases. The Centre also strengthens country capacities to address environment and health challenges through a range of training courses on environment and health, including health impact assessments.

Urban planning, design and management approaches to building resilience – an evidence review

First report on protecting environments and health by building urban resilience

Abstract

Urban planning, risk governance and resilience have become increasingly important pathways to promote and protect public health at the local level. Climate change, inadequately planned urbanization and environmental degradation have left many cities vulnerable to disasters. The COVID-19 pandemic has further highlighted the links between health and urban environments, and the relevance of sustainable and resilient planning. Various global frameworks have been established to address sustainable development, urban environments and resilience, and awareness of the local benefits associated with implementation of these global agendas is increasing. The Protecting environments and health by building urban resilience project aims to support local authorities and decision-makers to reflect on the environment and health dimensions of local preparedness and resilience, and to promote the application of urban planning approaches to establish safe, healthy and sustainable cities. This first report of the project compiles academic evidence on the urban environmental impact of disasters and extreme events, and the related implications for increasing preparedness and resilience through urban planning, design and management decisions.

Keywords

- Urban planning
- Environment and health
- Emergencies
- Healthy cities
- Prevention
- Resilience
- Preparedness
- Building forward better
- Sustainable development

WHO/EURO:2022-5647-45412-64987
© **World Health Organization 2022**

Some rights reserved. This work is available under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO; https://creativecommons.org/licenses/by-nc-sa/3.0/igo).

Under the terms of this licence, you may copy, redistribute and adapt the work for non-commercial purposes, provided the work is appropriately cited, as indicated below. In any use of this work, there should be no suggestion that WHO endorses any specific organization, products or services. The use of the WHO logo is not permitted. If you adapt the work, then you must license your work under the same or equivalent Creative Commons licence. If you create a translation of this work, you should add the following disclaimer along with the suggested citation: “This translation was not created by the World Health Organization (WHO). WHO is not responsible for the content or accuracy of this translation. The original English edition shall be the binding and authentic edition: Urban planning, design and management approaches to building resilience – an evidence review: first report on protecting environments and health by building urban resilience. Copenhagen: WHO Regional Office for Europe; 2022”.

Any mediation relating to disputes arising under the licence shall be conducted in accordance with the mediation rules of the World Intellectual Property Organization (http://www.wipo.int/amc/en/mediation/rules/).

Suggested citation. Urban planning, design and management approaches to building resilience – an evidence review: first report on protecting environments and health by building urban resilience. Copenhagen: WHO Regional Office for Europe; 2022. Licence: CC BY-NC-SA 3.0 IGO.

Cataloguing-in-Publication (CIP) data. CIP data are available at http://apps.who.int/iris.

Sales, rights and licensing. To purchase WHO publications, see http://apps.who.int/bookorders. To submit requests for commercial use and queries on rights and licensing, see http://www.who.int/about/licensing.

Third-party materials. If you wish to reuse material from this work that is attributed to a third party, such as tables, figures or images, it is your responsibility to determine whether permission is needed for that reuse and to obtain permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

General disclaimers. All reasonable precautions have been taken by WHO to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall WHO be liable for damages arising from its use. The named authors alone are responsible for the views expressed in this publication.

Design by ACW, London

Contents

Acknowledgements

The WHO Regional Office for Europe wishes to express its appreciation to all those whose efforts made the production of this report possible.

The report was written by Carlota Sáenz de Tejada, Laura Hidalgo, Carolyn Daher and Mark Nieuwenhuijsen (ISGlobal, Urban Planning, Environment and Health Initiative, Spain).

Inputs to content, structure and strategic development of the report were provided by Matthias Braubach and Sinaia Netanyahu (WHO European Centre for Environment and Health, Germany).

A draft version of the report was reviewed by Aleksandra Kazmierczak, Juan Calero Rodriguez and Gerardo Sanchez Martinez (European Environment Agency, Denmark); Michael Hagenlocher (United Nations University, Institute for Environment and Human Security, Germany); and Vladimir Kendrovski (WHO European Centre for Environment and Health, Germany).

The report was produced with the financial support of the German Federal Ministry of Health and the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

Abbreviations

EEA	European Environment Agency
EU	European Union
GIS	geographical information system
GHG	greenhouse gas
Hong Kong SAR	Hong Kong Special Administrative Region [China]
ICLEI	Local Governments for Sustainability
IPCC	[United Nations] Intergovernmental Panel on Climate Change
NBS	nature-based solution
PTSD	post-traumatic stress disorder
SDG	Sustainable Development Goal
UHI	urban heat island
UNDRR	United Nations Office for Disaster Risk Reduction
UNECE	United Nations Economic Commission for Europe

Glossary

For all three project reports and the summary report, the following terminology is used, as defined by the United Nations Office for Disaster Risk Reduction.[1]

Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.

Hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. Several hazards are socionatural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change.

Mitigation is the lessening or minimizing of the adverse impacts of a hazardous event.

Preparedness is the knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems, and includes such activities as contingency planning, the stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information, and associated training and field exercises.

Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Vulnerability reflects the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

[1] UNDRR (2021). Understanding disaster risk: terminology [website]. Geneva: United Nations Office for Disaster Risk Reduction (https://www.preventionweb.net/understanding-disaster-risk/terminology, accessed 25 March 2022).

Executive summary

Local crises and emergencies affect economic activity, damage environments, interrupt critical infrastructure services and cause direct and indirect health impacts. Cities need to ensure effective response and recovery from crises. They also need to reduce current and future hazard exposure and vulnerability. Urban design, management and planning have a prevention and risk mitigation role to play; they should therefore be integrated into local resilience strategies and plans. Several recent multilateral reports, frameworks and guidelines point to cities as leading actors in hazard mitigation and adaptation, setting priorities and enabling bottom-up approaches that further engage communities in (and make local governments more accountable for) building more healthy, sustainable, equitable and resilient cities.

As part of WHO's Protecting environments and health by building urban resilience project, a broad literature review of urban planning, design, management and preparedness related to disasters was carried out. Academic literature published during 2015–2021 applicable to cities in the WHO European Region was compiled, and risk-informed urban planning strategies for improved local-level resilience were extracted. A brief selection of recent international reports and guidelines was also included as resources to provide context and benchmarking.

This report identifies conceptual approaches, frameworks and strategies in the literature to help cities tackle the challenges of preparing for and preventing the likelihood and severity of impacts of local extreme events. It explores how (and to what extent) urban planning, management and design can be a mechanism for improved preparedness and resilience.

The findings show that published research based on a single hazard type is common: around 60% of the papers reviewed were found to be hazard-specific. The report discusses a number of strategies that are particularly relevant to certain hazard types, distinguishing between those entailing modification or design of physical infrastructure and those that relate to governance, communication and public engagement. For instance, heatwaves and the urban heat island effect are frequently linked to dense and impervious urban fabrics, and call for greater green coverage through nature-based solutions. In this sense, local planning regulations (such as mandatory minimum green space ratios) could help increase the amount of green coverage in cities. This in turn could be highly relevant for preventing (or mitigating the effects of) floods in urban environments – traditionally reliant solely on grey infrastructure, which may not be able to cope with the future levels predicted due to climate change. Earthquake preparedness involves optimal design of open spaces within the city to act as shelters, as well as up-to-date inventories of the road network and building stock. Improving building resistance is crucial when facing both seismic events and strong winds during storms. For the latter, increasing public knowledge and risk awareness related to storms can improve personal and household preparedness measures, which were also found to be potentially relevant in mitigating impacts and reducing recovery time.

Common cascading effects of these hazards are critical infrastructure failures – particularly disruption to energy supply, on which societies are highly dependent. In addition to technological innovations and behavioural change to reduce overdependence on the electricity grid, infrastructure design should consider the need for back-up solutions and redundancies among certain critical systems and links, anticipating potential dependencies throughout the city. The COVID-19 experience has brought to the forefront urban vulnerability to pandemics, giving rise to discussion about which urban models may help to protect health – now and in the future. Cities have provided many examples of temporary strategies (and some that may become long-lasting) to transform neighbourhoods, especially involving use of public space, mobility and access to green areas. Such reconfigurations may also provide opportunities to address inequalities among neighbourhoods and integrate urban greenery further, thereby achieving additional health and climate adaptation co-benefits.

The evidence review also showed growing interest in climate change-related hazards, accounting for around 30% of the selected papers. Interest is growing in adaptation planning and the integration of climate change scenarios within a broader resilience agenda. A number of drivers, barriers, trade-offs and unforeseen consequences in climate-change mainstreaming were presented. Among the most highlighted actions for local governments to work more effectively and successfully towards climate change adaptation were institutional innovation, breaking down silos, establishing common visions and priorities, and considering both potential health and equity outcomes from resilience projects (often through co-creation and participation processes). Local access to finance and funding was also identified as a key factor in implementation of resilience plans and adequate maintenance of existing infrastructure.

Preventing and/or mitigating the effects of hazards strongly depends on the availability of reliable information and predictions (however much uncertainty remains), for which scenario-wise thinking, risk analysis and assessment tools are crucial and rapidly developing. These involve incorporating quantitative estimations of costs and damages, simulating different disasters and potential cascading effects, and considering the impacts on vulnerable groups within a city. In addition, improved risk perception and personal preparedness may reduce the impacts of emergencies; for this, key elements are raising public awareness, improving city–citizen communication and implementing robust disaster education. These actions may also enhance public engagement and motivate behavioural shifts, which in many cases are an integral part of successful resilience projects.

Other cross-cutting issues are exposure to hazards linked to geographical location and urban form, or the role of buildings, transportation, green infrastructure and nature-based solutions in building more sustainable, healthy and resilient cities. For instance, while geographical and climatic characteristics make some cities more exposed to hazards than others, much literature (23%) has focused on how certain urban models may contribute to this vulnerability, generally advocating compact urban models (in combination with sufficient and well distributed open and green space) and controlling urban sprawl over risk-prone areas. Nature-based solutions can complement and enhance pre-existing grey infrastructure to manage floodwater, mitigate the impacts of storms, improve air quality, provide green space for recreation and protect health overall. Similarly, a public and active transport system can use pervious pavements for its pedestrian and cycle lanes and be shaded by tree canopy throughout its pathways, thereby combining stormwater management with cooling measures to mitigate heat exposure, reducing car dependency (and consequently greenhouse gas emissions), promoting physical activity and again protecting human health and the environment overall. If this is strategically planned and designed to benefit the population living in the most vulnerable neighbourhoods, the health benefits will be greater and more equitable.

Many cities are confronted with multiple hazards – sometimes with concurring, compounding or cascading effects. Planning in silos may not take into account win–wins or consider maladaptive consequences. This poses the challenge of moving from a hazard-by-hazard approach to an all-hazards and multirisk approach in prevention, planning and development. Despite the abundance of hazard-specific literature, a significant number of the papers reviewed (28%, and especially the most recent) mentioned the importance of establishing multihazard thinking and methods, and of considering cascading effects. This growing call for a more holistic approach to disaster risk reduction through risk-informed planning is in line with the principles of the multilateral reports and guidelines, and could be considered a key lesson learned from the findings of this review. Multiple strategies (such as institutional innovation, improving early warning, raising awareness and understanding risks and cascading effects) are important for all hazards, while others have synergies and co-benefits across multiple hazard types. Thus, individual solutions are probably not the answer. Strategies – even theoretically hazard-specific ones – must be integrated to enable structural or systemic transformation based on an all-hazards and multirisk approach, while ensuring that trade-offs or unforeseen consequences are minimized and that benefits are multidimensional. When synergies among strategies are found and unwanted consequences are controlled, resilient planning and preparedness for emergencies and crises can better align with the Sustainable Development Goals and, overall, make for better and healthier cities.

1. Introduction: the Protecting environments and health by building urban resilience project

1.1 Project context

Climate change, rapid and/or inadequately planned urbanization and environmental degradation have left many cities vulnerable to disasters. In addition, cities increasingly face local emergencies through industrial accidents and system failures, indicating the high degree of interdependencies, especially within large cities. Inadequate planning has thus been recognized as a relevant disaster risk factor, affecting urban hazards, exposure and level of vulnerability (UNDRR, 2021).

Disasters and local emergencies have a direct impact on population health, causing injuries, diseases, and mental and psychosocial outcomes. In addition, they may significantly affect the functionality of critical infrastructure, such as health-care facilities or water and energy supply, thereby further increasing existing health challenges due to lack of treatment and care services, with specific impacts for chronic and infectious diseases. Increasing local preparedness for health emergencies should therefore be considered a priority by national governments as well as local authorities (WHO, 2021a).

Cities need to understand what features and processes make them vulnerable to crises and environmental emergencies, and their associated health impacts. They also need to recognize the most effective counteractions to take to reduce risk, prepare and become resilient (WHO, 2020). Reflecting the global relevance of this challenge, various international commitments and agreements have highlighted the need to address disaster risk, emergency preparedness and resilience at urban scale. The Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations, 2015a) stipulates four action priorities: understanding disaster risk, strengthening governance to manage it, investing in disaster reduction for resilience, and enhancing preparedness for better response – all priorities to protect lives, livelihoods and health. Sustainable Development Goal (SDG) 11 on sustainable cities and communities (United Nations, 2015b) requires increased efforts by cities to adopt and implement policies on disaster resilience, and to establish disaster risk-management schemes. The Paris Agreement (United Nations, 2015c) established – alongside its focus on climate change mitigation – the first universal, legally binding global commitment on climate-change adaptation to strengthen resilience and reduce vulnerability.

Much can be done at the city level by local authorities, planners and managers to translate these global agendas into local action, using urban planning and design as an instrument to reduce risks and vulnerabilities and build resilience – ultimately resulting in the protection of health and well-being (WHO, 2021b). Reflecting this need to localize global commitments, the New Urban Agenda seeks to ensure healthy, resilient and sustainable cities through disaster risk reduction and management, reduced vulnerability, and increased resilience and responsiveness to natural and human-made hazards (United Nations, 2017).

1.2 Project objectives and deliverables

This report is one of the deliverables of the Protecting environments and health by building urban resilience project, led by the European Centre for Environment and Health of the WHO Regional Office for Europe. The project is designed to support local authorities and decision-makers in building urban resilience. The project team compiled local-level experiences and lessons learned in relation to:

- reducing health risks posed by local disasters and emergencies;
- mitigating local vulnerability to associated hazards; and
- identifying local priorities and actions for improving resilience (and health) through urban planning and design, as well as urban infrastructure management.

The project placed focus on availability of data and indicators to support local assessments and decision-making regarding vulnerabilities and resilience needs. Exploring how cities can use urban and infrastructural interventions to reduce local disaster risks, increase preparedness and improve resilience is therefore not only a mechanism to address health protection but also a central component of the broader objective of sustainable, equitable and healthy urban development.

A series of reports sets out the project findings on how urban resilience and preparedness can be improved by city structures and design, and through urban management and monitoring:

- *Urban planning, design and management approaches to building resilience – an evidence review*, which documents urban challenges and implications associated with disasters and extreme events, and identifies associated priorities to prepare for future challenges and increase urban resilience through urban planning, design and management;

- *Urban planning for health – experiences of building resilience in 12 cities*, which summarizes city interviews about their practical experience with local emergencies and disasters, and the local lessons learned for building forward better by reducing risks and vulnerabilities and creating more resilient urban design and infrastructure;

- *Review of indicator frameworks supporting urban planning for resilience and health*, which explores how international monitoring frameworks can be applied at subnational or city level to describe crisis impacts during an emergency situation, and/or to assess vulnerabilities and inform the establishment of more resilient urban settings; and

- *Urban planning for resilience and health: key messages*, a summary report compiling key messages from all three technical reports and providing a condensed briefing for urban decision-makers on how to protect health and well-being through preparedness and resilient urban planning, design and management.

All these reports can be accessed online via the WHO project website.[1]

2. Reviewing the evidence

Global disaster risk management has responded to threats ranging from terrorism to industrial events and, increasingly, climate-related events over several decades, providing many examples of practice at national and local levels. Multilateral institutions have also provided frameworks and guidelines to assist governments through the various phases of disaster prevention, preparedness, response and recovery, such as the Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations, 2015a). While the immediate impacts on health and well-being of disasters may be recognized, the academic literature about these impacts and the links between health, urban planning and disaster management has not been consolidated; such evidence from the local level is especially lacking.

Urban planning (defined in Box 1) has a prevention and risk mitigation role to play; it should therefore be included in cities' resilience and emergency strategies and plans.

Box 1. Urban planning definition

Urban planning is concerned with the social, economic, and environmental consequences of delineating spatial boundaries and influencing spatial distributions of resources. It encompasses the preparation of plans for and the regulation and management of towns, cities, and metropolitan regions, and attempts to organize sociospatial relations across different scales of government and governance (Huxley & Inch, 2020).

In this report, "urban planning" includes urban management aspects (such as city maintenance, governance and intersectoral coordination), as well as urban and infrastructure design and planning.

A broad review of recent literature on urban planning, design, management and preparedness related to disasters was undertaken within the Protecting environments and health by building urban resilience project. It included peer-reviewed academic literature applicable to cities in the WHO European Region. Specific examples of local experiences, interventions and policy approaches from other regions were included if these provided added value for the topic in general. Selected international reports were also reviewed to reflect the perspective of international agencies and organizations.

From the findings, this report compiles information on experiences of crises and disasters and the related adjustment of local planning, management and infrastructure design, either as a response to recent crises in urban settings or as a forward-looking measure to increase urban resilience and improve environmental conditions. It identifies available conceptual approaches and frameworks to help cities tackle the challenge of preparing for and preventing the likelihood and severity of impacts of local extreme events.[2] The report explores how (and to what extent) urban planning, management and design can become mechanisms for improved preparedness and resilience. It also investigates the links between health, urban planning and disaster management, extracting useful risk-informed urban planning strategies for improved local-level resilience.

Sections 3–6 outline the methodology and findings of the literature review, which are presented by hazard type and through the prism of a set of cross-cutting issues. Section 7 discusses the need for a shift towards an all hazards, multirisk, systems-based approach to build resilience in cities, highlighting the synergies and co-benefits between strategies, and section 8 offers conclusions on synergies and co-benefits of urban planning, design and management strategies to building resilience.

[1] Protecting environments and health by building urban resilience. In: WHO/Europe [website]. Copenhagen: WHO Regional Office for Europe; 2022 (http://www.who.int/europe/activities/protecting-environments-and-health-by-building-urban-resilience).
[2] Urban preparedness and establishment of resilient cities are further promoted by the Making Cities Resilient 2030 initiative of the United Nations Office for Disaster Risk Reduction (UNDRR, 2022).

3. Methodology

A preliminary search was based on an initial search strategy proposal by the European Centre for Environment and Health of the WHO Regional Office for Europe. The literature review drew mainly from academic literature (peer-reviewed articles) from six databases: five used for a primary search of scholarly journal papers (Web of Science, Scopus, EBSCO GreenFILE, PubMed and Avery Index to Architectural Periodicals) and one used for complementary searches on literature related to specific case studies or local events identified through the primary search (Google Scholar). The primary search was carried out using a combination of keywords referring to the spatial context of interest (cities), the event (emergency or disaster) and the outcome or reaction to this event (Table 1). A restricted set of search terms was used to make the search manageable in the time available for the task.

Table 1. Keywords selected for the primary literature search

Spatial context		Event		Outcome/reaction
city OR cities OR urban OR metropolitan	*AND*	crisis OR crises OR "natural disaster*" OR "environmental disaster*" OR "industrial disaster" OR "health risk" OR accident OR emergency OR hazard OR fire R flood OR storm OR earthquake OR "extreme temperature" OR heat OR heatwave OR "weather-related" OR "climate change" OR "power outage" OR "blackout" OR "energy outage" OR pandemic	*AND*	preparedness OR preparing OR mitigat* OR adapt* OR planning OR design OR infrastructure OR resilience* OR policy OR policies

The combination presented in Table 1 resulted in the most relevant titles within a manageable quantity of search results. Several other keyword combinations (including terms such as "health", "well-being", "mortality" or "disease" in the outcome category) were tested in preliminary searches, but in the end these added a large number of papers specific to health (systems and impacts) rather than to city/urban events or to urban planning or preparedness. Other terms such as "exposure", "vulnerability", "risk" and "transformation" were excluded from the set due to the large number of nonspecific or irrelevant results obtained. The term "COVID*" was also intentionally excluded from the search terms as it greatly increased the hits by adding largely unrelated articles. Despite being excluded, several papers specific to the COVID-19 pandemic came up in the search, and an additional review of the *Cities & Health* journal special issue on COVID-19 was carried out.

The inclusion criteria for the literature review were as follows.

- Documents included were scholarly (peer-reviewed) journal articles for primary searches involving studies in humans. All types of study design were included: scoping reviews; systematic reviews; meta-analyses; and ecological, prospective, cross-sectional, case-control and intervention studies. For complementary searches (using Google Scholar), book chapters and/or conference papers were included if considered relevant. In addition to original research papers, the review also considered papers that reviewed and summarized original research.
- The papers were in English, although some in Spanish were included if considered relevant.
- Global literature was searched, but the selection was made for content applicable to the cities in the WHO European Region.

The review included general planning approaches, concepts and frameworks on how to prepare through urban design, planning and management. It was restricted to publications from the past six years (2015–2021) in order to reflect the most recent urban planning and management concepts and implications (potentially avoiding concepts considered outdated), and to limit the amount of material to be assessed in the available time.

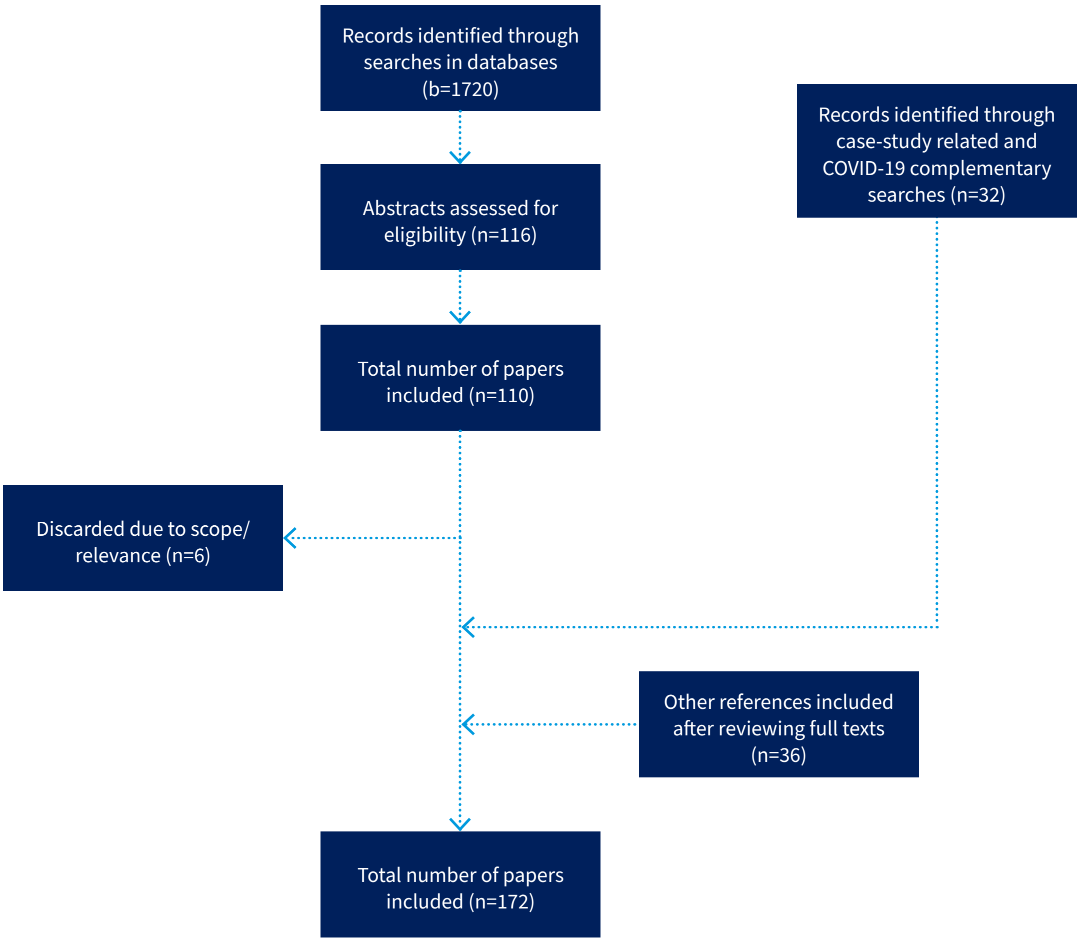
After advanced searches in all databases selected for the primary search (resulting in a total of 1720 hits), an initial screening of papers was carried out based on the information available in the title and abstract, in line with the inclusion criteria (Table 2). Discussion and agreement via consensus between two independent researchers resolved cases of doubt.

Table 2. Search strategy database results

Database	Focus	Location of keyword matches	Results of first screening
Web of Science (Core Collection)	Multidisciplinary	Title	1002
Scopus	Multidisciplinary	Title/abstract	53
EBSCO (GreenFILE)	Multidisciplinary	Title	172
PubMed (Medline)	Health	Title	212
Avery Index to Architectural Periodicals	Architecture and urban studies	Abstract	281
Total			**1720**

After the first screening and checking for duplicates, a list of 110 papers was selected for full-text review. This evaluation discarded six articles from the list due to scope/relevance, and introduced 36 new articles that were referenced in the full texts and considered especially relevant to the topic, despite not appearing in the primary searches. Furthermore, 32 articles were identified through complementary searches on specific case studies or events identified in the reviewed literature (including COVID-19 impacts), resulting in a final total of 172 papers (Fig. 1).

Fig. 1. Literature search strategy and outcome



A brief selection of recent international reports related to urban environment, planning and resilience was also reviewed for context and benchmarking in the discussion section. Subsections 7.4 and 7.5 explore potential links or gaps between the main principles and key messages of these international reports and agreements and the findings extracted from the primary search (focusing on peer-reviewed journal papers).

4. Results

The literature review revealed a wide range of urban planning themes and approaches to disaster preparedness and resilience. Most results covered some aspect related to climate change in cities (53 papers; 31% of the total), while the types of disaster or emergency most often covered were heat – heatwaves, extreme heat or the urban heat island effect (24; 14%), flooding (23; 13%) and earthquakes (21; 12%). Of the articles, 93 (54%) were based on case studies or specific events, and 80 of these (46%) explicitly mentioned urban design or planning. Table 3 gives an overview of the papers included in the review, by type of event and location of case study (if applicable).

No papers were found on cold extremes or on forest fires related to heatwaves. The lack of identified papers on forest fires may be related with the fact that these fires tend to be located outside cities. Thus, although they threaten cities, they may not be a priority issue for urban planning.

Table 3. Results of the literature review by type of event and geographical location

Topic	Number of papers	Proportion (%)
Type of event		
Climate change (general)	53	31
Heatwave or urban heat island effect	24	14
Flooding	23	13
Earthquake	21	12
COVID-19 pandemic	20	11
Industrial accident or infrastructure failure	9	5
Storm	7	4
No specific event, disaster or emergency	15	10
Geographical location		
General or no location indicated	79	46
Based on specific location or case study:	93	54
• countries in the WHO European Region	44	47
• countries outside the WHO European Region	37	40
• multiple case studies (within and outside the Region)	12	13

Note: results by type of event reflect the lead theme of the paper; however, some overlap may occur – for example, between a focus on climate change and a focus on climate-related events such as heatwaves or flooding.

The results show that literature based on a single hazard type is common (especially case studies and lessons learned after previous disaster experience, which was a topic of interest for this review). Around 60% of the articles reviewed were found to be hazard-specific (with an additional 30% focused on climate change-related hazards).

For this reason, section 5 presents the findings by type of hazard, distinguishing between strategies entailing modification or design of physical infrastructure and those that relate to governance, communication and public engagement. This approach may, however, have led to some redundancies in terms of relevance of strategies and their applicability to more than one hazard type. Nevertheless, a significant number of the papers reviewed mentioned the importance of establishing multihazard thinking and methods, and of considering cascading effects (especially the most recent articles), even when the main focus of the paper was on one specific hazard.
Section 6 further examines the findings through the prism of a set of cross-cutting issues, including climate change aspects, city location, urban forms and infrastructures, citizen preparedness and the role of nature elements.

5. Findings: urban preparedness and resilience by type of event

The following subsections present the main findings of the literature on urban disasters and disaster risk, and related insights into urban planning, design and management that are specific to a selection of natural and/or infrastructural hazards. This review does not compile all potential urban planning and management interventions related to disasters or health; rather, it focuses on what cities have done in practice over recent years.

Each subsection provides a brief description of the urban problem or challenge, followed by a summary of the strategies suggested or followed for each hazard type, distinguishing between those entailing modification or design of physical infrastructure and those that relate to governance, communication and public engagement.

The categories chosen for types of event reflect the lead theme of the papers, but some overlap may occur. For instance, about one third of the papers reviewed focused on climate change (and weather-related events), providing a clear indication of how cities seem to approach urban preparedness. The lessons and strategies found in these papers are presented in the specific subsections on heatwaves (and urban heat island effect) and floods, and also in the subsection on industrial accidents and infrastructure failure, since power outages are a common cascading effect of climate-related events. In addition, some strategies found in papers focused on flooding or infrastructure failure are relevant to preparedness for storm events, given the most usual impacts of heavy rain and wind on cities.

5.1 Heatwaves and the urban heat island effect

Heatwaves have been identified as a major challenge for urban planning, design and management. Variations in neighbourhood microclimate and temperature levels most often reflect the consequences of past planning and design choices, such as:

- the amount of impervious surface and vegetation present;
- the mobility model;
- the quality of housing stock; and
- the presence of anthropogenic sources of “waste heat”, including vehicular traffic, industrial processes and air-conditioning units.

Heatwave periods are growing in frequency and intensity, with significant impacts on urban infrastructure, economic activity and – above all – on public health and well-being (Hatvani-Kovacs et al., 2018). Elevated temperatures can affect human health negatively both directly and indirectly (causing dehydration, heat exhaustion and potentially life-threatening heat stroke), and can exacerbate existing medical conditions such as heart and kidney disease (Larsen, 2015).

Urban environments further elevate the rate of warming in cities through the urban heat island (UHI) effect – defined as a discernible temperature difference between urban and rural areas, caused by the excess heat emitted and the solar gain trapped by the urbanized environment (Araos, Austin et al., 2016). Construction materials used in urban areas increase the absorption of solar radiation, and reduced vegetation cover limits evapotranspiration as well as reflectivity and shading. Use of air-conditioning – which is encouraged in most heatwave response plans in Europe (Hatvani-Kovacs et al., 2018) – can expel warm air outside the building and therefore raise outdoor air temperatures, contributing to the UHI effect. This reduces the potential for natural cooling through passive architectural strategies, such as shading or natural ventilation (Larsen, 2015), and increases the risk of electricity blackouts (which can trigger a cascade of other failure). It can also contribute to increasing inequalities, as populations with fewer resources suffer a double burden. Heatwaves can also increase water consumption; this is especially challenging, given that water scarcity is growing, and climate change is likely to increase future droughts in already arid regions (Hatvani-Kovacs et al., 2018; Frumkin et al., 2020; CDP Worldwide, 2021).

Heatwave events and urbanization intensify UHI effects (Imran et al., 2019), and their frequency is also increasing. A study in California, United States of America, used simulations to show that climate change and population growth reinforce one another to drive substantial increases in future exposure to heat extremes, which are predicted to become more frequent, longer and more intense (Vahmani, Jones & Patricola, 2019).

5.1.1 Strategies entailing modification or design of physical infrastructure

Energy performance of the built environment should be improved alongside water efficiency measures to mitigate the effects of heatwaves. Strategies to reduce elevated urban temperatures largely focus on mitigating the UHI effect. Many of these have similarities to contextually appropriate passive-cooling strategies that were commonly used prior to the advent of air-conditioning, such as a simple window awning for shading (Larsen, 2015). Systems-based heating and cooling that take advantage of cooling towers or district distribution save energy and reduce sensible heat discharge; these may become an alternative to traditional domestic air-conditioning units (Lin et al., 2021).

In addition, extreme heat events can be mitigated by proper design of urban air flows and wind paths (via urban canyon geometry and wind penetration in the built area) using breezeways, low-rise buildings and linear parks (Capolongo et al., 2018). In the European climate, it is important to limit urban winter ventilation and to encourage summer ventilation. Ventilation can facilitate convective cooling in summer or in hot climates, and some greening solutions such as green walls need to be designed according to the type of climate and purpose, since they can be an effective insulator but can also reduce wind speed and impede ventilation (Koch et al., 2020). Urban air flows are also relevant in relation to static water bodies, since these have high heat capacity that can inhibit cooling, especially at night (Richards & Edwards, 2018). It is therefore crucial to consider the siting of these blue spaces and to design them (and their immediate surroundings) to take advantage of dominant wind patterns.

Cities typically contain less vegetation and fewer bodies of water than rural areas, and existing green and blue space is often under threat from increasing population density (Hatvani-Kovacs et al., 2018). Adding urban vegetation and reducing impervious surfaces or increasing their reflectivity are well known urban heat management strategies (see subsection 6.8 for examples). Evidence on how the potential benefits of these climate-adaptive land-use planning and design strategies are distributed is scarce, however. A study of three metropolitan areas in the United States using climate models for the year 2050 found that older populations (who are generally most at risk for heat-related illness) could benefit more from physical heat management strategies than younger populations (Vargo et al., 2016). The study also found a spatial association between income and imperviousness, suggesting that physical heat management strategies designed to enhance neighbourhood vegetation and albedo are expected to produce greater human health benefits in regions where lower-income populations are disproportionately located close to the historic urban core. In the European context, however, the appeal of urban living can sometimes mean that populations living in less green areas close to city centres are wealthier than suburban ones. It is therefore necessary to assess how these findings are relevant to specific local contexts, in order to target heat management strategies to the areas and population groups that could benefit most.

Also related to the impact of impervious surfaces (and lack of green cover) on health, a study in Oslo using a satellite-based land-cover classification model detected 10 °C lower land-surface temperatures in urban landscape units containing tree canopy or some other form of green infrastructure compared to those dominated by artificial or impervious surfaces. The study estimated that each tree in the city mitigates the additional heat exposure of one heat-sensitive person (characterized as over 75 years old) by one day (Venter, Krog & Barton, 2020). The authors found that physical heat management strategies designed to enhance neighbourhood vegetation and albedo are expected to produce greater human health benefits where urban thermal hotspots and population vulnerability overlap than in other areas. This includes targeted physical land-cover interventions, resulting in enhanced vegetative cover and cool materials at the neighbourhood scale, as well as broadening conventional emergency response planning for heatwaves to include mitigation strategies focused on cool land covers in neighbourhoods with large or concentrated elderly populations. Heat mitigation strategies should therefore coordinate infrastructure systems through comprehensive planning, paying particular attention to vulnerable populations.

Overall, heat stress-resistant design of public spaces can provide cool spots and shelters for citizens offer examples for private builders. By considering hazard maps with information about hot and cool spots in the city (in combination with heatwave vulnerability maps), public buildings such as libraries, schools and swimming pools could become thermally safe environments for the most vulnerable people who cannot access or afford the cost of air-conditioning or other means of creating acceptable indoor conditions (Hatvani-Kovacs et al., 2018).

5.1.2 Strategies related to governance, communication and public engagement

Human adaptation mainly entails behavioural change; this should be aided by a communication strategy that provides specific guidelines and raises knowledge and awareness of the risks associated with exposure to extreme heat (WHO Regional Office for Europe, 2021a). Mitigation strategies can decrease the intensity of the UHI process, although not fully. Thus, adaptation should be encouraged and driven by policy-makers (Hatvani-Kovacs et al., 2018). Current policies addressing heatwaves are fragmented across disciplines and government departments, however, even though cross-departmental synergies could open new pathways – particularly departments of health, energy and water resources, urban planning and transportation, and the building and construction industry.

A review focusing on Australian cities found that policy papers about heatwave risk and resilience provide recommendations in general terms, missing specific solutions in many cases (Hatvani-Kovacs et al., 2018). Several policy measures are designed to increase urban heat-stress resilience:

- **information and engagement** – including communication, education and information dissemination – such as accurate, understandable and actionable heat–health alerts with efficient provision of information to help avoid "alert fatigue", real-time heat–health information via internet and mobile applications, location-specific heatwave risk maps and information on recommended adaptation techniques tailored for different social groups;

- **incentives and disincentives**, such as additional subsidies and taxes – for example, increasing the water use component of the water bill to reduce use, or local councils subsidizing the extension of green roofs and walls in exchange for the savings generated from the reduced stormwater runoff charged by utilities (Larsen, 2015);

- **government provision and demonstration** through construction of cool/heat-resilient infrastructure, such as "green" public buildings and public parks;

- **regulation**, such as a mandatory minimum green space ratio introduced in local planning regulations (including for residential gardens and other private open areas) to maximize green space between buildings, or regulation of the ratio of cool roofs and green roofs and walls by local municipalities (as established in Denmark, France and Singapore).

Table 4 summarizes the findings of the literature review presented in this subsection.

Table 4. Summary of urban management and planning strategies related to heatwaves and the UHI effect

Type of strategy	Description
Modification or design of physical infrastructure	• Improvement of **built environment performance**, including energy and water efficiency measures (e.g. thermal insulation, systems-based heating and cooling that take advantage of cooling towers or district distribution to save energy and reduce sensible heat discharge) • Design of **urban air flows and wind paths** to improve ventilation in summer or hot climates (e.g. planning low-rise buildings and linear parks, and taking advantage of dominant winds near static water bodies) • Application of **passive-cooling strategies** to buildings and their surroundings (e.g. increasing albedo through cool roofs and pavements, thermal insulation, shading, orientation and natural ventilation) • Application of **urban heat stress-resistant design** (e.g. using heatwave vulnerability maps) and **management strategies** (e.g. NBSs, reduced impervious surfaces, increased albedo of built surfaces)
Governance, communication and public engagement	• **Information** and **engagement** through communication and education on the health risks of exposure to heat • Creation of local **heat–health action plans** or active engagement in regional or national ones • Use of **incentives and disincentives** (e.g. additional subsidies and taxes on water use) • Government **provision and demonstration** (e.g. "green" public buildings, public parks) • Application of **regulations** (e.g. mandatory minimum green space ratios introduced in local planning regulations to maximize green space between buildings)

The evidence review did not identify any papers discussing the impact of cold, although this may be relevant for many cities as an extreme event – especially in southern regions where winter temperatures are moderate, and infrastructure and preparedness levels are therefore lower.[3] Box 2 sets out additional insights into the relevance of cold events, based on selected sources.

Box 2. Extreme cold events

Exposure to non-optimal temperatures during the day (or preceding days) has been associated with a range of adverse health outcomes, including excess mortality and morbidity from various causes. This includes exposure to both extreme heat and cold events. The search strategy and inclusion criteria for this review included articles focused on cold events, but none were identified in the original search. Despite the resultant inability to carry out a detailed review, considering the relevance of this hazard type, the following highlights from selected papers that address cold are provided.

- Europe is the only continent where both cold-related and heat-related excess death rates are higher than the global average (during 2000–2019), although the highest cold-related excess death rate is found in sub-Saharan Africa (Zhao et al., 2021).
- Cold affects city districts differently. A study in Madrid found that the most determinant factors in the detection of risks associated with cold are the proportion of households without heating systems, followed by the proportion of the population aged over 65 years (López-Bueno et al., 2020).
- Cold spells (events below a temperature threshold lasting for a minimum duration of two days) are associated with increased mortality rates, especially among elderly people and those with cardiovascular and respiratory diseases (Ryti, Guo & Jaakkola, 2016).
- To prevent the health impacts of cold spells, adequate strategies include – alongside clearing roads and continuation of public and basic supply services – establishment of warning systems and temperature alerts, housing insulation programmes, and adequate heating systems (Laaidi et al., 2013).

5.2 Flooding

Urban flooding can be caused either by external events (such as tidal surges or high upstream-to-downstream flows) or by heavy rain within the city (Richards & Edwards, 2018). Climate change results in increased flood hazards caused by rising sea levels, more rainfall and increased frequency and intensity of extreme weather events (Francesch-Huidobro et al., 2017). Many cities are exposed to extreme rain events that exceed the

[3] See, for example, the impact of a snowstorm in Jerusalem, Israel, discussed in subsection 5.3.3 in Urban planning for health – experiences of building resilience in 12 cities: second report on protecting environments and health by building urban resilience.

stormwater management capacity for which their infrastructure was originally designed, and this exposure will probably increase through the effects of climate change (Richards & Edwards, 2018). In fact, many cities identify floods as one of their main climate change-related challenges (Hatvani-Kovacs et al., 2018; CDP Worldwide, 2021).

The direct health effects of flooding are injuries and drowning, which are often the result of individuals attempting to drive or walk through or near flooded areas. The indirect health effects of flooding include:

- exacerbated respiratory diseases, such as asthma, caused by compromised indoor air quality in previously flooded buildings;
- risk of increased incidence of mosquito-borne diseases several weeks after heavy precipitation events if land-use configurations support larval development – particularly if the event ends a dry spell;
- waterborne diseases and infections of the eye, ear, nose, throat or skin caused by compromised water quality following flooding events; and
- mental health concerns associated with the loss of loved ones, population displacement, loss of property and economic hardship (Houghton & Castillo-Salgado, 2017).

In addition, flooding is likely to destroy or impair critical infrastructure including hospitals, fire stations and basic supply networks (such as water or energy), or to reduce accessibility for emergency services. Among the social groups particularly vulnerable to the negative effects of flooding are older people, who may have great difficulty fleeing to safe areas if waters are high, and whose numbers are growing in Europe (Szewrański et al., 2018).

5.2.1 Strategies entailing modification or design of physical infrastructure

A long tradition of urban planning and design research has aimed to protect cities from flooding. Many tried and tested techniques have been developed for planners to ensure that water is efficiently removed from urban surfaces – for example, by constructing culverts, regulating rivers and introducing flood defences such as embankments and diversionary channels (Richards & Edwards, 2018). Li et al. (2016) distinguished two types of flood-control measures: structural (including reservoirs, dikes, detention basins and pumping stations) and non-structural (such as flood forecasting, emergency planning and response, and post-flood recovery). Typically, protection measures such as dikes, levees and seawalls have a designed capacity. When the flood scale exceeds this capacity, the structural measures can fail, and the damage can be more disastrous. A flood-risk analysis applied in the Pudong area of Shanghai, China, showed that flood-control works can significantly reduce flood risk in the medium term, but that it is difficult to meet the increasing demands for flood control beyond a 66-year period solely by relying on structural measures.

Heavy rain can become a problem in cities mainly because rainwater is not retained by impervious surfaces such as roofs and roads but runs rapidly into low-lying areas (Richards & Edwards, 2018). Through innovative solutions, however, this could also become a resource. The most common strategy is to reduce the risk of flooding by removing stormwater as quickly as possible, increasing the capacity of the drainage network, which is usually a system of highly engineered channels constructed of concrete and devoid of vegetation. This type of grey infrastructure has several limitations, however, such as being designed to handle a particular volume of runoff water (capacity), not considering changes to the land use, and being based on the concept of a fixed climate (with non-significant rainfall variation over time). In addition, retrofitting such infrastructure to accommodate new criteria is generally complex and costly (Pour et al., 2020).

An alternative approach, which has been gaining increasing attention in recent years, is to delay the flow of water into the drainage networks (and thereby reduce the pressure on this infrastructure) by increasing the proportion of intercepting and permeable surfaces (Richards & Edwards, 2018). Examples of this are tree canopies, green roofs, rain gardens, retentions systems and porous pavements; these also known as “low-impact development techniques” (Pour et al., 2020). Such surfaces temporarily retain rainwater, allowing more of it to infiltrate the ground.

Traditional drainage infrastructure removes rainwater rapidly, reducing the time available for evaporation to occur and therefore limiting evaporative cooling. In addition, the concrete-based materials usually used in urban drainage systems have great capacity to store heat throughout the day and contribute to the UHI effect. For example, tree canopies can slow the flow of water to the ground, where permeable surfaces allow a high proportion of water to infiltrate into the soil. Then, complex river networks with interconnected ponds and wetlands can provide overflow capacity for surplus water during periods of high flow (Richards & Edwards, 2018). These are commonly referred to as “sustainable urban drainage systems”, and they have great potential to be integrated into urban development plans.

Water-sensitive urban catchment management or design aims to apply ecological mechanisms wherever possible to regulate the flow of water and slow its movement into the drainage network. Technical solutions include (Richards & Edwards, 2018):

- infiltration systems that allow water to pass beneath impermeable surfaces (such as permeable pavements);
- bioretention systems that combine permeable surfaces with vegetation to increase evapotranspiration (such as rain gardens and swales);
- green roofs and green walls; and
- off-channel waterbodies that provide emergency flood storage areas when flows are high .

Costa et al. (2021) used a numerical flooding model to assess the effects of nature-based solutions (NBSs) – such as green car parking, green roofs and water storage on streets – to reduce flooding in the city of Eindhoven in the Netherlands, which has a history of urban flood events. They found that, overall, the simulated NBSs were effective in flood-risk mitigation, but the effectiveness tended to increase with an increase in NBS surface area, while it tended to decrease with increasing storm intensity. NBSs increasing street water storage were revealed to be more effective than those involving green car parks and green roofs.

5.2.2 Strategies related to governance, communication and public engagement
In practice, urban adaptation is closely tied to water issues, but institutionally these are largely separate (Huang-Lachmann & Lovett, 2016). For instance, municipalities are only generally responsible for protection from minor waterways, while regional administrative bodies have legal responsibility for major rivers (Patterson & Huitema, 2019). In fact, flood risks in a city can be strongly influenced by factors outside the city boundaries, such as upstream river management. Flood-risk management infrastructure (such as natural water-retention areas) may also be located at a considerable distance from downstream sites potentially exposed to flood hazards, and may often be within a different jurisdiction (Carter et al., 2018). This presents significant planning and governance challenges, and necessarily entails effective and efficient communication between bodies (local, regional and possibly national) – for instance, on risk assessment and response mechanisms.

Municipalities have only recently started to consider the issue of climate-change adaptation in planning and governance. Consequently, anticipatory measures remain rare and mainly relate to traditional flood-protection measures (such as embankments and pumping stations). In this context, municipalities often see their main – or only – task as putting pressure on higher-level authorities to take the necessary action. At the same time, more stringent regulation is helping to reduce flood-related risks, and NBSs are increasingly considered for both heat stress and flood mitigation (Wamsler, 2016). Interest is also growing, however, in exploring local-scale adaptation strategies – such as how public spaces in the urban environment can contribute to effective adaptation undertakings, as well as serving as spaces for community awareness and engagement in climate-change adaptation (Silva & Costa, 2018).

After a number of previous disasters, several German municipalities carried out improvements in longer-term planning and preparedness, mainly related to information provision (including emergency hotlines and online information) and improved compliance management mechanisms, such as flood-proofing domestic oil tanks (Wamsler, 2016). The city of Paignton, United Kingdom, developed an integrated participatory methodology to enhance the resilience of interconnected critical infrastructure to urban flooding under climate change (including climate-hazard scenario simulations, calculation of related cascading effects, economic valuation of the damage and cost/benefit analysis of each possible solution). The decision was made to build a second sea wall behind the pre-existing one so that the area between them would be flooded, but the flood would not expand further inland (Vamvakeridou-Lyroudia et al., 2020).

To promote effective river-basin management in urban areas and reduce runoff, the Government of Japan established a registration system called “Safety plan for 100 mm/hour rainfall” – a scheme for preventing and mitigating inundation caused by extremely heavy, short-term rainfall. Yamashita et al. (2016) explored how municipalities used this registration scheme effectively for watershed management, and found that in general they were not very active in promoting runoff reduction by subsidizing private facilities. They also found little community involvement in public works for runoff reduction (except when plans are devised with relatively new committees of watershed management). Further, registration did not necessarily strengthen public awareness of risk management.

Axelsson et al. (2021) studied the management approach to cloudburst events in six developed cities (New York City, United States; Vancouver, Canada; Sydney, Australia; Auckland, New Zealand; Copenhagen, Denmark; and Amsterdam, Netherlands) and found that, despite appearing to adopt different approaches, all used a mixture of five common policy alternatives to manage stormwater runoff:

- grey infrastructure overhauls (managing, updating and adapting existing grey infrastructure under a perpetual level of uncertainty about how climate change will affect rainfall volumes);
- public green infrastructure (projects undertaken on public property or essential public infrastructure that is largely funded by the government – a largely popular policy alternative within the case cities and the predominant focus of future developments);
- private green infrastructures (projects undertaken on private property that are largely financed privately or with government incentives – essential in securing urban areas against cloudburst flooding);
- government streamlining (a mixture of government reorganization – particularly the merging of water, stormwater and wastewater systems – civil servant education and producing a framework for management goals, which is crucial in effective urban rainfall management due to the sectorization of the issue); and
- maintaining urban environments – an assortment of actions for protecting infrastructure, removing blockages and mitigating flood damage, in which street-litter management, catch-basin management, land-use planning (managing urban sprawl and providing guidance for concentrated growth) and citizen education are fundamental steps.

Table 5 summarizes the findings of the literature review presented in this subsection.

Table 5. Summary of urban management and planning strategies related to flooding events

Type of strategy	Description
Modification or design of physical infrastructure	• **Grey infrastructure**: reservoirs, dikes, detention basins, pumping stations and water removal structures (e.g. drainage networks, culverts, regulation of rivers and introduction of flood defences such as bunds, embankments and diversionary channels) • **Green and blue infrastructure**: use of **intercepting and permeable surfaces** using low-impact development techniques (such as NBSs) and **water-sensitive urban design** (e.g. infiltration or bioretention systems, green roofs and walls, and off-channel waterbodies)
Governance, communication and public engagement	• **Improved communication** between government bodies at different levels • Exploration of **local-scale adaptation strategies** and **regulation** strengthening to reduce disaster-related risks • **Flood forecasting, emergency planning and response**, and **post-flood recovery plans** • Information provision on flood-related risks and responses (e.g. emergency hotlines and online information) • Promoting **compliance with current regulations** (e.g. flood-proofing domestic oil tanks)

5.3 Storm events

Storm events (including hurricanes, typhoons and tropical storms) involve heavy rain and wind, and can trigger many cascading effects, including flooding, building/infrastructure damage or collapse, and critical infrastructure failure. For instance, in the United States in October 2012, "Hurricane Sandy" [4] disrupted power for over 2 million city residents, many of whom were without electricity, water and heat for an extended period. Among the direct health effects were disruptions in dialysis treatment, increased emergency room visits for renal and respiratory-related conditions and an increase in carbon monoxide exposure and poisoning (Dominianni et al., 2018). The literature search provided very few results specific to storm events. Studies reporting on hurricanes, typhoons and tropical storms were all focused on lessons learned from past events for better future preparedness; however, the issues covered were often not directly linked to urban design and planning, but rather focused on emergency response plans, protocols, training, risk perception and personal preparedness. Nevertheless, several strategies covered in subsections 5.2 on flooding and 5.5 on infrastructure failure are included here as they are considered relevant, given the usual impacts of heavy rain and wind on cities.

5.3.1 Strategies entailing modification or design of physical infrastructure

Chan et al. (2019) listed a number of measures specific to storm preparedness, among which are:

- taping windows to reduce shattered glass pieces for injury prevention;
- collecting or tying down items that can be blown away to reduce the risk of impacts; and
- anti-flooding and leaking measures to reduce the risk of falls and injuries due to slippery surfaces, or allergies from airborne toxins related to mould and fungi.

These measures should be adopted in combination with more general emergency preparedness measures, such as ensuring:

- food security to maintain proper nutritional intake;
- access to clean water for sanitation, hydration and food preparation;
- availability of both basic and long-term medication for chronic diseases;
- access to a first aid kit with basic supplies;
- availability of a back-up light and electrical source; and
- availability of fire-extinguishing equipment.

Strong winds and heavy rain in cities often cause floods and infrastructure failure (including power outages). Strategies specific to flooding events – such as construction and/or overhaul of flood retention infrastructure and drainage networks (Li et al., 2016; Richards & Edwards, 2018) – and water-sensitive urban design or low-impact development techniques using NBSs – such as infiltration or bioretention systems, green roofs and walls, off-channel waterbodies, porous pavements (Richards & Edwards, 2018; Pour et al., 2020; Costa et al., 2021) – may help to mitigate the impacts and avoid or minimize the cascading effects of this type of event.

Other strategies specific to infrastructure failure could ameliorate delays in household recovery after a hurricane (Mitsova et al., 2019). These include addressing redundancies[5] in the energy supply network, identifying critical links and vulnerability to disruption in the roadway network (Mera & Balijepalli, 2020)

[4] Hurricane Sandy was a tropical cyclone that hit Atlantic City (New Jersey, United States of America) on 30 October 2012, directed onshore by a trough in the eastern United States and a ridge over far-eastern Canada. Its strong, sustained winds and storm affected 21 states and left an estimated US$ 78–97 billion in damage (Cole et al., 2017).

[5] "Redundancies" relate to a system designed with multiple nodes to ensure that failure of one element or component of the system does not result in failure of the entire system (Pourezzat, Nejati & Mollaee, 2010).

and estimating the degree of interdependence or dependence across the entire sociotechnical system that provides services to an urban region (Comfort, 2006) – such as through disaster-chain analysis (Tang, Xia & Wang, 2019). This could also hold true for other events such as floods or pandemics.

The *Urban adaptation in Europe: how cities and towns respond to climate change* report (EEA, 2020), although not included in the original literature review, includes several strategies that entail modification or design of physical infrastructure to mitigate the impacts of storm events (Box 3).

Box 3. Strategies against storm impacts

Moving power infrastructure underground can avoid prolonged power disruptions, as was evidenced in Sweden when Storm Gudrun hit in 2005. While cabling in urban areas was already underground, which meant power could be restored within hours, it took up to 20 days to return power to rural areas because of extensive damage to above-ground power infrastructure. Replacing vulnerable vegetation (e.g. tall conifers) and planting wind-resistant species (e.g. broadleaved trees) near homes and other assets could prevent damage to buildings and infrastructure from falling trees. Moving debris and mature vegetation away from transport infrastructure could also help prevent disruptions.

Source: EEA (2020).

5.3.2 Strategies related to governance, communication and public engagement

Studies focused on hurricane and typhoon experiences seem especially relevant in terms of preparedness measures such as raising public knowledge and awareness; preparing inventories, protocols and organizational systems for a more effective response; and promoting the importance of emergency drills (especially among medical personnel). A paper examining the impacts of Hurricane Katrina[6] on the city of New Orleans, United States (Comfort, 2006) found that, in addition to inadequate maintenance of critical infrastructure and lack of public knowledge or previous experience of storms of such magnitude, increasing unemployment rates had left approximately 25% of the city's inhabitants living in poverty and without means to leave the city prior to the event. Another study on the emergency response to Hurricane Katrina (Broz et al., 2009) identified a series of key operational successes and failures. For instance, the inventory of potential sites for emergency response centres proved inadequate, and there was a need to create key organizational systems (including medical information systems) during the response; this reduced the efficiency of the medical services. In addition, previous emergency drills were generally considered inadequate or insufficient. These findings confirm the importance of a clear, comprehensive and well communicated emergency response plan that can be tailored to disasters of various types, sizes and proximities – especially for other sudden-onset events, such as floods.

Chan et al. (2019) explored the association between risk perception and household preparedness and the self-reported impacts of 2018's Typhoon Mangkhut for urban residents of Hong Kong Special Administrative Region (Hong Kong SAR), China. They found that, while only 10% of respondents perceived their homes to be at high risk of danger during typhoons, the proportions undertaking emergency preparedness in general (93%) and typhoon-specific preparedness measures specifically (74%) were very high. Only 6% of respondents reported undertaking no preparedness measure at all. However, carrying out typhoon-specific preparedness measures was not associated with a reduction in short-term household impacts, suggesting that current preparedness measures may be insufficient.

Table 6 summarizes the findings of the literature review presented in this subsection.

[6] Hurricane Katrina, a Category 4 hurricane with winds of up to 145 miles per hour, made landfall slightly east of New Orleans on 29 August 2005. Later that day, one of the levees the city depended on to keep dry and operational was breached because of the storm, allowing the waters of Lake Pontchartrain to flood the city. The destruction left the entire city uninhabitable, with no functional services – communications, water, electrical power, sewerage, transportation and gas distribution – for weeks. Mandatory evacuation was the only possible course of action. The event resulted in over 1300 fatalities, 1.5 million people displaced from their homes, 60 000 million homes totally destroyed, and an estimated US$ 250 billion of disaster assistance and rebuilding costs (Comfort, 2006) .

Table 6. Summary of urban management and planning strategies related to storm events

Type of strategy	Description
Modification or design of physical infrastructure	• **Household preparedness measures** for injury prevention (e.g. taping windows, collecting potentially harming items, and anti-flooding and leaking measures) • **Personal preparedness measures** including provision of food, personal hygiene products, medication and equipment • **Critical infrastructure overhauls** (e.g. flood retention infrastructure and drainage networks, and electricity and water supply networks) • Moving **power infrastructure** underground • **Replacing vulnerable vegetation** and planting wind-resistant species near homes and other assets • Moving debris and mature vegetation away from **transport infrastructure**
Governance, communication and public engagement	• Increasing **public knowledge** and **risk awareness** related to storms to improve personal preparedness • Preparation of **medical information systems, inventories, plans** and **protocols** to increase medical and technical service efficiency during emergency response and recovery • Promotion of **emergency drills** for various hazards among the population, and especially among medical personnel • Development of a clear **communication emergency response plan** for different types, sizes and proximities of disasters

5.4 Earthquakes

Earthquakes are low-probability and high-impact natural hazards (Tang, Xia & Wang, 2019) that can trigger a great number of cascading effects, amplifying the impacts on health, infrastructure and the economy. For example, an earthquake may induce landslides by affecting the geological slopes in the urban area, resulting in power outages and other critical infrastructure failure. The risks of earthquakes related to health – beyond injury and death due to building collapse – are fire, contaminated water supply and electrical failure; these can have short- and long-term health impacts. Capacity to predict them is still quite limited, and the literature seems to point to building stock complying with current seismic resistance standards (to avoid collapse) being the most critical factor. Beyond the structural resistance of buildings, other articles on earthquakes and their effects on cities mention the importance of urban planning aspects such as the urban structure (including its compactness); sufficient size and distribution of open spaces for safe evacuation shelters; and a road network that facilitates adequate evacuation routes.

5.4.1 Strategies entailing modification or design of physical infrastructure

Urban planning and design can provide earthquake evacuation shelters in public spaces, offering key elements to reduce earthquake disaster risk and protect lives. These depend on multiple criteria, and necessarily need to be implemented in an existing (or projected) urban context, thereby potentially influencing urban planning decisions. For instance, in the great Hanshin or Kobe Earthquake in Japan (1995), more than 1000 city parks were used as earthquake evacuation shelters. Xu et al. (2016) proposed a series of planning and siting requirements for earthquake evacuation shelters, among which are principles such as:

- avoiding any potential risks (e.g. fault lines, liquefaction risks and chemical warehouses);
- government control over the land and use rights (e.g. city parks, schools and sports facilities);
- proximity to residential areas, with easy access for residents (meaning that spatial distribution and number of shelters should be adapted to suit the population density of the urban area); and
- economic viability of the investment.

Batsaris et al. (2019) also highlighted the importance of spatial distribution, size and capacity of urban evacuation shelters, including applying a slope restriction (under 5%) to the selection criteria. They indicated that shelter sites in urban areas are preferred to periurban sites, with the aim of serving the population within acceptable walking distance.

Planning for sufficient evacuation-route width to avoid or minimize blockage is important, as is anticipating risks linked to certain urban elements – such as risk of explosion in proximity to fuel stations or gas-pressure regulating and metering stations (Nasrollahi & Behnam 2018). The significant increase in population density in a specific area of the city with a high concentration of public buildings (such as schools), potentially causing obstructions and traffic jams in the event of an evacuation, should also be considered. A methodology using geographical information system (GIS) tools focuses on evaluation of the vulnerability of the relevant itineraries of evacuation routes, addressing one of the most pressing problems that may occur in the event of an earthquake: the impossibility of reaching the affected areas owing to obstructions on road infrastructures (mainly because of collapses) (Francini et al., 2018).

Although it is critical to mitigate the impacts, predicting the cascading effects of earthquakes is a complex challenge for urban planning and design. It often entails scenario-wise thinking – holistic and innovative approaches that facilitate identification of the potential hazardous events involved and their spatial or functional interrelationships. Tang, Xia & Wang (2019) proposed a network analysis model that provides guidance on developing cascading-effects scenarios of earthquakes in urban areas – such as dam emergencies and breakages, building collapse, traffic disruption or leakage of hazardous chemicals and toxic substances.

A study of seismic events in Italy showed the significance of adequate planning and design, noting that the resilience of buildings appears to be independent of seismic intensity, but is directly dependent on their seismic vulnerability (Vona, Harabaglia & Murgante, 2016). This highlights the importance of having up-to-date information on building stock characteristics (Elwood et al., 2020) and – in particular – of improving buildings' structural resistance to seismic events. This is especially critical for public service buildings and transport and supply networks (such as water, energy or sewage). A proposed GIS seismic vulnerability assessment of historical centres led to a list of aspects and elements crucial to emergency design and planning of buildings' surroundings, as well as to the urban context where they are applied (Anglade et al., 2020). These include evaluation of evacuation roads, identification of potentially inaccessible urban areas, estimation of potentially isolated people, and definition of evacuation routes and gathering areas.

A common consequence of earthquakes in urban areas is post-earthquake fire, which is considered one of the most complicated problems affecting buildings in urban areas. The initial fire resistance of the buildings' structure, calculated for a normal situation, may have declined significantly owing to damage caused by the earthquake. These fires can cause more damage than the earthquake itself, although this risk is not usually incorporated into the design process (Behnam, Skitmore & Ronagh, 2015). Thus, designing or retrofitting disaster-resistant buildings should be included in the city design process, considering both potential earthquake damage and its effect on fire resistance (Anglade et al., 2020). This is especially important in old city centres, where contemporary planning guidelines have not been considered. A number of factors have been identified as potential contributors to increasing fire risk (Ferreira et al., 2016):

- combustible materials present in traditional buildings;
- high density of buildings in old city centres with narrow street widths;
- wall sharing between adjacent buildings;
- inadequate adaptation of buildings to non-residential purposes;
- proliferation of unoccupied or derelict buildings, frequently storing large amounts of combustible materials; and
- the existence of old electrical installations with a lack of maintenance, which is one of the main causes of the fire risk of old building stock.

5.4.2 Strategies related to governance, communication and public engagement

While it is difficult to predict catastrophic incidents with a sudden onset such as an earthquake, training remains a key element of urban preparedness for this type of event. Lovreglio et al. (2018) proposed using virtual reality and serious games as novel techniques to overcome traditional training approaches and enhance preparedness in public buildings. Local governments often do not have the best available information about the state of buildings in their city; this hinders their capacity to predict and assess risks, or to introduce new ideas regarding prioritization of retrofits and the optimized regulatory structure to address the risk. According to Elwood et al. (2020), this issue proved to be a source of significant policy uncertainty after the 2016 Kaikoura Earthquake in New Zealand.[7] Triggered by this experience, the authors initiated a building inventory database for the city of Wellington; this includes georeferenced structural, economic and market information on practically all significant buildings in the most affected district. A study of the immediate response to earthquakes, published in the aftermath of the 2003 earthquake in Bam, Iran,[8] highlighted the importance of a clear data-flow diagram-based system and a holistic approach to managing operations and the various organizations involved in the rescue process (Pourezzat, Nejati & Mollaee, 2010).

Urban planners and health officials should be very aware that, when an earthquake hits a city, relocation of the population may have huge consequences; therefore, some aspects need to be considered as part of midterm planning after emergency evacuations. When the destruction of property is extensive, individuals are relocated to temporary shelters for varying degrees of time, depending on the circumstances. Reconstruction of homes can occur within months, but in some cases can take years (Najarian, Majeed & Gasparyan, 2017), or may even never be fully achieved so that shelter accommodation becomes permanent. The Italian Government began construction of 19 "new towns" on the outskirts of L'Aquila after the earthquake of 2009.[9] These towns sought to house over 15 000 people (of the over 65 000) who had lost their homes due to the disaster, but they were built in rural areas, far from the city centre, and lacked many basic services and access to public transportation. A study based on interviews with residents of three of these new towns (Grappasonni et al., 2017) found high prevalence of post-traumatic stress disorder (PTSD) and high levels of dissatisfaction with their living situation. Many respondents saw the new towns as "non-places" – far from their main memories, without residential and

[7] New Zealand shares its seismic risk profile with many other countries located along the Pacific Ring of Fire, which is considered the most earthquake-prone region in the world. The Kaikoura Earthquake of 14 November 2016 had a magnitude of 7.8 Mw. Although its epicentre was in New Zealand's South Island, about 200 km southwest of Wellington, it damaged numerous buildings across the city; especially in the central business district (Mitsova et al., 2019).

[8] On 26 December 2003, an intense earthquake measuring 6.6 Mw shook a large area of the Kerman province in Iran, approximately 5 km southeast of Bam city. The events led to the loss of over 26 000 lives, and over 30 000 people were injured. Tens of thousands of survivors became homeless and were displaced, and many historical buildings and properties were destroyed (Newman, 2020).

[9] An earthquake with a magnitude of 6.3 (Mw) struck the town of L'Aquila in central Italy on 6 April 2009, causing 309 deaths. 1600 people were injured, 200 were severely injured and hospitalized, and more than 65 000 were displaced. Many buildings collapsed, and large parts of the town were destroyed (Francesch-Huidobro et al., 2017).

planning references, and detached from social bonds. According to the authors, abandoning their homes could be considered an additional trauma. More than 40% of people living in the new towns either tried to return to their homes of origin or sought to find autonomous accommodation more suitable to their needs.

A 20-year follow-up study in Armenia examined the effect of relocation on individuals' adaptation after exposure to an earthquake in 1988. It found that most people exposed to the earthquake who remained in the affected city continued to experience PTSD 20 years after the event (30% meeting the criteria for full PTSD and 56% for partial PTSD). Levels of PTSD among the people who relocated were significantly lower. In this case, the reconstruction was delayed, and political and economic circumstances interfered with a return to normal life (for instance, massive unemployment and limited access to water, heat and electricity). This suggests that permanent relocation away from the city affected by the disaster may provide more adaptive functioning and less emotional disturbance, even in the presence of considerable stress in re-establishing a new life (Najarian, Majeed & Gasparyan, 2017). The capacity to return to a state of equilibrium after an earthquake depends on political choices and on economic resources, which are significantly involved. An analysis of several recent case studies in Italy concluded that recovery time has always been notably long – much longer than that predicted using available simplified models (Vona, Harabaglia & Murgante, 2016).

Table 7 summarizes the findings of the literature review presented in this subsection.

Table 7. Summary of urban management and planning strategies related to earthquakes

Type of strategy	Description
Modification or design of physical infrastructure	• Opening safe urban areas as **earthquake evacuation shelters** – considering their distribution, size and capacity throughout the city, access from residential areas, land-use rights and avoiding potential risks (such as fault lines, liquefaction risks or chemical warehouses) • Development of **evacuation routes** and safe gathering spaces within buildings' surroundings • Designing or retrofitting **disaster-resistant buildings** (improving structural resistance to both earthquakes and fire) • Designing **new developments for relocation** of displaced populations – considering access to services (e.g. public transportation) and place attachment, and involving the community throughout the process
Governance, communication and public engagement	• Improving **prediction methods** and **scenario-wise thinking approaches** to **seismic vulnerability assessments** (considering potential cascading effects) • Provision of **updated information on buildings' use and state** (e.g. year of construction, predicted structural resistance to earthquakes and other potential vulnerabilities – such as shared walls with other buildings or narrow access routes for evacuation and rescue) • Consideration of health impacts (short- and long-term) of **relocation** of the population after emergency evacuations

5.5 Industrial accidents and infrastructure failure

Urban planning and design shape cities and their infrastructure by making decisions on location, functionality, interdependencies and robustness of urban amenities and critical infrastructure. Preventing their failure and ensuring sufficient redundancies within service infrastructure are important elements for urban resilience, as infrastructure failure can be a primary hazard event or – most commonly – a cascading effect of many other hazards (such as heatwaves, floods, storms and earthquakes). Industrial accidents, such as chemical spills or nuclear accidents, can have both immediate and long-term health impacts that can affect cities. Energy supply failures (power outages) were found to be the issue most addressed in the literature, although the original search criteria included literature focused on other industrial accidents.

Power outages can greatly affect public health. For example, the August 2003 outage in the northeast United States, which affected the entire city of New York, has been associated with increased risk of all-cause mortality and respiratory hospitalizations. It disrupted refrigeration, potable water-pumping equipment in buildings with more than six floors, and elevators – compromising water and food safety, and stranding residents in their apartments (Dominianni et al., 2018). A cross-sectional survey of infrastructure service disruptions and post-disaster recovery following Hurricane Irma[10] showed that infrastructure disruptions – particularly electric power outages – delay household recovery (Mitsova et al., 2019). Another study on this case found positive spatial dependence between electric power outages following the hurricane and three socioeconomic variables: minority groups; populations with sensory, physical and mental disabilities; and economic vulnerability – expressed as the unemployment rate (Mitsova et al., 2018).

Among the most common causes of power outages are heatwaves (when there is peak electricity demand from air-conditioning), strong winds from storms, floods, ice and snow during winter (and especially with extreme cold

[10] Hurricane Irma (30 August–12 September 2017) caused property damage and disruptions to the electric power system throughout 30 counties in central and southern Florida, United States (Grappasonni et al., 2017).

events), lack of maintenance and old infrastructure. Groups vulnerable to health risks from power outages include older adults, people who rely on a caregiver to perform daily activities, and those who depend on electric medical devices and medical facilities. These populations often have more health problems and medication needs, and/or limited mobility (Dominianni et al., 2018). Low-income households and people living in high-rise buildings are also often considered vulnerable to power outages in the literature (Garschagen & Sandholz, 2018).

An added consequence of electricity blackouts is their potential damage to existing technical means of communication, which undoubtedly creates further difficulties in transmitting timely, accurate information during an emergency response, and strongly limits capacity to coordinate and assist those in need. This results from the rising societal dependence on technology, the ever-growing connectedness of infrastructure systems, and the growing global connectedness of people, production, trade and communication (Garschagen & Sandholz, 2018). For example, the failure of communication systems in the aftermath of 2005's Hurricane Katrina in the United States exacerbated enormously the difficulties with coordination between agencies and jurisdictions. Furthermore, little knowledge appeared to be shared among organizations operating at different jurisdictional levels prior to the disaster, and confidence in information exchanged between them was low (Comfort, 2006).

5.5.1 Strategies entailing modification or design of physical infrastructure

Electricity blackouts caused by overdependence on the electricity grid (especially during heatwaves, with use of air-conditioning) could be addressed during the planning stage with solutions such as redundancies, back-up systems or generators for critical infrastructure – such as for hospitals, pharmacies and so on (Santamouris & Cartalis, 2015; Araos, Austin et al., 2016; Garschagen & Sandholz, 2018). Installing power infrastructure underground (see Box 3 above) can also help to avoid prolonged power disruptions (especially in the event of strong winds).[11]

Innovative solutions, such as integrating energy generation systems like micro wind turbines and photovoltaics, can enhance diversity and redundancies of energy supply (Sharifi, 2021), as can building large, commercial batteries for frequency control and to store generated electricity. Such batteries can increase the stability of the electricity grid – charging from adjacent wind farms before electricity demand peaks during heatwaves, and discharging during peaks. Implementation of smart meters in households can also facilitate monitoring of population consumption patterns and compliance with regulations (Hatvani-Kovacs et al., 2018).

Another consequence of electricity blackouts can be failure of transportation systems. After the rail system in Adelaide and Melbourne, Australia, failed in 2009 during a heatwave, leaving daily commuters stranded outdoors, Hatvani-Kovacs et al. (2018) proposed that transport planning and management should include preparation strategies such as cooling rails with cold water following heatwave alarms, replacing wooden rail sleepers with more heat stress-resistant concrete sleepers where appropriate, providing timely communication about non-operating train lines, and providing alternative transportations such as buses.

Land transportation networks are heavily reliant on extensive land-based infrastructure such as roadways and railways, and this requires proper planning and maintenance. It can be affected by undesired events such as flooding, landslides or earthquakes, which deteriorate roadway capacity and eventually cause complete loss of connectivity. A mathematical model developed by Mera & Balijepalli (2020) to support planning decisions identified critical links and vulnerability to disruption in the roadway network, factoring in budgetary constraints, in order to develop a plan to minimize disruption to the network caused by natural incidents.

One of the main challenges for planners attempting to prevent or prepare for infrastructure failure is that the vulnerability of the technical systems that support basic operations in a city cannot be calculated separately; rather, the calculations must be based on careful estimates of the degree of interdependence or dependence across the entire sociotechnical system that provides services to an urban region. For instance, the most devastating effect of Hurricane Katrina in 2005 – the flooding of the city of New Orleans, United States – was due to the failure of the levees the city depended on to remain dry and operational. According to Comfort (2006), the levee system had not been adequately maintained, and requests for federal financing to reinforce it had been turned down repeatedly in previous years. Furthermore, an issue of dependence between the levee system and the pumping stations meant that, once the levee (which was holding back the waters of Lake Pontchartrain) was breached, the flood overwhelmed the pumping stations in the city's system of flood control and the electrical generators that drove them.

Other types of dependency may be spatial – as when distribution systems overlap physically for economic efficiency reasons (for example, if gas mains are located close to underground water and sewer mains), or temporal – when the sequence of time is critical to the performance of related systems. Sometimes poor spatial planning can mean, for instance, that two facilities handling hazardous substances are close to each other; this may make sense from a logistics point of view but could also lead to the effect of two accidents combined (such as a spill in one facility that causes an explosion or chemical reaction in the other). Disaster-chain analysis methods focus on interactions between hazards and elements at risk with specific vulnerabilities (Tang, Xia & Wang, 2019). A study on recovery and reconstruction after a nuclear disaster, focusing on the potential of NBSs to contribute to enhancing urban resilience in post-disaster settings, studied the area in Futaba County, Fukushima Prefecture,

[11] As shown in the case studies in Urban planning for health – experiences of building resilience in 12 cities: second report on protecting environments and health by building urban, Flix (Spain) experienced greater exposure to power outages as a consequence of a forest fire due to above-ground power infrastructure, while Helsinki (Finland) had implemented an entirely underground power network, which minimized the risk of power outages in the event of strong winds and/or floods.

Japan, after the 2011 earthquake, tsunami and nuclear disaster[12]. It found that implementation of NBSs as part of the recovery and reconstruction plan (such as involvement in tree-planing for coastal forests, collaborative management of green and open spaces, and organization of culturally meaningful festivals linked to the landscape) was critical to recovering a sense of identity and pride among locals (Mabon, 2019).

5.5.2 Strategies related to governance, communication and public engagement

Energy, water, food, transport, telecommunications, health, and banking and finance are generally considered "critical infrastructure", which requires increased efforts in planning, design and management to be protected against external factors and remain functional. Across most contexts and sectors, duties and responsibilities during management of a disaster situation are shared between government authorities and the private infrastructure providers that usually take care of the supply under normal conditions (Garschagen & Sandholz, 2018). It is therefore crucial to establish roles and responsibilities among parties, and to have emergency plans and protocols in place for effective response and recovery in case of an emergency, as well as tools to assess damage and monitor the response. Night-time satellite imagery to detect power outages in urban areas proved a useful tool to identify the location and scale of the initial loss of light following Hurricane Sandy in 2012, as well as the gradual restoration of electrical power (Cole et al., 2017).

According to Garschagen & Sandholz (2018), after the Fukushima disaster, the European Union (EU) gave increasing attention to assessing the exposure and sensitivity of critical infrastructure and the crisis contingencies in their management. This approach does not adequately link with the domain of social vulnerabilities, however, and the differential impacts of critical infrastructure failure on different parts of society (derived from different hazard and crisis scenarios) are not yet well understood. Vamvakeridou-Lyroudia et al. (2020) proposed a methodology based on co-design and participation to enhance the resilience of interconnected critical infrastructure to urban flooding under climate change, assessing the risk and introducing adaptation measures into various climate-hazard scenarios. Providing minimum supply to those social groups that might need it the most has a number of challenges, however. For instance, the infrastructure behind most services (such as electricity and water) is designed for large system entities. In a multiapartment block, for example, vulnerable residents can live next door to others who are not considered vulnerable, and the electricity grid cannot deliberately supply at such a high resolution, as it functions in much larger entities such as neighbourhoods (Garschagen & Sandholz, 2018).

Therefore, in addition to technical innovations, it is crucial to increase awareness about power outages. This may include people – especially those at risk – registering with a utility company to receive early notification of outages (Dominianni et al., 2018), or companies providing instructions to the community on how to avoid non-life-threatening consumption during peak hours of electricity demand (Hatvani-Kovacs et al., 2018).

Table 8 summarizes the findings of the literature review presented in this subsection.

Table 8. Summary of urban management and planning strategies related to industrial accidents and infrastructure failure

Type of strategy	Description
Modification or design of physical infrastructure	• Promoting **systems independence** (electric, spatial, temporal) through redundancies, back-up systems or generators for critical infrastructure • Moving **power infrastructure underground** • Development of **innovative technical solutions** such as large, commercial batteries for frequency control and to store generated electricity • Implementing **smart meters** in households to monitor electricity use • Development of emergency **preparation strategies** for transport planning and management (e.g. cooling rails after heatwave alarms, providing communication about non-operating train lines and providing alternative transportation) • Promoting **NBS co-design** to enhance urban resilience and recovery of a sense of identity and pride among locals after a disaster
Governance, communication and public engagement	• Increasing **community awareness** of electricity use and risks of power outages • Use of **night-time satellite imagery** for power outage detection (including scale and location) and monitoring gradual supply restoration • Enhancing the **resilience of interconnected critical infrastructure** through co-design and participation by assessing the risks and introducing adaptation measures into various climate-hazard scenarios • Ensuring adequate **decision-making and prioritization** for intervention planning

[12] On 11 March 2011 an earthquake with a magnitude of 6.6 Mw struck northeast Japan, triggering a large tsunami. 212 people in Futaba County were either killed immediately or remain missing (Mabon, 2019). The earthquake and tsunami also disabled cooling systems at the Fukushima Dai'ichi Nuclear Power Plant, located on the border between the towns of Okuma and Futaba. The resulting meltdowns and hydrogen explosions released radiation over the surrounding land and sea. Evacuation orders were issued for all eight municipalities in Futaba County, as well as some beyond. The orders have since been lifted or refined, depending on progress in decontamination and understanding of local contamination (Francesch-Huidobro et al., 2017).

5.6 Emerging questions arising from the COVID-19 pandemic

This subsection presents an analysis of a selection of the literature on how the COVID-19 pandemic has affected cities and, especially, on lessons learned and how planning and design can help to protect health and well-being while preventing or minimizing the spread of the virus. This needs to be approached with caution, as the event is very recent, and evidence on its impact and related urban planning implications is still evolving worldwide. Nevertheless, interesting questions and reflections have emerged regarding urban planning/design and public health, and existing approaches to urban development are being re-evaluated.

The compact versus dispersed urban model discussion (see subsection 6.5 for further detail) has been the main focus of most of the analysed literature explicitly linking urban planning/design and the COVID-19 pandemic. The COVID-19 outbreak raised the question of whether compact urban developments are still a desirable model, as dense areas (in theory) lead to more face-to-face interaction among residents, potentially escalating incidence of contagious diseases and making them hotspots for the rapid spread of pandemics (Francesch-Huidobro et al., 2017). In this sense, at-risk residents could be identified as those particularly affected by compact living and commuting, with transit-dependent populations experiencing a workplace–residence separation that is further exacerbated by the digital divide (Banai, 2020). In addition, many articles highlighted the importance of sufficient and accessible public green space throughout the city; others investigated potential changes to the design, use and perception of public space; and some reported on the usefulness of smart city technology for public health crises.

The novel coronavirus brought to the fore the issue of urban vulnerability to pandemics, showing the need for preparation, response and adaptation measures (Sharifi & Khavarian-Garmsir, 2020). The dynamics behind pandemic spread are highly complex, and several variables could confound contagious disease transmission (and access to health care), including demographic characteristics, socioeconomic disparities and tourism. Urban residents who are subject to overcrowding, who lack access to safe drinking-water and proper sanitation, or who live in inadequate housing – such as populations living in slums – can be especially susceptible to infectious diseases (Hamidi, Sabouri & Ewing, 2020). A study in the United States suggested that structurally vulnerable neighbourhoods (characterized by higher pollution levels, limited walkability, lower quality housing stock or fewer resources – including accessible health care) may contribute to racial or ethnic inequities in SARS-COV-2 exposure and COVID-19 morbidity and mortality (Berkowitz et al., 2020).

Megacities can be incubators for new epidemics, and zoonotic diseases can spread in a more rapid manner and become worldwide threats (Xu et al., 2019). In fact, the pandemic has led to a boom in second-home real estate, which is likely to increase investment in suburban developments and may lead to greater biodiversity loss (Rastandeh & Jarchow, 2020). Great uncertainty remains, however, over whether these changes might last or – conversely – whether cities will return to a state of previous normality (Honey-Rosés et al., 2020).

COVID-19 has also highlighted particular health challenges of water scarcity and heat, including the difficulty of handwashing when water access is limited (for example, in informal settlements), the difficulty of socially isolating indoors when the temperature is extremely hot, and the paucity of green space and parks in hot, dry places (Frumkin et al., 2020). In fact, from the Hygiene and the Green City movements (which facilitated current principles for healthy architecture regarding sunlight, ventilation and access to green space) to the more recent Green Architecture and Urbanism movements, targeted solutions such as water drains, wastewater treatment, waste removal, air circulation, lighting and sunlight have been implemented to face infectious diseases such as tuberculosis, to alleviate public health and sanitary crises (Fezi, 2020).

5.6.1 Strategies entailing modification or design of physical infrastructure

Communities have had to deal (and in many cities are still dealing) with social-distancing measures, which have altered access to and use of public space and services. Especially regarding green space, some cities have restricted access to parks and playgrounds for long periods of time, with impacts on health that are still being evaluated (see, for example, Kyriazis et al. (2020)). A recent literature review (Sharifi & Khavarian-Garmsir, 2020) indicated that COVID-19 can also have long-lasting and structural effects on travel behaviour and people's mobility – by decreasing total travel (as teleworking grows) and increasing walking and cycling choices (for social distancing). A risk of greater use of private transport and increased socioeconomic inequalities and segregation derived from these changes in travel behaviour also exists (Gutiérrez, Miravet & Domènech, 2020). Strategies implemented by cities that could be considered "tactical urbanism" include (Bereitschaft & Scheller, 2020; Hanzl, 2020):

- subsidized bike-sharing programmes;
- conversion of some streets into bicycle and pedestrian paths;
- bans of non-local traffic from certain streets;
- repurposing/closing streets to become recreational areas (slow street programmes);
- creation of parklets and "pocket parks" (over former parking spaces) for seating areas and outdoor dining; and
- building of temporary hospital facilities.

Restrictions on the use of public space and physical distancing have been key policy measures to reduce transmission of COVID-19 and protect public health in densely populated urban settings. Great uncertainty remains, however, about how COVID-19 will affect future public space design, use and perceptions – an issue especially relevant for socially vulnerable residents for whom public spaces are often their only recreational outdoor spaces, which provide relief from cramped living conditions (Honey-Rosés et al., 2020). While empirical evidence on the effects of the design of streets and open/public spaces on the dynamics of COVID-19 spread and associated response measures is lacking, the argument can be made that to facilitate effective physical distancing in times of pandemics, cities need to allocate more space to active transport modes and open/public spaces (Sharifi & Khavarian-Garmsir, 2020).

In fact, some cities lack appropriate levels of green and open spaces to meet the outdoor exercise and recreation demands of their citizens while fulfilling social-distancing requirements (Fezi, 2020). Solutions may involve replacing space optimization with social distance optimization, including one-way flows of people between and within buildings, combined with effective digital connectivity enabling employees to live away from densely populated urban agglomerations (Andres, Bryson & Moawad, 2021) – in line with the idea of polycentricity, mentioned in subsection 6.5. Use of public space may change (for example, by people avoiding peak hours or large gatherings, or through an increased perception of insecurity), and building community through spontaneous and informal interaction might be more difficult. In fact, the design of intensively used green spaces in compact cities may need to be rethought, attracting cohorts to different subspaces within a public green space at different times of the day in a manner that facilitates segregation between vulnerable and less-vulnerable users, while facilitating multiuse over the duration of the day by different cohorts (Lennon, 2020). Teleworking models may also change who is using which public spaces, and may further exacerbate spatial segregation and inequalities, as skilled workers in the knowledge economy can more easily shift to online and distance working than lower-income workers (Honey-Rosés et al., 2020).

Urban areas have rigidity built into them (for instance, with infrastructure), but they also must be adaptable and cope with change by facilitating processes of smooth transformation in line with very diverse, rapid or slower disruptions – of various natures and strengths. This has led to an increase in temporary uses of urban land and buildings (Andres, Bryson & Moawad, 2021). Functionally flexible spaces (such as large green spaces, convention centres, stadiums and malls) can help city managers to cope with the crisis and its demands, showing how important it is to have such adjustable spaces distributed across the city. Cities converted these spaces into temporary recovery facilities or vaccination centres during the COVID-19 pandemic; hotels became quarantine centres or housed the homeless; religious buildings and even ice-skating rinks were used as temporary morgues. The recognized value of these large public spaces for the management of the pandemic may therefore promote the future application of modular and decentralized urban planning and designs that allow for this flexibility (Honey-Rosés et al., 2020).

Public spaces, parks and street furniture were altered to support social distancing, and designated sidewalks expanded to allow the spread of outdoor dining. Some city leaders are surveying residents regarding their programmes' utility (implemented during the pandemic in a temporary manner); other cities have instituted their own slow street pilot programmes (Bereitschaft & Scheller, 2020). Soft and swift transitions may also involve rapidly transforming streets into pedestrian spaces to enhance well-being for a short period – for example, to hold a party or create a temporary play area (Andres, Bryson & Moawad, 2021). Such reconfigurations may also provide opportunities to integrate urban greenery into cities further, thereby achieving additional health and climate adaptation co-benefits (for instance, in the event of heatwaves or floods, as mentioned in previous subsections).

Regarding neighbourhood transformation efforts to prioritize addressing health inequities (which have also arisen during the COVID-19 pandemic), the literature points to creation of mixed-income housing, support for cradle-to-college education, and investment in community wellness resources (including access to quality green space), all in partnership with community residents (Berkowitz et al., 2020). Providing spaces with a variety of activities designed for young people (sports, arts, theatre and peer-support activities) – such as green open spaces, relaxation spaces and benches, pedestrian walkways, cycling lanes and safe road designs – are components of mental health-friendly cities, and can also promote young people's mental health (Sinha et al., 2020). Many of these strategies may also improve the urban environment for children, who have traditionally been marginalized in urban settings (much before COVID-19), in many cases impeding their rights to play, of healthy environment and of participation (Kyriazis et al., 2020). The literature also shows a rise in "proximity living" urban models as a result of the pandemic (and as ways to reconcile urban compactness with quality of life), such as the 15-minute city model of Paris, France, and Milan, Italy, or the "superblock" of Barcelona, Spain (Hanzl, 2020; Lennon, 2020).

Overall, COVID-19 can become an opportunity to address critical gaps in community resilience by integrating sustainability, health imperatives and climate objectives through long-term integrated planning. Newell & Dale (2020) highlight the benefits of strategically optimizing local production–consumption and global supply chains (of food, medical equipment and energy resources) to increase resilience to exogenous shocks. This would be beneficial in terms of local supply of critical infrastructure services, with co-benefits of reduced transport costs, local and regional economic development, and associated reductions in greenhouse gas (GHG) emissions.

5.6.2 Strategies related to governance, communication and public engagement

Urban management interventions such as control programmes and adequate surveillance during a pandemic are key to preventing major health concerns and high costs for health care services. Cities are environments in which there is great capacity to implement and deploy surveillance, control, prevention and public knowledge programmes. Cities also gather resources and political and financial power, which leads to unique possibilities for action and quick response when needed (Neiderud, 2015).

During the COVID-19 outbreak, various smart technologies have been repurposed to inform appropriate response measures, minimize human-to-human contact, identify infected individuals, predict diffusion patterns and facilitate quarantine measures (Sharifi & Khavarian-Garmsir, 2020). For instance, the city of Newcastle, United Kingdom, repurposed existing data capture systems (which collected and stored real-time data on traffic and air quality, among other metrics) to provide real-time insights into the impacts of lockdown policy on urban governance (James et al., 2020) These technology-driven approaches, however, raise concerns about their implications in terms of privacy and enforcement of power relations (Sharifi & Khavarian-Garmsir, 2020). They also present further challenges such as incompatible systems among regions due to lack of standardization of protocols and networks, or segregation of data management in silos within independent private corporations – especially social media empires (Allam & Jones, 2020).

Planning practice and research has traditionally focused on the interactions between urban development and health in the context of regulation of land use. More trans- and inter-disciplinary discussions are required for the planning for healthy liveable cities, however (Andres, Bryson & Moawad, 2021), involving key stakeholders such as public authorities, enterprises, the research community and citizens (Pirlone & Spadaro, 2020). Allam & Jones (2020) reported that urban planning and architectural professional institutions had not produced a clear message on urban planning and design strategies in the context of the COVID-19 pandemic. According to the authors, this may originate from the fact that pandemics are not classified or recognized within built-environment institutional disaster-deployment protocols, despite the legacy of incidents such as the plague pandemics and cholera epidemics of the thirteenth and nineteenth centuries.

While emergency response, with short time-spans, is seen mostly as an engineering challenge rather than a design challenge – for example, building temporary health facilities and installations (Mir, 2020) – pandemic preparedness protocols could gain much from the COVID-19 experience when they become part of planning and design strategies (Allam & Jones, 2020). Authors called for the design of municipal and intergovernmental strategic plans for future pandemics that focus on contact tracing, mitigation strategies, patient housing, resource allocation, information provision and intergovernmental cooperation (Bereitschaft & Scheller, 2020). This may also include considering alternative distribution networks (of food, medical equipment or energy resources), optimizing local production–consumption to increase resilience to exogenous shocks (Atalan-Helicke & Abiral, 2021). This could be beneficial in terms of local supply of critical infrastructure services, with co-benefits of reduced transport costs, local and regional economic development, and associated reductions in GHG emissions (Newell & Dale, 2020). It should also entail careful evaluation of potential inequities and exclusions derived from such actions, however (Honey-Rosés et al., 2020).

Table 9 summarizes the findings of the literature review presented in this subsection.

Table 9. Summary of urban management and planning strategies related to COVID-19

Type of strategy	Description
Modification or design of physical infrastructure	• Promotion of **public infrastructure for walking and cycling** choices that enable social distancing and respond to changes in mobility patterns • Implementation of **tactical urbanism strategies** in public space distribution and use – e.g. conversion of some streets into bicycle and pedestrian paths, non-local traffic banned from certain streets, repurposing/closing streets into recreational areas (slow street programmes), creation of parklets and pocket parks (over former parking spaces) for seating areas and outdoor dining • Promotion of **proximity services** within a walkable or cyclable time frame (e.g. the 15-minute city model) to increase the quality of life • Increasing **space allocated for (and access to) open/public spaces** (particularly **green spaces**) throughout the city to facilitate social distancing in times of pandemic while allowing recreation and physical activity for the community – especially in vulnerable neighbourhoods • Promoting **effective digital connectivity** that enables employees to live away from densely populated urban agglomerations • **Rethinking/redesigning intensively used green spaces** in compact cities, promoting use of different areas and furniture within the green space by different population groups and at different times of the day • Construction of **adaptable and functionally flexible spaces and buildings** (e.g. streets that can be transformed into pedestrian spaces, large green spaces, convention centres, stadiums and malls) across the city for multiple uses during an emergency (including health services)
Governance, communication and public engagement	• Improving capacity for **surveillance, control, prevention and public knowledge programmes** • Using/repurposing **smart technologies** to inform appropriate response measures, minimize human-to-human contact, identify infected individuals, predict diffusion patterns and facilitate quarantine measures • **Involving key stakeholders** (e.g. public authorities, enterprises, the research community and citizens) in land-use regulations and planning towards healthy and resilient cities • Designing **municipal and intergovernmental strategic plans** for future pandemics that focus on contact tracing, mitigation strategies, patient housing, resource allocation, information provision and intergovernmental cooperation – including urban planning and infrastructure design strategies (e.g. building temporary health facilities and installations, and alternative distribution networks of food, medical equipment and energy resources)

6. Cross-cutting issues

This section covers several urban planning, design and management topics considered cross-cutting and relevant to multiple hazard types, or to making cities more resilient and healthier in general.

6.1 Climate-change mitigation and adaptation

Human-induced climate change is already affecting many weather extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts and tropical cyclones – and in particular their attribution to human influence – has increased in recent years (IPCC, 2021), and over 90% of cities worldwide are facing significant climate risks (CDP Worldwide, 2021). Cities therefore have a natural interest in contributing to climate-change mitigation through reduction of climate-relevant emissions, and an increasing need for climate adaptation processes to adjust to actual or expected climate change and its effects, seeking to moderate or avoid harm or exploit beneficial opportunities (IPCC, 2014). Box 4 sets out the European Environment Agency (EEA) definitions of climate-change adaptation and mitigation, and notes how these are used with specific relevance to urban planning and resilience in this report.

Box 4. EEA definitions of climate-change mitigation and adaptation

"**Adaptation** means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise. Examples of adaptation measures include large-scale infrastructure changes, such as building defences to protect against sea-level rise, as well behavioral shifts, such as individuals reducing their food waste. In essence, adaptation can be understood as the process of adjusting to the current and future effects of climate change."

In this report, "adaptation" integrates risk reduction and adaptation considerations, and relates to changes carried out in a preventive manner to avoid or minimize the damage of other emergencies or disasters that are not necessarily related to climate change (such as industrial accidents).

"**Mitigation** means making the impacts of climate change less severe by preventing or reducing the emission of GHG into the atmosphere. Mitigation is achieved either by reducing the sources of these gases – e.g. by increasing the share of renewable energies, or establishing a cleaner mobility system – or by enhancing the storage of these gases – e.g. by increasing the size of forests. In short, mitigation is a human intervention that reduces the sources of GHG emissions and/or enhances the sinks."

In this report, "mitigation" also refers to amelioration of the effects or impacts of an emergency or disaster in general, whether or not this disaster is climate change-related.

Source: EEA (2022).

Recently, the focus of urban management and planning has broadened from mitigation (mainly of GHG emissions) to adaptation planning, increasingly embedding climate-change planning within a broader resilience agenda (Meerow & Woodruff, 2020). A recently published review of climate-change action plans in Europe found, however, that mitigation is still more extensively considered: only a minority of the European cities surveyed (147 of 885) considered both mitigation and adaptation in their climate action plans (Grafakos et al., 2020). Another study showed that local governments tend only to have a mitigation, adaptation or joint plan in large cities (with over 500 000 inhabitants) – especially those in central and northern Europe (Reckien et al., 2018). In fact, recent studies suggest that city size and wealth are predictors of whether they will plan for climate change (Meerow & Woodruff, 2020). More developed cities could also have greater knowledge capacity and more opportunity for agency (Patterson, 2021). Compared to megacities, medium-sized cities have received less attention in the literature in the context of climate risk management. Growing medium-sized cities, however, have an opportunity to integrate adaptation to climate change into their ongoing development process (Birkmann et al., 2021).

Current and projected impacts of climate change on public health include (Rychetnik, Sainsbury & Stewart, 2019):

- increased intensity, duration and frequency of some extreme weather events (placing increasing pressure on health services and infrastructure);
- increases in the range and prevalence of food, water and vector-borne diseases due to warmer climate and changing rainfall patterns;
- increased risk of heat-related illnesses, work accidents and death linked to hotter temperatures;
- increased mental illness and stress linked to environmental change and social and economic impacts; and
- increased exposure to aeroallergens due to increases in atmospheric temperatures.

Despite these relevant health impacts, a global study of large cities (with over 1 million inhabitants) found that only 10% of the sampled urban areas reported any public health adaptation initiatives. Further, most of these initiatives addressed risks posed by extreme weather events, and involved direct changes in management or behaviour rather than capacity-building, research or long-term investment in infrastructure. The study identified several gaps, such as general lack of information-based adaptation initiatives, limited focus on initiatives addressing infectious disease risks (although this might have changed after the experience of the COVID-19 pandemic) and absence of monitoring, reporting and evaluation (Araos, Berrang-Ford et al., 2016). In fact, investing in climate-change and public-health research, monitoring and surveillance can lead to better understanding of the adaptation needs and potential health co-benefits of climate mitigation at the local and national levels (Watts et al., 2015). Systematic reporting could also improve transparency and accountability, and might raise public awareness of the effects of climate change.

The road ahead is long. Evidence that municipal authorities are aware of the risks (including health risks) from climate change is increasing, however (Araos, Berrang-Ford et al., 2016). The recently published CDP Worldwide (2021) survey of 812 cities worldwide showed that 57% of cities have a climate adaptation plan (compared to under 4% in 2011), mainly involving urban greening, education and community awareness programmes, crisis/emergency management, flood-risk mapping, and design and building of resistant infrastructure. The literature suggests, however, that adaptation as a policy is generally underdeveloped compared to mitigation – possibly because adaptation receives attention only when extreme weather events occur (Huang-Lachmann & Lovett, 2016). According to Francesch-Huidobro et al. (2017), at present, the climate-change adaptation agenda is somewhat peripheral to government agendas in many cities (including notable examples of delta cities (see subsection 6.4.1 for further detail), which are highly vulnerable to flood risk). It tends to be allocated low priority in the decision-making process, making it susceptible to budget cuts in times of economic crisis. This may be different in the European context, however, where several countries are developing local adaptation plans that municipalities are compelled to follow.

Overall, recent literature suggests that a major gap or lag remains between climate-change planning and implementation: many climate mitigation and adaptation plans exist, but few are put into practice and monitored (Meerow & Woodruff, 2020). Wamsler et al. (2017) identify four key approaches for adaptation mainstreaming at the local level, exemplifying their application when aiming to mainstream NBSs for climate-change adaptation.

- The first approach entails **reducing (current and future) hazard exposure**. Exposure to floods can be reduced through risk-informed urban planning that protects natural environments to help distance residential areas or critical infrastructure from a hazard (or prevent development of future settlements in hazard-prone areas). Other NBSs include beach nourishment, restoring or managing mangroves, and improving water management on the outskirts of urban areas. Slopes can be stabilized through planting or use of retention walls (combining elements of grey and green infrastructure) to reduce exposure to landslides.
- **Reducing vulnerability** can be achieved by creating redundancies through NBSs; reducing dependency on cooling, transportation or drainage systems using green infrastructure; and creating buffer zones, retention ponds and increased permeable surfaces (through green roofs or urban agriculture) in the case of flood risk.
- **Ensuring an effective response** requires early warning systems that are understandable and actionable, preparations for temporary refuges (such as well designed green areas that can provide space for temporary shelter) and preparation of cooling mechanisms or structures to be used during heatwaves.
- The final approach is **ensuring effective recovery.** Actions include use of materials or green infrastructure elements that can be recovered or replaced easily, preparation for post-disaster assistance, designating green areas that can be used for accommodation during reconstruction, preparation for clearing or reuse of rubble (including green materials), provision of health and psychological support, and provision of awareness-raising campaigns and guidance.

6.1.1. Drivers and instruments for climate-change adaptation

Adaptation is rarely conducted without a political crisis that can generate the necessary investment in change (Newman, 2020). Nevertheless, opportunity structures, political pressure and increased knowledge and risk concern are other possible drivers for climate-change adaptation. Local policy mechanisms include formal enforcement of institutional design, voluntary platforms for partnerships and financial incentives to encourage the private sector to innovate, provision of guidelines, and voluntary certification mechanisms to recognize higher building standards (eco-labelling). A study comparing the cases of Hamburg and Rotterdam (Huang-Lachmann & Lovett, 2016) compared strict regulation and formal enforcement with institutional eco-innovation[13] and voluntary measures. Both are considered effective pathways, but overemphasis on strict formal rules for land development could provide less opportunity for citizen participation, while relying heavily on a market-oriented pathway could lead to higher housing and land-use prices. Another study exploring institutional adaptation in 96 major cities worldwide (Patterson, 2021) found that the tendency is towards "softer" actions (such as coordination arrangements, implementation instruments and organizations) rather than "harder" ones (such as policy and legal frameworks). Huang-Lachmann & Lovett (2016) also found that very high and stringent environmental standards are generally positive towards implementation of climate-change adaptation policy.

[13] An institutional eco-innovation is defined as any change in institutional structure, including structural change, that redefines the roles and relationships between the actors involved (OECD, 2009).

Examples of strategic adaptation action instruments are raising risk awareness; combining broad waste reduction, greening and energy-efficiency programmes; creating plans to combat extreme impacts such as storms and heatwaves; and creating plans to delay the onset of events such as increasing temperatures, changing precipitation patterns and sea-level rise. These can be carried out through environmental management, asset procurement and public finance mechanisms; cooperating with civil society organizations to improve equity, awareness and knowledge transfer; and engaging with the creative potential of residents through cross-sectoral tools and experimentation with different participatory processes (Chu, Anguelovski & Roberts, 2017). These strategies, however, require institutional innovation and usually involve changes in underlying rules-in-use and better ways to address governance dilemmas (Patterson & Huitema, 2019).

Urban governance systems require institutional innovation to adapt to and deal with unfolding uncertainties, dynamics and pressures of climate change. Protection of the city can no longer be considered only a function of public organizations, however. Private and non-profit organizations, as well as households, have significant roles to play (Comfort, 2006). Wamsler (2016) emphasizes that local adaptation policies and planning should create conditions that foster autonomous adaptation at the private household level, and provide public adaptation when autonomous adaptation is insufficient or fails to take place. This requires a distributed risk governance system and city–citizen collaboration, where the citizen can play an important part in assessing and managing environmental risks to increase resilience. In addition, active involvement of stakeholders (in the form of working groups or roundtable discussions) is highlighted as a crucial part of a robust basis for effective joint climate adaptation and mitigation institutionalization (Göpfert, Wamsler & Lang, 2019). Further, open access to information can increase transparency and reduce transaction costs in communication (Huang-Lachmann & Lovett, 2016). Overall, social mobilization initiatives – from government-led planning processes to neighbourhood-scale grass roots initiatives – can lower perceived barriers to sustainable climate solutions and motivate action through engagement, learning and hands-on involvement (Lin et al., 2021).

City-to-city learning[14] is another pathway towards climate-change adaptation. This involves sharing lessons learned and strategies for better urban adaptation (for example, through city networks – especially among cities where their future climate resembles the current climate of others), and emphasizing the importance of local policy development when facing the challenges of climate change (Goh, 2019; Axelsson et al., 2021). A study analysing city pairs among 520 major cities of the world found that 77% of future projections for these cities are very likely to experience a climate closer to that of another existing city than to their own current climate. Cities tend to shift towards the subtropics, with cities in the northern hemisphere shifting to warmer conditions and those in the tropics shifting to drier conditions (Bastin et al., 2019). While many proposed solutions may be relevant among cities with similar climates, landscape types and populations, however, they require further development and context-sensitive translation (Lin et al., 2021).

6.1.2 Barriers, trade-offs and unforeseen consequences of climate-change adaptation

The need for urban resilience and preparedness for extreme events is not new, and many cities have already planned and implemented a range of strategies, policies and interventions. These local experiences have enabled the identification of challenges and restrictions related to both implementation and effectiveness of the applied actions. Overcoming these barriers will improve the validity of local measures to protect citizens through urban planning, design and management.

To face the effects of climate change, the barriers of the sector-minded, single-issue approaches typical of municipalities organized according to territorial jurisdictions need to be overcome (Bowen & Ebi, 2015; Chu, Anguelovski & Roberts, 2017; Göpfert, Wamsler & Lang, 2019; Grafakos et al., 2020; Sharifi, 2021). Instead, the cross-sectoral nature of both risks and related responses needs to be emphasized. For instance, green spaces, roads, parks, water systems, heat management and urban ecology are all important factors in rainfall management, but these issues often extend outside any one city government department (Axelsson et al., 2021). A review focused on Australian cities found that current policies addressing heatwaves are fragmented across disciplines and government departments, even though cross-departmental synergies could open new pathways (Hatvani-Kovacs et al., 2018).

Given the need for place-based solutions, local authorities play a pivotal role in comprehensive adaptation planning. Municipalities in many countries have no formally defined responsibility for climate-change adaptation, however, and responsibility may often be seen in terms of putting pressure on higher-level authorities to take protective action. This can sometimes mean that updating or implementing preparedness plans is ignored, or it may be undermined by other demands such as political pressure due to lack of land and housing or potential impacts on property values (Wamsler, 2016). Another common situation is that urban governance of climate-change adaptation is crowded with many actors but a lack of clarity exists over specific roles, responsibilities and leadership (Patterson & Huitema, 2019).

As a city grows, the more complex its government institutional structure becomes, making reorganization more difficult and often limiting the potential effectiveness of policy (Axelsson et al., 2021). A reliance on building on existing planning processes may be indicative of structural constraints that inhibit cities from distributing resources to table new, multiscalar environmental problems such as climate change (Chu, Anguelovski & Roberts, 2017).

[14] See also subsection 5.5 on city-to-city learning in Urban planning for health – experiences of building resilience in 12 cities: second report on protecting environments and health by building urban resilience.

Changing legislation to incorporate higher standards than those in existing rules can also be a challenge. For instance, in many cities changing the building code would require a change in federal, state and local governments; this could take years to be passed and approved by all administrative bodies (Huang-Lachmann & Lovett, 2016).

According to Chu, Anguelovski & Roberts (2017), two main sources of tension when planning for climate-change adaptation are differences in internal priorities, visions and capacities within local government; and tension between local governments and communities, including external economic pressures seeking to redirect strategic actions. For instance, in the city of Ludwigsburg in Germany, prediction of more intense heat-stress and UHI effects in the city centre led to calls for protection of open green space to support cold air streams; this has become an important goal for urban and spatial development. At the same time, however, the city is characterized by an ever-increasing population and a severe lack of affordable housing. This has led to tensions between the general goal of preserving open space and the need for future urban growth (Birkmann et al., 2021). The search for co-benefits, or "win–win" solutions that connect adaptation goals with general development needs (such as environmental protection, poverty reduction and infrastructure and economic growth) seems to be a way to articulate shared visions of the future for strategic urbanism interventions to be successful (Anguelovski et al., 2016; Chu, Anguelovski & Roberts, 2017).

Maintenance of engineered infrastructure is a long-term policy problem for urban planning and management – one that does not usually fit the annual budget cycles that drive most urban agendas. It is also a complex policy problem, as major engineering projects are often financed with federal funding, but once built, states and cities are expected to maintain them (Comfort, 2006). Other persistent challenges to implementation of adaptation plans are access to funding and finance (Meerow & Woodruff, 2020), for which cities could consider resilience fees or insurance-based fees (which provide a new revenue stream while also encouraging developers to avoid high-risk areas or to invest in risk reduction). A recently published review of climate-change action plans in Europe suggested that one of the main gaps of the evaluation and implementation of more integrated climate-change actions in cities is insufficient quantitative evaluation of the costs and funding schemes for adaptation and mitigation action implementation (Grafakos et al., 2020).

Mitigation and adaptation strategies related to land use do not always complement each other and can even be counterproductive in some cases. For instance, high-density and compact cities seem desirable for mitigation (as this urban form contributes to greater savings of GHG emissions from the transportation sector), but addressing adaptation stresses such as the UHI effect requires more land to be left as open space, and a less dense built environment overall (Xu et al., 2019). Therefore, if land-use strategies for mitigation or adaptation are considered in isolation, they may affect each other and require trade-offs. The literature also mentions the possibility of NBSs (with great potential to deliver multiple benefits and reduce climate risks) creating unintended consequences such as fostering gentrification, methane production or providing habitats for disease vectors. Evidence of such effects is relatively scarce, however (Frantzeskaki et al., 2019).

While climate-change adaptation involves dealing with unprecedented new risks, it also magnifies many existing socioeconomic and environmental challenges for urban planners (Patterson & Huitema, 2019). Despite the difficulty of attributing outcomes to specific institutional changes, equity and inclusiveness are important parameters when assessing adaptation outcomes due to the uneven distribution of power and resources in cities. Further, low-income communities in regions, cities, neighbourhoods within a city and especially the informal space (such as homeless people) tend to be most vulnerable to climate impacts and have least capacity to respond (Larsen, 2015; Chu, Anguelovski & Roberts, 2017; Long, Cornut & Kolb, 2021). They also take longer to recover (Mitsova et al., 2019). This could be the case with informal settlements in the peripheries of cities (some of which could be built on flood-risk areas), neighbourhoods with older buildings (which are therefore especially vulnerable to collapse in the event of an earthquake) and urban areas with less vegetation and more impervious surfaces (creating a microclimate in which residents are exposed to greater heat stress).

Although broadly inclusive planning processes are critical, their success is diminished if they do not recognize that facilitating equitable outcomes of climate action is equally important (Chu, Anguelovski & Roberts, 2017). For instance, promoting active transit in cities (with multiple well known health benefits) could entail systematic exclusion of certain groups, populations and neighbourhoods. Walking and cycling is ideal for the short distances (5–10 km) but more challenging for longer commutes, and active commuters tend to live closer to their workplaces, often because they have the financial means to afford more expensive city life (while those living in the more affordable periphery might not benefit from the investment) (Honey-Rosés et al., 2020)

A study of three metropolitan areas in the United States found that the spatial association between built density and the regional location of vulnerable populations is a key indicator of the potential effectiveness of physical heat mitigation strategies in large urbanized areas (Vargo et al., 2016). Thus, to be most protective of human health, urban heat management must prioritize areas of greatest population vulnerability. Where urban thermal hotspots and population vulnerability overlap spatially, physical heat management strategies designed to enhance neighbourhood vegetation and albedo are expected to produce greater human health benefits than in other areas. Relevant data for vulnerability scenarios (such as ageing trends) are generally provided solely for the entire city, however, thereby impeding reflection on how they might materialize in different parts of the city. Very few data (or none) exist in terms of projections or scenarios for the future development of poverty, employment and migration at a local scale, despite these issues being of high importance for local authorities and urban planning (Birkmann et al., 2021).

Table 10 summarizes the findings of the literature review presented in this subsection.

Table 10. Summary of challenges and local responses related to climate-change mitigation and adaptation

Challenge	Local urban planning and management responses	Environmental/health benefit
Climate adaptation and mitigation institutionalization	Considering both **mitigation and adaptation strategies** in the development of **local climate action plans** **Putting climate action plans into practice**, implementing **systematic monitoring and reporting** of climate change impacts at the local level (open access information) to improve transparency and accountability, and raise public awareness Promoting/developing **public health adaptation initiatives**, including capacity-building, research and long-term investment in infrastructure **City-to-city learning**, sharing lessons learned and strategies (e.g. through city networks) **Actively involving stakeholders** in climate action plans and initiatives (e.g. through working groups, roundtable discussions) Implementing **institutional innovation** that facilitates **cross-departmental synergies** and **defines responsibilities** for climate-change adaptation action	Increased community awareness and engagement, improved effectiveness in emergency response and recovery, protection of vulnerable populations, delay in the onset of climate-change related events
Reducing hazard exposure and vulnerability to climate change	Developing **risk-informed urban planning** that protects natural environments, residential areas and critical infrastructure (e.g. hazard maps, buffer zones) **Integrating adaptation strategies into ongoing local development processes** (e.g. in growing medium-sized cities) **Implementing NBSs** (e.g. beach nourishment, planting to reduce exposure to landslides)	Protection of vulnerable areas and groups, delay in the onset of climate-change related events
	Reducing GHG sources (e.g. by increasing the share of renewable energies, establishing a cleaner mobility systems and energy efficiency programmes for buildings) **and enhancing GHG storage** (e.g. by increasing the size of forests)	Health benefits from improved air quality and exposure to green space, reduced dependency on fossil fuels
	Investing in large-scale infrastructure changes (e.g. building defences to protect against sea-level rise) and **considering maintenance costs** **Creating redundancies** through NBSs and other critical infrastructure	Reduced risk of personal, material and environmental damage during and after an emergency event
	Promoting **behavioural shifts** (e.g. individuals reducing their food waste, water use) through improved communication and reporting, awareness campaigns, or financial incentives and disincentives	Reduced dependency on basic services

6.2 Risk perception, behaviour change and personal preparedness

People and communities can be perceived as more than susceptible targets, and may rather be active agents in the process of managing urban vulnerability (Silva & Costa, 2018). Personal preparedness may reduce the impacts of emergencies. For instance, especially in dry cities or cities at risk of water scarcity, behaviour change such as avoiding outdoor exertion during hot times of the day, carrying water and keeping hydrated, and being alert to signs of dehydration and hyperthermia can directly protect health. Other changes, such as reducing water use, can benefit health indirectly (Frumkin et al., 2020). For urban planners, this may suggest the need to consider establishment of public water taps or fountains across the city.

A study focused on public risk perception and behaviour regarding city smog found that knowledge is a positive antecedent variable in risk perception, and risk perception is significantly positive in predicting attitude and behavioural intention to respond to the issue (Zhu et al., 2020). The authors highlighted the key role of local governments and organizations in spreading information concerning the harmful health effects of city smog, as this may strengthen people's intention to participate in smog-reduction behaviour. Here, urban management can be involved in information and awareness campaigns, in addition to infrastructural measures aiming at emission reductions. A review of climate-change adaptation plans in Mediterranean cities, however, showed that – while awareness and education were included in all the plans surveyed – raising awareness and knowledge mostly remained general concepts within the plans, lacking detailed means and specific objectives (Paz et al., 2016). A study exploring the associations between risk perception, household preparedness and the self-reported impacts of 2018's Typhoon Mangkhut for urban residents of Hong Kong SAR, China, found that carrying out typhoon-specific preparedness measures was not associated with a reduction in short-term household impacts; this suggests that current preparedness measures may be insufficient (Chan et al., 2019).

A study in New York, United States, found that households with a member who is dependent on electric medical devices tended to have higher preparedness (Dominianni et al., 2018). Among this group, however, only 40% reported being registered with a utility company to receive early notification of outages, indicating that management and preparedness approaches exist but could be applied more effectively. The authors highlighted the need to increase power outage awareness (including power outage notification programmes) and preparedness among at-risk people. In the case of Hurricane Katrina in the United States in 2005, although the impacts on individuals and households seemed inevitable, public knowledge about the likely consequences of severe hurricanes was lacking prior to the event, as was previous experience of storms of such magnitude (Comfort, 2006). A study analysing lessons learned from this event and from two major earthquakes (in Pakistan in 2005 and Haiti in 2010) highlighted how disaster preparedness could be enhanced with more robust disaster education for civilians and better communication between administrations and civilians, as well as other initiatives such as creation and maintenance of a database of pre-credentialed, pre-certified medical specialists (Born et al., 2011).

The memory of past experiences can become a motivation for climate-change adaptation, while having no experience of previous disasters can exacerbate vulnerability due to lack of preparedness (Garschagen & Sandholz, 2018). A study in the United States surveyed a sample of urban coastal residents, and found that living close to flooding hazards significantly predicted respondents' perceptions of household or neighbourhood risks regarding sea-level rise and inundation. It also found that experience of past events significantly increased residents' knowledge and concern about impacts (Akerlof et al., 2016). According to a study of 96 major cities worldwide, perceptions of risk are greater in cities that are more populous (Patterson, 2021).

According to Wamsler (2016), individuals generally take few anticipatory measures (insurance being the dominant one), while focus is put instead on pressuring the municipality to take action. This study of German municipalities found that in general, however, citizens comply with municipal legislation – especially if it is legally binding, provides clear information or guidance, has financial benefits and has transparent control mechanisms. Further, especially after a disaster, many people volunteer to work for institutions.

Improved insurance coverage at the household level can help homeowners rebuild and recover at a faster pace. According to a study in the United States, while coastal cities and those prone to flooding tend to have higher rates of flood insurance coverage, overall levels are still extremely low; only 17% of homeowners in the counties most affected by Hurricane Harvey in 2017 had flood insurance policies (Mitsova et al., 2019). Another study in the United States found that, although being hit by at least one hurricane in the previous year increased net flood insurance purchases (by 7.2%), this effect faded away within three years (Kousky, 2017).

In addition to general preparedness measures enabling the public to shelter at home safely, preparedness plans should include delineation of safe zones, identification of exit routes from homes and neighbourhoods, and a meeting point for all household members if home evacuation is required. For people who depend on electric medical equipment, however, preparedness also includes signing up with their utility companies to receive notifications before a power outage, and having a back-up supply of power for their equipment (Dominianni et al., 2018). Designing and implementing minimum supply standards in situations of major infrastructure failure is also mentioned in the literature, but this entails some technical difficulties (see subsection 5.5 on industrial accidents and infrastructure failure) and has so far received little attention from public authorities (Garschagen & Sandholz, 2018). Acknowledging current dependence on mobile phone communication in civil society, power outlets for device charging are one aspect to be considered for power supply needs.[15]

Table 11 summarizes the findings of the literature review presented in this subsection.

[15] Also see experiences on the relevance of continued energy supply in subsection 5.3.4 in Urban planning for health – experiences of building resilience in 12 cities: second report on protecting environments and health by building urban resilience.

Table 11. Summary of challenges and local responses related to risk perception, behaviour change and personal preparedness

Challenge	Local urban planning and management responses	Environmental/health benefit
Raising public awareness of disaster risks	Developing **public awareness and knowledge plans** defining detailed means and specific objectives (e.g. awareness campaigns on the harmful health effects of emergencies and possible solutions)	Behavioural changes and motivation for personal and household preparedness, which may reduce vulnerabilities and protect health
	Implementing robust **disaster education** (including drills) for citizens, authorities and decision-makers	
	Improving communication between administrations and civilians (using social media and targeting specific population groups)	
Supporting and improving personal and household preparedness	Providing citizens with **clear information and guidance** on general preparedness measures (e.g. having a working flashlight with extra batteries, a three-day supply of nonperishable food and drinking-water and extra medications on hand; identifying exit routes and meeting points if home evacuation is required)	Reduced risk of personal damage and/or illness during and after the emergency
	Providing financial benefits or incentives for **improved insurance coverage**	Help for faster rebuilding and recovery, stress reduction
	Designing and implementing **municipal legislation for household preparedness** that is legally binding, provides clear information and guidance, and has financial benefits and transparent control mechanisms for greater compliance	Reduced vulnerabilities and risks in the home, and health and environmental protection
	Designing and implementing **minimum supply standards** in situations of major infrastructure failure (also considering dependence on mobile phone communication) to stay functional during emergencies	Protection of vulnerable populations

6.3 Risk analysis and assessment tools

Since the impacts of hazards are deeply uncertain, scientific predictions and scenarios should become increasingly important as references for planning decision-making. This review found multiple proposals of approaches, methodologies and tools for risk analysis and assessment, most of which use GIS tools for mapping and visualization. Some seek to assess the probability of multiple hazards taking place, mapping susceptibility to risks (Pourghasemi et al., 2020) and, in some cases, reaching preliminary quantification of the potential effects on an urban environment (Almeida et al., 2020). Large parts of these tools concern climate-related incidents. The examples below outline opportunities and examples for the application of tools and assessment approaches across a range of urban disaster types, showing how science can also contribute to urban decision-making.

Hazard-specific tools include a model to aid the design of fire risk mitigation strategies (Ferreira et al., 2016) and a large-scale seismic vulnerability assessment method related to emergency planning – considering inaccessible urban areas, isolated people and possible evacuation routes (Anglade et al., 2020). Specific to itineraries and evacuation routes, other methodologies address the difficulty of reaching affected areas because of obstructions on road infrastructure – mainly because of collapses (Francini et al., 2018) – or disruption of the roadway network due to natural hazards, identifying critical links and vulnerabilities (Mera & Balijepalli, 2020). Several methodologies address flood hazards in cities (Li et al., 2016; Kourgialas & Karatzas, 2017). For instance, Kim & Newman (2019) used a land transformation model (a GIS-based land-use prediction tool) to compare the efficacy of flooding protection systems and land-use planning in Amsterdam, Netherlands, and Houston, United States, finding that Houston has developed much more urban area within high-risk flood-prone zones than Amsterdam.

Socioenvironmental vulnerability linked to hazard events has also been addressed (see, for example, Szewrański et al. (2018)). Frantzeskaki et al. (2019) reported that the growing availability of new data streams (from OpenStreetMap, remote-sensing products, weather data, census data, social media and three-dimensional building data layers, among others) can help with identification of where NBSs are most needed. Scenarios that inform vulnerability and adaptation planning can encompass both tangible aspects (such as the proportion of people living in extreme poverty, income distribution and the proportion of elderly people in the population) and intangible ones (such as corruption issues and the strength of social networks), owing to the multifaceted nature of social or physical vulnerability. These can be used, for example, to complement existing heat-stress or climate-change assessments and maps (Birkmann et al., 2021).

Table 12 summarizes the findings of the literature review presented in this subsection.

Table 12. Summary of challenges and local responses related to risk analysis and assessment tools

Challenge	Local urban planning and management responses	Environmental/health benefit
Disaster uncertainty	Development of scientific predictions and scenarios to assess approaches across a range of urban disaster types by using different tools (e.g. GIS and risk-factor maps)	Improved planning decision-making to reduce vulnerabilities and enhance public health benefits
Socioenvironmental vulnerability	Use of new data streams (e.g. OpenStreetMap, remote-sensing products, weather data, census data, social media and three-dimensional building data layers) to inform vulnerability and adaptation planning	

6.4 Geographical location and exposure to hazards

A city's location often determines its exposure to certain types of hazards. The literature generally identifies cities in coastal and river floodplains as those most exposed to the effects of climate change and associated emergencies. Much less material was found on inland and dry cities, while none reported on landslides or vulnerable seismic areas (or only when describing a case study briefly). The following subsections present the findings of the literature review specifically linked to the geographical locations (and/or climate characteristics) of cities. They do not aim to cover all city locations in Europe but only those mentioned in the selected articles.

6.4.1 Coastal urban areas

Around 75% of all large cities worldwide are located on the coast, and more than half of the world's population lives in coastal areas. Although, in terms of urban heat, coastal urban areas may benefit from cooler air due to sea-breeze (Imran et al., 2019; Vahmani, Jones & Patricola, 2019), these areas are also becoming increasingly vulnerable to flooding events. In fact, population density in flood-prone coastal zones and megacities is expected to grow by 25% by 2050 (Huang-Lachmann & Lovett, 2016). Long, Cornut & Kolb (2021) identified two main (and conceptually opposed) strategies for adapting to coastal risks: holding the coastal line through hard constructions such as seawalls or ripraps; and managed retreat of activities and populations to a part of the territory not exposed to hazards. Using the French mainland coast as a case study, the authors highlighted how the attraction of affluent residents and high price of land in these coastal urban areas induces the presence of inequalities. These can be maintained or reinforced in the short and medium term when a strategy based on hard constructions is implemented because of maintenance costs of the structures and the uncertainties relating to the hazards (such as marine submersion, rising sea levels and coastal erosion). These factors would not have to be considered in a managed retreat strategy that, conversely, would lead these territories towards greater resilience in the long term. This is particularly relevant for future developments: in the case of existing urban areas, populations can move away temporarily, but pre-existing critical infrastructure cannot be moved and, if destroyed, can still affect the population once it returns.

The "giving water more space" approach is also clearly reflected in policy reframing in the Netherlands since the 2000s (although it is a strategy that could be applicable to inland cities too). While Dutch tradition is premised on building dikes to withstand high river discharges, the expected extreme future weather events have led to new planning strategies of giving land back to the water – such as the Room for the river strategy in Rotterdam (Lu & Stead, 2013). These have further evolved into innovative adaptation plans such as the "water city" or "floating city" concept, where floating housing is favoured in order to meet the increasing demand for residential area in the city (Huang-Lachmann & Lovett, 2016). This is considered a win–win strategy for land developers, as a close relationship with the water is generally associated with higher house prices.

Rotterdam is an example of a delta city – built mostly behind dikes and with large parts of the city below sea level. Like Hong Kong SAR[16] and Guangzhou,[17] China – both located in the Pearl River Delta – Rotterdam is exposed to coastal, fluvial and urban pluvial flooding. Before the urbanization of deltas, floods were not a threat but rather the driving force of the process of making delta landscapes. Today, however, urban infrastructure such as drainage systems, dikes and dams – together with accelerated processes of land reclamation and the training of rivers – have disrupted the natural process of land-making, decreasing the capacity of delta cities to cope with excessive water (Francesch-Huidobro et al., 2017).

[16] Hong Kong SAR, China, depends heavily on reclaimed land for its infrastructural developments (such as the financial district and the airport), which are built only a few metres above sea level. It also relies on imports for the supply of water, food and energy, making it very vulnerable to trade disruption and failure of critical infrastructure (Comfort, 2006).

[17] The metropolitan area of Guangzhou, China, faces similar risks to Hong Kong SAR. New developments are taking place in originally rural and natural areas to facilitate dispersed, polycentric population growth. Influenced by land-use change and hydraulic infrastructure, the surface water system has largely been altered from its original natural water networks to create artificial lakes and canals (Elwood et al., 2020).

6.4.2 Inland cities

Although inland locations have received less attention in the literature, Cerra (2016) identifies a number of site-planning and design practices for inland locations that – while not yet configured as a comprehensive scope of services for climate adaptation – possess climate-adaptive potential. Examples of these are:

- floodplain storage (periodically floodable open spaces to store large volumes of in-channel flows);
- low-impact developments (using vegetated swales, bioswales, infiltration planters and pervious pavements, for example, to manage increased stormwater runoff);
- resilient planting designs (to reduce vulnerability and stress on ecosystems and species);
- landscape connectivity (through creation and preservation of corridors and stepping-stones to face the shifts and dispersal of species range and distribution);
- use of vegetation, shading of impervious surfaces and buildings, green roofs, cool pavements and similar (to mitigate the effects of extreme urban heat); and
- multimodal mobility (through smart growth and nodal development strategies, providing alternative transportation options and improving walkability).

6.4.3 Dry cities

Numbers of dry cities are increasing, and much urban growth is expected to occur in arid regions (Frumkin et al., 2020). Some cities are dry because of their location in arid environments; these therefore usually have low levels of freshwater and precipitation. Other cities are dry because of a temporary scarcity of water, or drought, influenced by factors including local hydrology, climate and human activities. Semi-arid regions may have dry cities if they are suffering water scarcity; this is the main concern of 60% of cities worldwide, which report having a substantial risk of water insecurity towards 2030, according to a recently published report by CDP Worldwide (2021). According to Frumkin et al. (2020), dry cities have unique health challenges, as climate change and scarcity of water intensify rising heat and propel diseases of hot climates. Dry weather can also be punctuated by sudden heavy rainfall.

Water scarcity can amplify the effects of urban environmental hazards; for example, by concentrating water pollutants and limiting provision of green space. It can also be a critical factor for public health, as clean water is essential for infectious disease control – in both households and health-care facilities. When the water supply is unreliable, informal sources of water and home water storage can increase the risk of contamination. In terms of noncommunicable diseases, severe heat exposure without readily available water for hydration may have health effects ranging from mild symptoms to more severe respiratory and neurological difficulties, heat stroke and mortality. Scarcity of water may also reduce the amount of fresh food available, and lead to reduced physical activity (Frumkin et al., 2020). As possible technological solutions, sensors and automated or unmanned systems (such as on-demand watering systems) are increasingly common within smart-cities frameworks to save, recycle and upcycle water before or during droughts and floods (Lin et al., 2021).

As a possible subcategory of dry cities, Mediterranean cities are characterized by high population density and growth; they are also considered extremely vulnerable to climate change. For instance, the Mediterranean basin has become warmer since the 1960s, with a significant increase in the frequency, intensity and duration of heatwaves. It is also characterized by a reduction in the availability of potable water as a result of a reduction in the total amount of precipitation, changes in rainfall patterns and water overuse by the growing population, mainly in urban areas (Paz et al., 2016). Water-sensitive urban design (such as regulating use of water efficiency devices in new developments or minimizing garden irrigation using techniques like shared common bore water, recycled grey water and stormwater collection) are long-term adaptation plans (Newman, 2020) that could be especially suitable for dry and Mediterranean cities.

Table 13 summarizes the findings of the literature review presented in this subsection.

Table 13. Summary of challenges and local responses related to cities' geographical location

City type	Challenge	Local urban planning and management responses	Environmental/health benefit
Coastal urban areas	Sea-level rise, coastal erosion, marine submersion	Building **grey infrastructure**/hard constructions (e.g. seawalls or ripraps) to hold coastal lines from hazards	Flood hazard mitigation
		Managed r**etreat of activities and population** to areas not exposed to hazards (e.g. farther from the coastline)	Flood/storm hazard and exposure reduction, and long-term resilience
		Development of adaptation plans that "**give land back to water**" (e.g. floating housing or "water city" concepts)	Flood-risk adaptation
Inland cities	Flooding	Development of **floodplain storage** measures (e.g. periodically floodable open spaces to store large volumes of in-channel flows)	Flood-risk adaptation
		Low-impact development (e.g. bioswales, infiltration planters and pervious pavements) to manage stormwater runoff	Flood-risk mitigation and adaptation
	Ecosystems and species stress and vulnerability	Promotion of **resilient planting design** (e.g. improved functional redundancies and response diversity of plant palettes)	Greater likelihood that project installations will persist in the current landscape as well as in future climate-change scenarios
		Increased **landscape connectivity** (e.g. creation and preservation of green corridors and stepping-stones)	Facilitation of correct species range and distribution
	Heat	Use of **urban cooling solutions** (e.g. vegetation, shading of impervious surfaces and buildings, green roofs and cool pavements)	Heat mitigation
	Multimodal mobility	**Smart growth and nodal development strategies** (e.g. facilitation of pedestrian-oriented and transit-oriented experiences)	Improved walkability, provision of transportation alternatives and climate-hazard mitigation
Dry cities	Water scarcity	**Water-sensitive urban design** (e.g. water efficiency devices and garden irrigation regulation)	Reduced water demand and increase of potable water availability
		On-demand watering systems using sensors to save, recycle and upcycle water	Reduced and optimized water consumption

6.5 Urban form/models

The growth of cities worldwide was mentioned in the vast majority of reviewed articles as a major challenge and motivation for implementation of climate-change mitigation and adaptation strategies. The urban form is usually (but not exclusively) measured in terms of density, land-use mix, accessibility, connectivity, green space, impervious surface area, shape and configuration (Neiderud, 2015). The most specific references to the urban form in relation to vulnerability to disasters in the material analysed focus on the issue of density. In particular, compact urban models with high population density are often compared to more dispersed models (urban sprawl or polycentric city structures).

As an "in-between" model, polycentricity advocates multiple centres in the same metropolitan area to distribute the population and most economic activities evenly across centres of comparable size, rather than being concentrated in one main centre. The results of a study focused on the coastal city of Xiamen, China (Xu et al., 2019), partly overlap with this idea. The authors found that the appropriate urban form typically possesses features including:

- moderate population density that limits urban sprawl and eases overcrowding of urban centres;
- moderate mixed residential uses, workplaces, retail and leisure uses;
- high road connectivity, with adequate intersections; and
- properly planned and well protected green open space, minimizing its negative impact on urban density.

Decentralization of places of employment was also mentioned in the context of the COVID-19 pandemic as a solution enabling people to work closer to their place of residence, avoiding crowded spaces in public transport, improving the environmental situation (especially in terms of air quality) and making all areas of the city relatively equally attractive for housing (Mir, 2020).

From a mitigation perspective, a recently published literature review (Sharifi, 2021) found many studies demonstrating that compact urban development featuring appropriate levels of density, coupled with land-use mix and improved accessibility and connectivity, contributes to mitigation through promoting active and public transportation. This thereby reduces per capita travel demand and associated energy consumption (leading to greater savings of GHG emissions by the transportation sector). In addition, compact developments also reduce energy needs for cooling and heating of buildings, as housing size in high-density areas tends to be smaller, and buildings can benefit from the thermal efficiency contributions of shared walls. Other studies focusing on the UHI effect and its potential to exacerbate the effects of heatwaves (and lead to peak use of air-conditioning) could seem to differ, however (Xu et al., 2019). The review also found evidence showing that water consumption is lower in compact cities; this can contribute to mitigation by reducing energy demand for water and creating higher feasibility of developing efficient large-scale community energy systems (such as district energy and cooling systems), providing additional mitigation opportunities.

From an adaptation perspective, the literature review found that, unlike urban sprawl, compact urban development reduces demand for land, thereby enabling avoidance of risk-prone areas. This can reduce exposure to risks such as flooding and wildfire, and can contribute to protection of valuable ecosystems such as forests and wetlands (critical assets for adaptation to flood risk and heat events). Compactness also entails less infrastructure development, allowing better maintenance in general, and reducing demand for resources. While this could also apply in terms of speed and efficiency for emergency teams dealing with high-density, mixed-use and well connected areas (Sharifi, 2021), other studies focusing on fire risk or impacts of earthquakes highlighted potential challenges specific to dense urban areas, such as difficulty accessing victims in high-rise buildings and blocking of emergency routes and narrow evacuation roads (Ferreira et al., 2016; Nasrollahi & Behnam, 2018; Anglade et al., 2020). This may be especially true in the case of older, more deteriorated urban areas, where premises are small and densely populated, and buildings are built with low-quality materials and/or have deteriorated over time (Soleimani & Poorzahedy, 2021).

From a flood-risk perspective, concentrated growth (and a commitment to managing urban sprawl and the rural environment) seems to fit nicely within land-use strategies for coastal and fluvial flooding protection (Axelsson et al., 2021). A study using a GIS-based land-use prediction tool to compare the efficacy of flooding protection systems and land-use planning in Amsterdam, Netherlands, and Houston, United States (Kim & Newman, 2019), found that Houston has developed much more urban area within high-risk flood-prone zones. According to the authors, political circumstances in Houston requiring no zoning regulations promote low density sprawl and limited flood-protection infrastructure. Conversely, flood-prone future urban areas in Amsterdam are relatively smaller than in Houston, possibly due to development control in the Amsterdam City Vision Plan 2040. The study found that this, paired with the existing dike rings and dike upgrade plans, will make Amsterdam safer than Houston from the predicted effects of sea-level rise.

From a UHI effect perspective, compaction and dispersal arrangements of urban forms can affect air flows and wind paths. Although temperature extremes (and the UHI effect) could provide an argument against dense urban living due to increased building density and the obstruction of wind corridors (Francesch-Huidobro et al., 2017), compact forms of development that encourage higher UHI intensity also favour the formation of cooling breezes by enhancing the city–country temperature gradient, while dispersed developments weaken it (Gunawardena, Wells & Kershaw, 2017). Therefore, although proper design of air flows and wind paths in urban areas is often linked to the use of low-rise buildings and linear parks (Capolongo et al., 2018), lower population densities in general do not necessarily solve the problem (Larsen, 2015). In fact, much of the increased land usage in dispersed urban developments is likely to be greenfield land, leading to the loss of relevant features in terms of enhancing city–country breeze, such as greenbelts and other peripheral green areas (Gunawardena, Wells & Kershaw, 2017). A study of metropolitan regions of the United States using weather data from 1956 to 2005 found that low-density urban and suburban developments experienced more extreme heat events (more than double the rate of increase) than most compact metropolitan regions (Stone, Hess & Frumkin, 2010).

From a pandemic perspective, the COVID-19 outbreak raised the question of whether compact urban developments are still a desirable model. In theory, dense areas lead to more face-to-face interaction among residents, potentially escalating the incidence of contagious diseases and making them hotspots for the rapid spread of pandemics (Francesch-Huidobro et al., 2017). This has been suggested, for instance, as a factor in the spread of tuberculosis in the early twentieth century, when links between tuberculosis mortality and housing density were drawn (Neiderud, 2015).

On the other hand, dense areas may have better access to health-care facilities and greater implementation of social-distancing policies and practices (Fezi, 2020). An analysis of COVID-19 spread throughout 913 United States metropolitan counties (Hamidi, Sabouri & Ewing, 2020) found metropolitan population to be one of the most significant predictors of infection rates, although county density was not significantly related to the infection rate, suggesting that connectivity matters more than density in the spread of the pandemic. A recent literature review on the topic also found that density alone is not a key risk factor contributing to the spread of the virus (Sharifi & Khavarian-Garmsir, 2020), as other factors such as the state of development, availability of prevention and response measures, the extent of adherence to sanitation and social-distancing measures, and the extent of access to amenities and public health infrastructure are also important.

Connectivity was also a factor in the centre of the Ebola virus disease epidemic in 2014. The centre of the epidemic (Guinea, Liberia and Sierra Leone), with a large population living in rural settings, was highly interconnected in these countries via travel and cross-border traffic, with good road access between rural and urban settings. According to Neiderud (2015), these communications made the magnitude of the Ebola epidemic possible. In general, however, the literature highlights the importance of access to green spaces (especially during lockdowns), and some authors report that this is extremely problematic in very dense areas (Andres, Bryson & Moawad, 2021).

Table 14 summarizes the findings of the literature review presented in this subsection.

Table 14. Summary of challenges and local responses related to urban form/models

Challenge	Local urban planning and management responses	Environmental/health benefit
Compacity (high density)	Introduction of **land-use mix**, **improved accessibility**, **planned and well protected green spaces** and **connectivity**	Lower travel demand and associated energy consumption (climate-change mitigation), better air quality and promotion of active and public transportation
Energy and water demand	Promotion of compact urban development coupled with development of **efficient large-scale community energy systems** (e.g. district energy and cooling systems)	Reduction of energy and water demand (climate-change mitigation), optimization/ efficiency of infrastructure layout and maintenance
Exposure to natural hazards	Promotion of compact urban development, which **reduces demand for land**	Reduced exposure to risks (e.g. floods and wildfires) and ecosystem protection
	Promotion of compact urban development coupled with **flooding protection systems** (e.g. dike rings, dike upgrade plans and NBSs), and land-use plans incorporating estimated future flood-risk areas	Coastal and fluvial flooding protection
UHI effect	Design of **air flows and wind paths** in urban areas using low-rise buildings and linear parks	Heat mitigation
	Creation/protection of **greenbelts** and other peripheral greenspace to enhance city–country breeze	
Pandemics	Management and control of **connectivity within metropolitan areas** during peak periods (along with other prevention and response measures)	Risk mitigation and limiting virus spread

6.6 Buildings

The review found that the contribution of buildings to disaster resilience in cities was mentioned in relation to heat (and their potential to incorporate climate-sensitive design elements for cooling), to flooding events (including stormwater management), and especially to improving their structural resistance to earthquakes and fire. The results also show how the COVID-19 pandemic has increased attention paid to certain design aspects of buildings and their immediate surroundings, especially in terms of access to outdoor and green space.

From a heat perspective, passive-cooling design strategies applied to buildings and their surroundings – such as increasing albedo through cool roofs and pavements, shading, orientation and natural ventilation – contribute to mitigation as well as to adaptation, providing cooling benefits and reducing cooling energy demand (Sharifi, 2021). Biophilic design also makes density more appealing, providing extra habitat opportunities when tall buildings are landscaped, and making urban environments more aesthetically appealing (Newman, 2020). Further efforts should be put into building design and retrofitting to increase occupants' capacity to cope with heatwaves (and be less dependent on air-conditioning), however. This goes beyond energy efficiency which, in many cases, entails an airtightness that – conversely – may make new buildings become more overheated (Hatvani-Kovacs et al., 2018).

From a flood-risk perspective, outdoor strategies such as site selection, layout and design of parking lots, and surrounding landscape design (integrating climate-sensitive strategies) are relevant flood management strategies included in one of the most widespread "green building" rating systems (Houghton & Castillo-Salgado, 2017). Biophilic design also helps manage stormwater, reduces air pollutants, and provides multiple health advantages (Newman, 2020). In addition to these, many structural property-level flood resilience measures exist, such as floodgates (Depietri & McPhearson, 2017), changes of internal materials, moving electrical installations to higher levels, and putting appliances on plinths.

From an earthquake/fire perspective, designing or retrofitting disaster-resistant buildings should be included in the city design process, considering both potential earthquake damage and its effect on fire resistance (Anglade et al., 2020). This is especially important in old city centres, where a number of factors have been identified as potential contributors to increasing fire risk (Ferreira et al., 2016):

- combustible materials present in traditional buildings;
- high density of buildings in old city centres with narrow street widths;
- wall sharing between adjacent buildings;
- inadequate adaptation of buildings to non-residential purposes;
- proliferation of unoccupied or derelict buildings, frequently storing large amounts of combustible materials; and
- the existence of old electrical installations with a lack of maintenance, which is one of the main causes of the fire risk of old building stock.

After a seismic event affecting the city of Wellington, New Zealand, a building inventory database for the city was initiated; this includes georeferenced structural, economic and market information on practically all significant buildings in the most affected district (Elwood et al., 2020).

From a pandemic perspective, the COVID-19 pandemic provided relevant insights for urban planning and design, such as increased demand for exterior space in the vicinity, and improved ventilation indoors. Lockdown experiences highlighted the need for residential units to be designed as multimodal spaces to support effective work–life balance, including dual career homeworking and allowing access to green infrastructure (Andres, Bryson & Moawad, 2021). They also highlighted the importance of flexibility of public buildings to be repurposed (for example, as temporary hospitals or vaccination centres). If space optimization is replaced by social distance optimization (in line with recommended "physical distances" established during the pandemic), however, the dimensions of buildings and their associated footprints would grow considerably (Honey-Rosés et al., 2020). There is also great potential in flat roofs of apartment buildings, allowing recreational areas to be equipped for the residents (especially relevant during lockdown periods, when access to parks was restricted in many cities), and even potentially becoming food sources if transformed into small eco-farms (Mir, 2020), with multiple connections to health and well-being (Andres, Bryson & Moawad, 2021). These benefits are in addition to the climate and energy-related benefits associated with green roofs and urban agriculture (see subsection 6.8 on green infrastructure and NBSs).

Table 15 summarizes the findings of the literature review presented in this subsection.

Table 15. Summary of challenges and local responses related to buildings

Challenge	Local urban planning and management responses	Environmental/health benefit
Heat	Application of **passive-cooling design strategies** (e.g. increasing albedo through cool roofs and pavements, thermal insulation, shading, orientation and natural ventilation) to buildings and their surroundings	Heat mitigation and adaptation
	Application of **biophilic design** (e.g. green roofs and walls, and water features)	Provision of extra habitat opportunities and improved aesthetics of urban areas
Flooding	Application of **climate-sensitive strategies** (e.g. risk-sensitive site selection and design, layout and design of parking lots, surrounding landscape design)	Flood management
	Application of **biophilic design** (e.g. green roofs and walls, and water features)	Stormwater management and air pollution reduction (climate-change mitigation)
Earthquakes and fires	**Design or retrofit of disaster-resistant buildings** (considering wall sharing between adjacent buildings, electrical installations, adaptation to non-residential purposes and evacuation routes)	Earthquake and fire risk mitigation
Pandemics	Improved **neighbourhood exterior spaces** (e.g. NBSs and increased use of shared rooftops in apartment buildings, pocket parks, vegetation and pervious pavement in backyards)	Stormwater management, improved air quality, heat mitigation (climate-change mitigation) and access to green space during lockdown periods
	Promotion of repurposable **flexible public buildings** (e.g. large multipurpose buildings and open areas, and use of modular designs that can be extended, reduced or replicated)	Improved disaster response to multiple disaster types and reduced costs for new constructions

6.7 Transportation

Few articles selected for this literature review focused on transportation planning and its role in making cities more resilient to emergencies or disasters. Transportation was referred to as a critical infrastructure to be considered in the event of disasters such as earthquakes or floods, as a planning mechanism to promote health and equity in cities, and as a concern and opportunity in the context of COVID-19 pandemic.

From a disaster risk reduction perspective, the transportation network was often referred to in the literature as a critical infrastructure that may be affected by several types of hazards (Garschagen & Sandholz, 2018; Hatvani-Kovacs et al., 2018; Mitsova et al., 2019). It was also addressed in terms of street width and routes in case of earthquakes or fires, highlighting the vulnerability of older urban centres. Several articles provided tools to identify the most efficient links and itineraries in case of emergency (Nasrollahi & Behnam, 2018; Armaghan & Pazani, 2019). Public transportation infrastructure is generally considered relatively robust against adverse events and more effective for disaster absorption, as it can facilitate better emergency access and quicker and easier evacuation (Sharifi, 2021). Houghton & Castillo-Delgado (2017), in a literature review on resilience to urban flooding, highlighted the link between flooding vulnerability and access to transportation to evacuate exposed/at-risk areas before, during and after flooding events. They suggested that access to multiple modes of transportation can play a protective role for vulnerable populations during flooding events; this is currently overlooked, but is relevant for resilient transport planning.

From a walkability and multimodal transportation perspective, promoting walkability (and reducing car dependence) in urban environments is a well known goal of healthy city planning. Interestingly, a study focused on the post-earthquake city of L'Aquila proposes a tool to assess the most walkable and cyclable-walkable streets within the network of this city, which is being reconstructed after the 2009 earthquake. This tool considers the noise pollution and overlapping flows of traffic produced by the heavy vehicles and work machines linked to building reconstruction to classify streets according to how pedestrian or bike-friendly they are (Di Ludovico & Rizzi, 2019). Promotion of transit-oriented development is mentioned in the literature as a means to reduce traffic congestion, pollution, and other unwanted outcomes of the extensive automobile use in large metropolitan areas (such as low-income city periphery developments) (Soleimani & Poorzahedy, 2021). Innovations under way (such as electrifying transport) and other emerging disruptive innovations such as "trackless trams", which function like light rail but at significantly less cost, or hydrogen in fuel-cell vehicles for heavy transport, are also considered for the design of more sustainable and resilient cities, where automobile dependence is reduced and urban footprints are regenerated (Newman, 2020).

From a pandemic perspective, a recent literature review on the impacts of the COVID-19 pandemic on cities (Sharifi & Khavarian-Garmsir, 2020) indicated that COVID-19 can have long-lasting and structural effects on travel behaviour and people's mobility. These include decreasing total travel (as teleworking grows) and increasing walking and cycling choices (for social distancing). For example, in the United States, New York City's bike-sharing programme, Citi Bike, had a surge in use during the early phase of the pandemic, and officials in Berlin, Germany, subsidized bike-sharing user fees, making the bicycles free of charge (Bereitschaft & Scheller, 2020).

On the other hand, the COVID-19 experience may increase negative attitudes towards public transportation and preferences for individual travel modes. As the pandemic has led to a boom in second-home real estate, this is likely to increase investment in suburban developments, consequently increasing reliance on private vehicles. Nevertheless, cities have also tried out temporary solutions during the pandemic which, in some cases, could become permanent. For example, long-term sanitation practices in public transportation could become the norm to prevent more common viruses and bacteria (such as the common cold, influenza and Staphylococcus), as people become more aware of the risks of sharing seats, handles, turnstiles and fare-card machines with many others. Temporary road closures could serve as catalysts for embarking on more ambitious projects in cycle paths, pedestrianization and public space enhancement that citizens have demanded for years. Micro-mobility device use (such as e-scooters) is also predicted to grow, as they are affordable and facilitate social distancing, but it could benefit from street redesigns that provide wider sidewalks or enlarged cycling lanes (Honey-Rosés et al., 2020).

Table 16 summarizes the findings of the literature review presented in this subsection.

Table 16. Summary of challenges and local responses related to transportation

Challenge	Local urban planning and management responses	Environmental/health benefit
Transportation networks, routes and modes	**Identification of most critical links and efficient itineraries** in case of emergency	Efficiency during emergency response
	Promotion of **public transportation infrastructure** throughout the city	Usually better emergency access, quicker and easier evacuation, equity and reduced dependence on private vehicles
	Promotion of **transport infrastructure for different types of vehicles and users** (particularly cycle paths and pedestrianized routes for active transportation)	Reduction of traffic congestion and pollution, climate-change mitigation and increased physical activity
	Promotion of **access to multiple modes of transportation** throughout the city, especially in vulnerable neighbourhoods	Promotion of public transportation use (climate-change mitigation) and protection of vulnerable populations during flooding events
Reduction of private vehicle dependence	Promotion of **walkability** (e.g. through development of walkable and cyclable streets, and encouraging bike-sharing programmes) and **tools to assess its use**	Reduction of traffic congestion and air and noise pollution, climate-change mitigation, increased physical activity and improved safety conditions for young and elderly people
	Promotion of **transit-oriented development** and **innovations** (e.g. electrifying transport and trackless trams)	Reduction of traffic congestion and air and noise pollution, and climate-change mitigation
	Promotion of **long-term sanitation practices** in public transportation beyond pandemic outbreaks	Prevention of viruses and bacteria spread
	Temporary road closures and **street redesign** to enhance public spaces for people (e.g. wider sidewalks, enlarged cycling lanes, cycle paths and pedestrianization)	Reduction of noise and air pollution, safe environments for vulnerable groups, and increased physical activity and social interactions

6.8 Green infrastructure and NBSs

By integrating NBSs into urban landscapes, multiple benefits related to climate-change adaptation and mitigation (such as ameliorating high temperature in cities or regulating air and water flows) are increasingly recognized as influential determinants of human health and well-being (Andersson, Borgström & McPhearson, 2017). The strength of the NBS concept is its integrated perspective for addressing societal challenges, including (Faivre et al., 2017):

- increasing human well-being;
- urban regeneration;
- enhancing coastal resilience;
- multifunctional watershed management and ecosystem restoration;
- increasing sustainable use of matter and energy;
- developing the insurance value of ecosystems; and
- increasing carbon sequestration.

Thanks to their potential for multiple health benefits, green infrastructure and NBSs are crucial elements of urban planning for disasters and beyond. As noted earlier, however, this often leads to debate and conflicting priorities (as with urban growth/development versus hazard reduction).

At the building scale, biophilic architecture and urbanism use strategies such as green walls, green roofs and green balconies to reduce the temperature in and around the buildings and promote carbon sequestration within the fabric of the city (Newman, 2020), as well as to improve air quality and reduce noise pollution (though these benefits were not well addressed in the literature). At the landscape scale, green infrastructure encompasses various land uses including forests, woodlands, moorlands, agricultural land and urban green spaces such as parks, rivers and lakes. It is also capable of being scaled from individual projects to landscape initiatives, giving it great flexibility in the policy framework (Axelsson et al., 2021).

Although green infrastructure landscapes have the potential to contribute to climate-change adaptation and flood-risk management goals, their large-scale, cross-boundary nature – and the multiple sectors and stakeholders potentially involved in their ownership and management – present notable planning and governance challenges (Carter et al., 2018). In fact, green infrastructure landscapes (such as water-retention areas) may be located at a considerable distance from downstream sites potentially exposed to flood hazards, as when intermediate agricultural areas make space for flood water before reaching downstream urban regions (Kourgialas & Karatzas, 2017). They may also often be within different jurisdictions, requiring planning processes and governance structures that cross administrative boundaries (Carter et al., 2018).

Use of NBSs is an effective resource that is increasingly implemented in urban planning to deliver multiple health benefits and reduce climate risks. Environmentally, NBSs may build urban resilience through heat mitigation, rainfall retention and runoff reduction, wind shielding and sustenance of ecosystem health via biodiversity conservation (Mabon, 2019; Axelsson et al., 2021). For instance, wetlands contribute to water purification and flood attenuation, while urban forests and street trees can provide refuge from heat and ameliorate the worst impacts of coastal and surface flooding (Frantzeskaki et al., 2019). Open green spaces can also serve as safe evacuation shelters in the event of an earthquake (for example, in the great Hanshin or Kobe Earthquake in Japan in 1995, more than 1000 city parks were used as earthquake evacuation shelters (Xu et al., 2019). In addition, NBSs (and urban greening strategies in general) can help boost biodiversity in urban areas; for example, by de-paving unnecessary paved areas, or using green roofs to provide predator-free micro-habitats for birds (Rastandeh & Jarchow, 2020).

Socially, NBSs can enhance ability to cope with changing conditions by improving physical and mental well-being or increasing social cohesion and support networks (Mabon, 2019). While they are positive strategies in principle and provide multiple benefits, however, trade-offs need to be evaluated carefully: many NBSs entail increased water demand, which may be problematic in dry cities experiencing water scarcity (Frumkin et al., 2020). For this reason, the resilience of urban vegetation must be planned under alternative future climate-change scenarios to ensure that the benefits can continue to be delivered (Lin et al., 2021).

From a post-disaster setting perspective, NBSs (such as tree planting, establishment or improvement of parks and open spaces, stormwater controls such as retention ponds, restoration of urban rivers, installation of green roofs or rain gardens, and urban agriculture) have the potential for regulating and provisioning of water, and contributing to enhancing overall urban resilience in post-disaster settings. For instance, these ecosystem services were considered critical to recovering a sense of post-disaster identity and pride following the 2011 earthquake, tsunami and nuclear disaster in Futaba County, Fukushima Prefecture, Japan (Mabon, 2019). Thus, “building back greener” as part of disaster recovery is an opportunity to take stock of how NBSs can help a community to recover, in a manner that may not have been done previously. A study analysing the recovery and reconstruction experiences after the 2011 earthquake that led to the Fukushima nuclear disaster and Hurricane Sandy in the United States in 2012, however, suggested that technical guidance and guidelines alone are not sufficient to mainstream ecosystem-based approaches for disaster risk reduction in reconstruction from large-scale disasters (Furuta & Shimatani, 2018). It highlighted the critical role of participatory planning processes with cross-sector, cross-professional and interactive designs; these may lead to more innovative solutions that can more broadly protect health.

From a disaster risk reduction perspective, there is strong evidence that coastal ecosystems reduce wave energy and can also reduce inland flooding depths during storm surge events by providing resistance to the flow of water. A regional study in the United States estimated that temperate coastal wetlands reduced flood heights and thus avoided more than US$ 625 million in flood damage across 12 coastal states affected by Hurricane Sandy in 2012 – from Maine to North Carolina (Narayan et al., 2017). Coastal wetlands provided significant risk reduction services, even where their distribution had been heavily affected by human activity. Furthermore, these ecosystems provided additional benefits related to health such as fish production, nutrient cycling and carbon sequestration.

A study in the United States used a stormwater model to predict a set of flooding scenarios on two sites: one built-out urban area, with greater impervious surface cover and reduced surface storage, and one developing suburban area, with intact green infrastructure corridors (Moore et al., 2016). It concluded that maintaining an intact green infrastructure network is the most cost-effective approach to enhancing the resilience of urban stormwater systems to climate uncertainties and urbanization, and that adaptation planning should include policies to maintain and/or restore wetland riparian areas and other hydrologically connected green infrastructure.

From a thermal-sensitive strategy perspective, increasing the proportion of green spaces and higher albedo materials in urban areas has the potential to mitigate the UHI effect in cities (Maggiotto et al., 2021). A cool surface material conducts less heat into its interior, stores less heat in its volume, and either reflects or (in the case of permeable materials) has a high level of embodied moisture to be evaporated or infiltrated into the soil (Hatvani-Kovacs et al., 2018). These concepts, considered thermal-sensitive strategies for urban green infrastructure, include:

- green roofs and walls;
- urban tree canopies;
- urban agriculture;
- mixed forests, shrublands and grasslands; and
- blue space.

Green roofs and cool roofs[18] are effective design strategies to decrease the temperature in urban environments (and thus mitigate the UHI effect) because of the substantial area covered by rooftops within cities. A study analysing the impacts of green and cool roofs on human thermal comfort during the 2009 heatwave in Melbourne, Australia,[19] found that they were able to reduce heat stress, even when very strong and extreme heat stress occurred at the pedestrian and roof surface levels during the day (Imran et al., 2019). While green roofs improved human thermal comfort by up to 1.5 °C for the pedestrian and 5.5 °C for the roof surface levels, cool roofs improved comfort by 2.4 °C °C for the pedestrian and 8 °C for the roof surface levels. Another study in California, United States, found through simulations that widespread implementation of cool roofs can offset a substantial fraction (51–100%) of the increased heat exposure and associated building energy demand caused by climate change in urbanized regions (Vahmani, Jones & Patricola, 2019).

Green walls provide shading on otherwise exposed surfaces and are able to protect the building wall from overheating, lowering both indoor air and ambient air temperatures. These effects can increase thermal comfort for citizens and reduce the energy demand for cooling. Local climate (along with season and orientation) should be considered in order to integrate the most suitable structure and plant species, however: the significant reduction in cooling costs these solutions can provide in warm climates (up to 61%) could also result in a need to increase energy consumption for heating in winter or in cooler climates (Imran et al., 2019). Green walls also need a design according to the type of climate and purpose, since they can be effective insulators but can also reduce wind speed and impede ventilation (Koch et al., 2020); this is desirable in summer or in hot climates for human comfort, and can be crucial in the event of heatwaves.

In general, it is difficult to achieve the desired heat-reduction effect using only one strategy, but very few studies explored the effects of combined strategies. A study using a multistrategies model suggested that combinations of four thermal-sensitive strategies (tree planting, grass planting, albedo reduction of building walls and albedo reduction of sidewalks) can provide synergistic benefits (Koch et al., 2020). A study of two neighbourhoods in Toronto, Canada, during extreme heat events found that, according to a predicted energy budget model, “cooling” design strategies (addition of deciduous trees, maximizing shading of the parking lot, increasing albedo in pavements by replacing darker asphalt with lighter concrete and replacement of roofing material with either green roof or light coloured material with high albedo) could significantly reduce the energy overload on people, resulting in an estimated 40–50% reduction in heat-related ambulance calls (Graham et al., 2017).

Urban tree canopies can reduce stormwater runoff by catching rainfall on branches and leaves and increasing evapotranspiration. It can also contribute to reducing the UHI effect by keeping neighbourhoods cooler in the summer (Richards & Edwards, 2018; Park et al., 2020). Trees also have to cope with increasingly extreme climatic conditions, however – especially periods of heat and drought, which may also increase pest abundance (Larsen, 2015).

[18] Cool roofs are designed to reflect more sunlight and therefore absorb less heat than a standard roof. They are commonly defined as having high solar reflectance or albedo.
[19] This heatwave took place on 27–30 January 2009; temperatures reached 45.1 °C.

Tree species choice, location and shape must be considered to minimize problems such as reduced security, unwanted shadowing, allergies, excessive maintenance costs or potential damage to underground infrastructure. A study proposing and evaluating a morphology-based approach to select the right tree for the right location for optimum urban heat mitigation found that the main determinant of heat-reduction efficiency is foliage density (FEMA, 2021). In particular, high foliage-dense trees are optimized when placed in open areas; conversely, they can underperform in high-density areas due to the competing shadow-cast shading effect from buildings. Nevertheless, the magnitude of heat-reduction potential will depend on the prevailing climate (hot-humid, hot-dry, temperate or cold climate). A study in Gothenburg, Sweden, found that when assessing vulnerability of the population to heat stress using spatial maps of the distance to the nearest shaded location, not the size of the canopy but rather the location of the trees is critical. Trees in open areas reduce potential vulnerability of the population for the entire surrounding area (Morakinyo et al., 2020). A study in 544 neighbourhoods of Toronto, Canada, during four extreme heat events reported that heat-related ambulance calls were 12.3% higher during the heat events than in the preceding or following weeks, and that the number of heat-related ambulance calls was negatively correlated to canopy cover and positively correlated to hard, impervious surface cover. In fact, areas with fewer trees (<5% canopy cover) and higher percentages of impervious surfaces made up to five times more heat-related emergency calls during the extreme heat events than areas with more trees (>5%), and nearly 15 times more than areas where tree canopy cover was >70% (Lindberg et al., 2016).

Urban agriculture offers clear adaptation and mitigation co-benefits, as well as multiple ecosystem services and health benefits. It reduces the need for energy-intensive food transportation, improving soil carbon sequestration capacity through promoting sustainable agriculture, improving microclimatic conditions and facilitating transition towards low-carbon, plant-based and healthy diets. Multiple adaptation co-benefits include improved thermal comfort, stormwater management and food security – since urban food production, while often season-dependent, can cover some of the food needs of communities and make them less dependent on food transportation that might be disturbed in cases of major disasters (Sharifi, 2021). In Munich, Germany, Gondhalekar & Ramsauer (2017) reported that urban agriculture could cover local fruit and vegetable demand, as well as providing an opportunity for people from different income groups and cultural backgrounds to interact, improving social connection – a key determinant of health.

A study analysing the role of green infrastructure during the 2009 heatwave in Melbourne, Australia, focused on different vegetated patches: **mixed forests, shrublands and grasslands** (Graham et al., 2016). The results show that increasing fractions of vegetated patches from 20% to 50% reduced the near surface (up to 2 m) by 0.4–3.7 °C, with small variations depending on the type of green infrastructure. The vegetated patches were not effective in improving human thermal comfort during the day, but substantial improvement was obtained during the night. A study assessing the potential impact of two different adaptation strategies (cool surfaces and urban forestry) on a Mediterranean city in southern Italy found that urban forestry seemed to lower temperatures (representing the major cause of urban overheating) better than a strategy based on cool surfaces, although at a risk of producing thermal discomfort owing to the relative humidity produced by evapotranspiration (Imran et al., 2019). The findings suggested that urban forestry represents the first step towards an adaptation approach where there is a hot climate during the summer season and no blue infrastructure is available.

While rivers and other flowing water elements usually have a cooling effect, static water bodies have high heat capacity, which can inhibit cooling – especially at night (Richards & Edwards, 2018) – and can provide habitat for disease vectors (Frantzeskaki et al., 2019). A study indicated how, when considered in isolation, green space is of greater benefit to heat risk mitigation than **blue space** as its cooling effect are greatest during conditions typical of high UHI effect intensity and heatwaves (Gunawardena, Wells & Kershaw, 2017). When employed together, however, both green and blue space provide mutually dependent environmental capital, offering many benefits including synergistic cooling and other valued ecosystem services. The study concluded that the addition of multiple smaller interventions (whether green or blue) that take advantage of dominant wind patterns tends to offer greater effect across a larger canopy-layer area than a solitary larger feature. This suggests that green and blue infrastructural networks can be usefully introduced as infilling features, even in high-density compaction and regeneration strategies.

Table 17 summarizes the findings of the literature review presented in this subsection.

Table 17. Summary of challenges and local responses related to green infrastructure and NBSs

Challenge	Local urban planning and management responses	Environmental/health benefit
Temperature reduction	Promotion of **biophilic architecture** in buildings (e.g. green walls, roofs or balconies) **Urban forests** and **street trees**	Carbon sequestration, climate-change mitigation, increased thermal insulation, reduced energy consumption, reduced heat and provision of extra habitat opportunities
Storms and flooding events	Implementation of **NBSs** in urban areas (e.g. wetlands, which contribute to water purification and flood attenuation; urban forests, street trees and mangrove forests, which provide refuge from heat and ameliorate impacts of coastal and surface flooding; stormwater controls such as retention ponds and restoration of urban rivers; and open green spaces, which can also be used as evacuation shelters in the event of an earthquake)	Climate-change mitigation and adaptation, reduced energy consumption, reduced heat and reduced flooding risk
	Participatory planning processes with cross-sector, cross-professional and interactive design (especially for NBS implementation)	Improved social cohesion and sense of identity
	Implementation of policies to **maintain and/or restore wetland riparian areas** and other **hydrologically connected green infrastructure**	Resilience of urban stormwater systems
UHI effect	Increased proportion of **green spaces** and **high albedo materials** in urban areas (e.g. green roofs and walls, urban tree canopies, urban agriculture, mixed forests, shrublands and grasslands, and blue spaces)	Mitigation of the UHI effect

7. Discussion

The following sections summarize the findings presented in sections 5 and 6, adding further discussion on the need for a shift from a hazard-by-hazard approach to an all-hazards and multirisk approach.

7.1 Building resilience, hazard by hazard

The review findings show that literature based on a single hazard type is common: around 60% of the articles identified were found to be hazard-specific. For instance, **heatwaves and the UHI effect** were frequently linked to dense and impervious urban fabrics and calls for greater green coverage through NBSs. This increase in green coverage is also highly relevant in preventing (or mitigating the effects of) **floods** in urban environments, which traditionally rely solely on grey infrastructure that may not be able to cope with predicted future water levels due to climate change. **Earthquake** preparedness involves optimal design of open spaces within the city (especially in densely populated areas) to act as shelters, as well as up-to-date inventories of the road network and building stock. Improving building resistance is crucial when facing both seismic events and strong winds during **storms**. For the latter, personal and household preparedness measures were also found to be potentially relevant in mitigating impacts and reducing recovery time. This generally requires greater public knowledge and risk awareness in communities, however, as well as financial incentives for household modifications and improved insurance coverage to help homeowners rebuild and recover at a faster pace.

Common cascading effects of these hazards are **infrastructure failures** – particularly power outages, which cause disruption to a critical infrastructure on which societies are highly dependent. In addition to technical innovations and behavioural change to reduce overdependence on the electricity grid, infrastructure design should consider the need for back-up solutions and redundancies among certain critical systems and links, anticipating potential dependencies throughout the city. The COVID-19 experience has brought to the fore the issue of urban vulnerability to **pandemics**, giving rise to discussion about which urban models may help protect our health – now and in the future. Cities have provided many examples of temporary strategies (and some that may become long-lasting) to transform neighbourhoods, especially involving our use of public space, mobility and access to green areas. Such reconfigurations may also provide opportunities to address inequalities among neighbourhoods and integrate urban greenery further, thereby achieving additional health and climate adaptation co-benefits (for instance, in the event of heatwaves or floods).

7.2 Cross-cutting mechanisms to build resilience

A set of cross-cutting elements was also identified from the literature. These include issues related to climate-change adaptation, risk perception, behaviour change, personal preparedness, risk analysis and assessment tools. Papers also discussed city exposure to hazards linked to geographical location and to urban form/models, and covered typical intervention areas through which urban design can improve resilience and preparedness, such as buildings, transportation, green space and NBSs.

The literature review also showed growing interest in **climate change-related hazards**, accounting for around 30% of the selected papers. The material revealed a growing interest in adaptation planning and embedding climate change within a broader resilience agenda. A number of drivers, barriers, trade-offs and unforeseen consequences in climate-change mainstreaming were presented. Among the most highlighted actions for local governments to work more effectively and successfully towards climate-change adaptation were institutional innovation, breaking down silos, establishing common visions and priorities, and considering both potential health and equity outcomes from resilience projects (often through co-creation and participation processes). Local access to finance and funding was also identified as a key element for implementation of resilience plans and adequate maintenance of existing infrastructure.

Preventing and/or mitigating the effects of hazards strongly depends on the availability of reliable information and predictions (however much uncertainty remains), for which **risk analysis and assessment tools** are crucial and rapidly developing. These involve incorporating quantitative estimations of costs and damages, simulating different disasters and potential cascading effects, and considering the impacts on vulnerable groups within a city. In addition, improved **risk perception and personal preparedness** may reduce the impacts of emergencies; for this, key elements are raising public awareness, improving city–citizen communication and implementing robust disaster education. These actions may also enhance public engagement and motivate **behavioural shifts**, which in many cases are an integral part of successful transformative strategies.

While **geographical and climatic characteristics** make some cities more exposed to hazards than others, much literature has focused on how certain **urban models** may contribute to this vulnerability, generally advocating compact urban models (in combination with sufficient and well distributed open and green space) and controlling urban sprawl over risk-prone areas. Intervention in **buildings** to contribute to disaster resilience were mentioned in the literature in relation to heat (and their potential to incorporate climate-sensitive design elements for cooling), to flooding events (including stormwater management), and especially to improving their structural resistance to earthquakes and fire. The results also show how the COVID-19 pandemic has increased attention paid to certain design aspects of buildings and their immediate surroundings, especially in terms of access to outdoor and green space. **Transportation** was referred to as a critical infrastructure to be considered in the event of disasters such as earthquakes or floods, as a planning mechanism to promote health and equity in cities (particularly through enhancement of active and multimodal transportation networks), and as a concern and opportunity in the context of COVID-19 pandemic. Green spaces and NBSs (such as green roofs and walls, urban forests and street trees) are an effective resource increasingly being implemented in urban planning to deliver multiple health benefits and reduce climate risks.

7.3 Towards an all-hazards, multirisk approach

Many cities are confronted with multiple hazards – sometimes with concurring, compounding or cascading effects. Possible silos do not take into account win–wins (such as collecting rainwater both for stormwater management and to mitigate dry periods) or consider maladaptive consequences (such as a solution like wetlands, which reduce flood risk but can also be habitats of vector-borne diseases). This poses the challenge of moving from a hazard-by-hazard approach to an all-hazards and multirisk approach in prevention, planning and development.

Much of the literature found for this review focused on particular hazards, as reflected in the presentation of the findings (particularly in section 4). The presence of such a high volume of hazard-specific articles (approximately 60%, in addition to 30% focused solely on climate change-related hazards) might have been influenced by the search method, as some of the search terms selected referred to specific hazards – for instance, fire, flood, storm, earthquake, heatwave, power outage and pandemic – but literature investigating a single hazard type is common (especially case studies and lessons learned from past disaster experience, which was a topic of particular interest). Nevertheless, a significant number of the papers reviewed (especially the most recent) mentioned the importance of establishing multihazard thinking and methods, and of considering cascading effects, even if the main focus of the paper was on a specific hazard. This growing call for a more holistic approach to disaster risk reduction through risk-informed planning is in line with the principles of multilateral reports and guidelines, and could be considered a key lesson learned from the findings of this evidence review.

Multiple strategies are important for all hazards, while others have synergies and co-benefits across multiple hazard types. Table 18 summarizes the issues, challenges and strategies for improving resilience found in the literature, and draws links to urban management and planning dimensions and their relevance for different hazards.

Table 18. Summary of issues, challenges and strategies for improving resilience, with links to urban management and planning dimensions, and relevance for hazards

Cross-cutting issue	Challenge	Examples of urban planning and management strategies	Urban planning and management dimensions involved							Relevant for hazard type					
			IC	DT	C	PR	M	BI	NI	H	E	S	F	IF	P
Climate-change mitigation and adaptation	Institutional innovation	Improving cross-sectoral and multilevel communication, leadership, city–citizen collaboration, city-to-city learning	x		x	x				x	x	x	x	x	x
	Overcoming barriers	Defined roles and responsibilities, breaking down silos, establishing a common vision and priorities, innovative funding mechanisms	x		x	x				x	x	x	x	x	x
	Considering and mitigating trade-offs and unforeseen consequences	Prioritizing health benefits for vulnerable populations and neighbourhoods, promoting co-creation and participation processes	x	x	x	x				x	x	x	x	x	x
Risk perception, behaviour change and personal preparedness	Raising public awareness of disaster risks	Public awareness plans, disaster education, improved city–citizen communication	x		x	x				x	x	x	x	x	x
	Supporting and improving personal and household preparedness	Financial benefits and incentives for improved insurance coverage, municipal legislation for household preparedness, minimum supply standards			x	x		x		x	x	x	x	x	x
Risk analysis and assessment tools	Managing and minimizing disaster uncertainty	Development of scientific predictions and scenarios	x	x						x	x	x	x	x	x
	Considering socioenvironmental vulnerability	Use of new data streams to inform vulnerability		x						x	x	x	x	x	x

Table 18. contd

Cross-cutting issue	Challenge	Examples of urban planning and management strategies	Urban planning and management dimensions involved							Relevant for hazard type					
			IC	DT	C	PR	M	BI	NI	H	E	S	F	IF	P
Geographical location and exposure to hazards	Managing and mitigating sea-level rise and coastal erosion	Grey infrastructure, NBSs, managed retreat of activities and population, adaptation plans that "give land back to water"		x		x		x	x				X	x	
	Managing and mitigating flooding	Floodplain storage measures, NBSs, low-impact development				x		x	x				X		
	Ecosystems and species stress and vulnerability	Resilient planting design, landscape connectivity				x			x	X		x	X	x	x
	Mitigating heat	Urban cooling systems						x	x	X				x	x
	Implementing and/or improving multimodal mobility	Smart growth and nodal development strategies	x	x	x	x	x	x		x	x	x	x	x	x
	Managing and mitigating water scarcity	Water-sensitive urban design, on-demand watering systems, changing public behaviour towards water consumption			x			x	x	X			X	x	
Urban form/model	Promoting compacity and controlling urban sprawl	Land-use mix, improved accessibility to basic services, planned and well protected green spaces and connectivity	x	x	x	x	x	x	x	x		x	x	x	
	Reducing and optimizing energy and water demand	Efficient large-scale community energy systems, changing public behaviour towards energy and water consumption			x	x		x	x	X				X	
	Reducing exposure to natural hazards	Risk-informed urban planning using hazard maps, buffer zones, flooding protection systems	x	x		x		x	x	x	x	X	X	X	
	Mitigating the UHI effect	Considering "city–country breezes" through urban design, distributing open green spaces across the city				x		x	x	X			x		x
	Pandemic	Managing and controlling connectivity with and within metropolitan areas	x			x	x							x	X

Table 18. contd

Cross-cutting issue	Challenge	Examples of urban planning and management strategies	Urban planning and management dimensions involved							Relevant for hazard type					
			IC	DT	C	PR	M	BI	NI	H	E	S	F	IF	P
Buildings	Heat	Passive-cooling strategies, biophilic design			x			x	x	X			x		
	Flooding	Climate-sensitive strategies, biophilic design			x				x	x			X		
	Earthquakes and fires	Improving structural and fire resistance of buildings, upgrading electrical installations, defining clear evacuation routes				x		x			X			x	
	Pandemics	Improving amount and quality of neighbourhood exterior spaces, designing flexible public buildings				x		x	x	x	x	x	x	x	X
Transportation	Improvement of transportation networks, routes and modes	Identifying the most critical links and efficient itineraries, promoting public transportation infrastructure (including cycling lanes)					x	x		x	X	x	x	X	x
	Reduction of private vehicle dependence	Promoting walkability, transit-oriented development and innovation, and long-term sanitation practices in public transportation, using temporary road closures and street redesign to favour pedestrians	x		x	x	x	x	x	x				x	x
Green infrastructure and NBSs	Heat mitigation	Biophilic design and climate-sensitive strategies, increased proportion of green cover and high albedo materials			x	x		x	x	X			x		
	Storms and flooding events	NBSs in urban areas, participatory planning processes, policies to maintain/ restore wetland riparian areas and other hydrologically connected green infrastructure			x	x			x	x		x	X		

Notes: Urban management and planning dimensions involved: IC = institutional capacity; DT = data and tools; C = community involvement; PR = plans and regulations; M = mobility; BI = built infrastructure; NI = natural infrastructure.
Hazard types: H = heat/UHI effect; E = earthquakes; S = storm events; F = flooding events; IF = infrastructure failure; P = pandemics.
"X" denotes a direct link; "x" denotes an indirect link; a blank cell denotes no link.

7.4 Relationship of review findings to international reports

The literature review focused on the findings of articles published in peer-review journals, as presented in sections 4, 5 and 6. This subsection explores the relationship of these findings with the main principles and key messages included in a brief selection of recent international reports for context and benchmarking. Relationships are discussed through a set of topics.

Table 19 presents the list of international reports by multilateral institutions reviewed for context and benchmarking.

Table 19. List of international reports by multilateral institutions reviewed

Title	Institution	Year
How to make cities more resilient: a handbook for local government leaders	UNDRR	2017
Words into action: local disaster reduction and resilience strategies	United Nations Office for Disaster Risk Reduction (UNDRR)	2019
Resilient cities, thriving cities: the evolution of urban resilience	Local Governments for Sustainability (ICLEI)	2019
Urban adaptation in Europe: how cities and towns respond to climate change	EEA	2020
Integrating health in urban and territorial planning: a sourcebook	UN-Habitat & WHO	2020
WHO manifesto for a healthy recovery from COVID-19: prescriptions and actionables for a healthy and green recovery	WHO	2020
A handbook on sustainable urban mobility and spatial planning: promoting active mobility	United Nations Economic Commission for Europe (UNECE)	2020
Heat and health in the WHO European Region: updated evidence for effective prevention	WHO Regional Office for Europe	2021
Climate technologies in an urban context	UNEP DTU Partnership	2021
Nature-based solutions in Europe: policy, knowledge and practice for climate change adaptation and disaster risk reduction	EEA	2021
Advancing health emergency preparedness in cities and urban settings in COVID-19 and beyond	WHO	2021
Framework for strengthening health emergency preparedness in cities and urban settings	WHO	2021

7.4.1 Communication and coordination: breaking down silos

The literature review papers noted the importance of improved communication and collaboration between government sectors and levels, and between local government and the community, to build resilience. Cross-level and cross-sectoral communication is also a common theme of the selected reports. These note that collaboration across government sectors is beneficial for managing environmental determinants of health (WHO, 2020), and that an organizational structure with strong leadership and clarity of coordination and responsibilities is crucial for disaster risk reduction (UNDRR, 2017). Health emergency preparedness goes beyond the health sector (WHO, 2021b). While health protection may be implicit in disaster risk reduction strategies extracted from the review, the potential role of the health sector in contributing to urban planning and management plans and mechanisms seems weak, according to the literature. Nevertheless, health should be thought as an essential input to the process as well as an outcome (UN-Habitat & WHO, 2020).

International reports also call for concerted action at all governance levels (from the EU through national to local levels) to support resilience efforts (EEA, 2020). This includes conducting multisectoral simulation exercises within cities and urban settings, engaging with commerce and industry stakeholders (WHO, 2021b), and creating opportunities for regular resilience dialogues between various levels of government (ICLEI, 2019).

The literature review highlighted the significant role that private organizations and households play in successful implementation of resilience actions – particularly in the case of climate change-related projects. Active community involvement (through government-led planning processes or neighbourhood-scale grass roots initiatives) can lower perceived barriers around sustainable climate solutions and motivate action. Recent reports support these findings, stating that local communities have a pivotal role in contributing knowledge about the experience and use of their living environments; without them, local buy-in and outcomes are weakened (UN-Habitat & WHO, 2020). Incorporating community perspectives enhances policy and programme development, and ensures effective translation and implementation (WHO, 2020), minimizing conflict and unintended negative consequences (UN-Habitat & WHO, 2020). It also engenders trust in governments and public systems at all levels (WHO, 2021b) and a sense of ownership in each project (ICLEI, 2019). In particular, working with groups most at risk of vulnerability (such as migrants, refugees and residents in informal settlements) is critical to increased resilience and successful responses to health emergencies (WHO, 2021b). This aspect was also highlighted in the literature review – particularly in terms of avoiding systematic exclusion of these groups from resilience project development and health/environmental benefits.

The review papers also mentioned how city-to-city learning can become a pathway towards climate-change adaptation, sharing lessons learned and strategies for better urban adaptation (however this remains theoretical). Recent reports also state how local and city governments can share experiences, good practices and financial opportunities through platforms such as networks, meetings, study visits and exchanges, publications and events – all of which should be supported by international organizations (ICLEI, 2019; EEA, 2020; WHO, 2021b). Local and global reporting of successes, failures, barriers and gaps can inspire others and replicate good practices (EEA, 2020). At an international level, global solidarity is also mentioned as a key aspect of effective health emergency preparedness that can affect the local urban level, as shown during the COVID-19 pandemic (WHO, 2021a).

7.4.2 Emphasis on climate-change adaptation

The findings of the literature review noted that the focus of urban management and planning has broadened from mitigation (mainly of GHG emissions) to adaptation planning, increasingly embedding climate-change planning within a broader resilience agenda. Recent papers suggest that a major gap or lag remains between climate-change planning and implementation, however, as many mitigation and adaptation plans exist, but few are put into practice and monitored. This is also noted by the EEA, reporting that despite climate change growing substantially in Europe (supported by the emphasis on urban adaptation in national adaptation strategies, EU policy and key international frameworks), implementation of specific actions still lags far behind, particularly in smaller cities and towns (EEA, 2020; UNEP DTU, 2021). Despite the large amount of scientific literature and the many reports focusing on climate-related hazards, however, resilience involves more than successful adaptation to climate change. Governments therefore need to find solutions to the wide range of climate, anthropogenic, technological and socioeconomic shocks and stresses (UNECE, 2020).

7.4.3 Compacity and proximity

Adequate levels of urban compactness are also mentioned in recent reports, in combination with better connections, access to local amenities and greater opportunities for everyday physical activity through mobility for all (EEA, 2020). Urban environments should also become more socially inclusive and less demanding on resources (ICLEI, 2019), and should avoid built-up floodplains, progressive surface sealing, small amounts of green space or urban sprawl encroaching on wildfire- and landslide-prone areas, as this kind of unsustainable urban development magnifies the impacts of climate-related hazards (UN-Habitat & WHO, 2020). These aspects are in line with the findings of the literature review, where compact urban models (in combination with sufficient and well distributed open and green space) and controlling urban sprawl over risk-prone areas seem to yield more environmental and health benefits, despite recent discussion linking urban density and greater risk of COVID-19 spread.

7.4.4 Scenario-wise thinking

Anticipating various scenarios can be critical to mitigating the impacts of future emergencies by predicting cascading effects of different hazards, assessing interdependencies and vulnerabilities. This appeared in the literature review in relation to seismic vulnerability assessments and impacts of critical infrastructure failure on different parts of society, and was linked to identification and protection of vulnerable groups. It is also mentioned in international reports as relevant in flood estimation and forecasting (UNEP DTU, 2021), and in general as a way to identify and understand risks and to guide local decision-making (UNDRR, 2017; ICLEI, 2019).

7.4.5 Risk-informed urban planning and design

Creation of and compliance with risk-informed urban planning (for example, using hazard maps and up-to-date risk assessment tools) can protect natural environments, help distance residential areas or critical infrastructure from a hazard, and prevent development of future settlements in hazard-prone areas. These strategies surfaced in the literature review, especially in relation to flood protection. The use of risk-informed urban planning and design is also present in recent international reports with reference to contributing to reducing heat risks in cities (UN-Habitat & WHO, 2020), protecting and updating critical infrastructure (EEA, 2020) and disaster risk reduction (WHO, 2021b) and resilience in general (UNECE, 2020).

7.4.6 Finance and funding

The literature review found examples of how a lack of access by local and regional governments to sufficient long-term funding for resilient strategies can hinder implementation and/or effectiveness of projects, or limit maintenance of critical infrastructure. Several recent reports also touch on this issue, highlighting the need for better access to national and international funding, private finance and markets (UNDRR, 2019). Examples include:

- preparing financial plans that understand and assess the significant economic impacts of hazards (UNDRR, 2017);
- showing the private sector how local resilience initiatives have economic value (UNDRR, 2017; ICLEI, 2019; WHO, 2021b);
- allocating resources across sectors (WHO, 2020); and

- using fiscal and financial mechanisms to influence environmental determinants of health through investments in adequate housing, energy efficiency, cycling and pedestrian networks and mass transit, as well as taxation of unhealthy products and practices (UNDRR, 2017).

7.4.7 Urban greening and NBSs

The association of urban greening and NBSs with health benefits, climate-change adaptation and disaster risk reduction was present throughout the literature, and occurs in most selected multilateral reports. Papers also supported the statement that future implementation of NBSs needs to be accompanied by developing technical standards, collaborative governance, capacity-building and sufficient funding (ICLEI, 2019) – such as building regulations that support increasing installations of green walls and roofs (WHO, 2020). In terms of risk-informed urban planning, the findings also mentioned the protective functions of natural areas as buffers, including the need to safeguard and monitor these natural ecosystems within and outside the city geography and to enhance their use in risk reduction (EEA, 2021).

Although urban greening can also be associated with exposure to health risks, the literature review clearly focused on its multiple co-benefits; indeed, evidence of its health benefits was stronger and much more consistent (UNEP DTU, 2021). An aspect that was not mentioned in the literature review, however, was the fact that the potential of NBSs (which depend on healthy ecosystems that are vulnerable to climate change) for climate-change adaptation and disaster risk reduction could be reduced in the future (UNDRR, 2017).

7.4.8 Finding synergies through a shared vision

Establishing a common vision within local government, and between the government and other key stakeholders is a way to reduce tensions between different priorities by aligning with (and not confronting) other development dimensions, such as preserving open green space to support cold air streams and increasing affordable housing development. This is also highlighted by several multilateral reports as a strategy to shape local development processes through shared guiding principles and priorities (WHO, 2021b), reconciling different perspectives through a common language (EEA, 2021). Reports also highlight the importance of giving preference to integrated actions that yield cross-cutting co-benefits, mainstreaming and aligning local resilience to other sustainability agendas to ensure an integrated approach to sustainable development and well-being (UNDRR, 2019).

7.4.9 Implementation of global goals in the local context

Several recent reports highlight the importance of local action, and note that implementation of global goals should be adapted to the specificities and needs of each individual urban space and its communities (ICLEI, 2019). This can be overwhelming for cities, which often operate within limited capacities and resources. Implementation barriers that came up in the literature review mainly focused on climate-change adaptation, noting the difficulty of managing hazards of a cross-sectoral nature with a sector-minded, single-issue approach (hence the need for institutional innovation and improved cross-sectoral and cross-level collaboration), and the lack of defined roles and responsibilities at the local level. The literature also touched on the difficulty of collecting and accessing locally relevant disaggregated data to inform decision-making processes and better target vulnerable groups.[20] While local-level data for action may be limited, their improved use can help cities be better prepared (WHO, 2021b). National-level blanket approaches will not be effective; nor will they achieve the desired outcomes without risk assessment at the local level based on relevant hazard exposure, vulnerabilities and capacity information (ICLEI, 2019; UNDRR, 2019). Recent reports also highlight the low engagement of local authorities in urban interventions related to heat–health action plans, as the lack of tools for intersectoral action frequently prevents health systems from integrating health protection considerations successfully into mainstream urban planning and management (WHO Regional Office for Europe, 2021b).

7.5 Relationship of review findings to international agreements and agendas

To further delve into the issue of how (or whether) global goals are implemented and embedded in local-level policy and action, the papers selected in the original literature review were assessed against three recent international commitments and frameworks: the Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations, 2015a), the SDGs (United Nations, 2015b) and the Paris Agreement (United Nations, 2015c).

Overall, few papers contained references to these international framework documents, and very few local plans, strategies and actions were explicitly linked to their principles. Only 33 of the 172 papers included in the review (19%) referenced at least one of the three international frameworks: 13 mentioned the Paris Agreement, 13 the Sendai Framework and another 13 the SDGs.[21] Only three papers mentioned all three of the frameworks: one provided context on the role of the EU in research and innovation for implementation of NBSs (Faivre et al., 2017); one noted the emergence of resilience as a central concept and outlined the challenge of mainstreaming NBSs for climate-change adaptation in urban governance and planning (Wamsler et al., 2017); and one reviewed multilateral agreements in cities, climate change and sustainable development relevant to building urban resilience (Greenwalt, Raasakka & Alverson, 2018).

[20] The challenge for cities to access relevant local-level data is also discussed in Review of indicator frameworks supporting urban planning for resilience and health: third report on protecting environments and health by building urban resilience.

[21] These results differ from what the findings of the city interview report, where cities seemed to be most familiar with the SDGs (and in some cases used them in their plans and actions), while the Paris Agreement was known but generally not used at the local level, and the Sendai Framework was seldom known or used at the local level, according to the interviewees. See subsection 5.5 in Urban planning for health – experiences of building resilience in 12 cities: second report on protecting environments and health by building urban resilience.

Other international frameworks and agreements mentioned in the reviewed literature are the World Bank Strategic Framework for Climate Change and Development (World Bank, 2008), the New Urban Agenda (United Nations, 2017), the United Nations Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (IPCC, 2014) and summary for urban policy-makers of 2018.

The **Paris Agreement** (United Nations, 2015c) was usually mentioned within the introduction/background section, linked to the challenges of growing urbanization and adaptation to climate change (Araos, Berrang-Ford et al., 2016; Chen et al., 2016; Venter, Krog & Barton, 2020; Sharifi, 2021), or as a reference to the global climate governance regime (Patterson & Huitema, 2019). Grafakos et al. (2020) highlighted the role of cities as leading climate-change adaptation and mitigation actors, reflecting both a shift towards a more bottom-up approach (as seen in the Paris Agreement) and, for example, setting GHG emission reduction targets for their local territories. Similarly, Greenwalt, Raasakka & Alverson (2018) highlighted the role of some mayors (such as those of Pittsburgh and Salt Lake City, United States) in showcasing efforts already under way and commitments for the future – especially on energy and transportation projects.

In addition to a focus on local governments, Klein et al. (2018) focused on the role of the private sector and citizens in urban climate-change adaptation, also linking it to the principles of the Paris Agreement. Reckien et al. (2018) provided a detailed database of local climate plans and actions (including spatial development plans, air quality plans and emergency response plans) which, according to the authors, contributed to establishing patterns of local climate action and assessing the effectiveness of action by cities meeting the objectives of the Paris Agreement (among other EU policy targets). The literature also noted, however, that the initial focus of global climate policy processes and conventions (including the Paris Agreement) was more on climate mitigation than climate adaptation (Mammarella & Grandoni, 2011; Klein et al., 2018; Grafakos et al., 2020).

The **Sendai Framework for Disaster Risk Reduction 2015–2030** (United Nations, 2015a) was included in the introduction of the paper by Pourghasemi et al. (2020) to highlight the importance of a multihazard approach in risk reduction projects and studies addressing risks associated with human activities or climate change on a regional and local scale. Capolongo et al. (2018) listed two practical, feasible, repeatable urban management and planning strategies and actions to be adopted from the Sendai Framework:

- to improve disaster preparation to ensure an effective first response, and to implement "build back better" practices in recovery, rehabilitation, and reconstruction; and
- to improve resilience of health infrastructure, cultural heritage and workplaces.

Depietri & McPhearson (2017) referenced the framework as a recognition of green approaches as "low regret" measures for disaster risk reduction and climate-change adaptation. Imperiale and Vanclay (2020) applied the lessons learned from the 2009 L'Aquila earthquake in Italy, emphasizing the need for social impact assessment to accompany disaster management interventions – including post-disaster reconstruction, as also stated by De Nicola et al. (2020) – to succeed in "building back better", while Leandro et al. (2020) referred to the lack of agreement on how to assess "building back better" strategies based on suitable indicators. Wamsler (2016) identified a set of key drivers and barriers to enable city–citizen collaboration for adaptation co-production, which provides essential input for implementation of the Sendai Framework, as it highlights the importance of mobilizing relational webs in urban planning and governance. This involves a change in perceptions, understanding and practice by building links between individuals and officials. Chen et al. (2016) referred to the Sendai Framework when presenting adaptation options to face flooding events – in particular, regarding the importance of monitoring flood risks and updating flood-risk assessment on a regular basis. Others mentioned the framework in the "problem statement" as an important international agreement to consider, but limited discussion to a brief description of its aims and objectives, without linking it to any particular strategy or project (Kocabaş, 2019; Rychetnik, Sainsbury & Stewart, 2019).

Most papers mentioning the **SDGs** (United Nations, 2015b) did so when providing context rather than explicitly linking local strategies or projects to them (see, for example, Xu et al. (2019)). There were exceptions, however. Faivre et al. (2017) identified a number of NBS projects in cities in the EU and linked them to the SDGs. Examples include:

- the urban restructuring Madrid Río project in Madrid, Spain – linked with SDG 10 on reduced inequalities;
- the natural coastal protection Wadden Sea project in Schleswig-Holstein, Germany – linked with SDG 14 on life below water;
- the natural water-retention Sigma Plan project in Flanders, Belgium –linked with SDG 6 on clean water and sanitation;
- the nature-based education Living Landscape education resource pack in Edinburgh, United Kingdom – linked with SDG 4 on quality education;
- the nature-based therapy Urban Ecological Zone in Ljubljana, Slovenia, and the green roofs and pocket parks Green Urban Agenda in Amsterdam, Netherlands – linked with SDG 11 on sustainable cities and communities.

Lennon (2020) noted that certain urban planning strategies can illustrate joined-up thinking and spatially integrate SDG 3 on good health and well-being, SDG 11 on sustainable cities and communities and SDG 13 on climate action. For example, green spaces could be planned and/or retrofitted to furnish commuting avenues that enhance resilience in urban mobility. Further, designing green roofs as proximate, accessible and pleasant environments could provide "safe spaces" for vulnerable people to enjoy the green outdoors during a pandemic, while concurrently assisting adaptation to climate change by helping to manage drainage and mitigate the UHI effect. Sinha et al. (2020) linked the principles of mental health-friendly cities (such as open green spaces, safe road designs and environment-friendly building designs) and SDGs 1, 3, 4, 10, 11, 16 and 17. Faivre et al. (2017) also highlighted how NBSs and green infrastructure networks would address both SDG 10 on reduced inequalities within and between societies and SDG 3 on good health and well-being.

The SDG most mentioned in the literature and linked to urban management and planning strategies to build resilience is SDG 11 on sustainable cities and communities, with its aim to "make cities and human settlements inclusive, resilient and sustainable". Examples include:

- identifying green infrastructure implementation and management of urban green spaces as "low regret" measures for climate-change adaptation (Sturiale & Scuderi, 2019);
- linking micro digital data collection in urban centres to modelling and land-use analysis and, consequently, to building resilience (Allam & Jones, 2020);
- connecting it to flooding adaptation actions (Axelsson et al., 2021) or to the planning and management of water and health systems in dry cities (Frumkin et al., 2020); and
- stating that other SDGs and many of the 169 SDG targets relate closely to urban design and health planning dimension with specific regard to housing, transportation, water management and air quality (Azzopardi-Muscat et al., 2020).

Almeida et al. (2020) studied the city of Lisbon, Portugal, showing how the municipality is involved and proactively committed to increasing its resilience and achieving the 17 SDGs through risk identification and evaluation of interdependencies among sectors such as energy, communications, urban water cycle, waste collection and mobility.

8. Conclusion: synergies and co-benefits of urban planning, design and management strategies to building resilience

This evidence review does not aim to assess reliably whether cities have learned adequately from urban crises to improve urban preparedness and resilience. It does, however, find strong motivation to learn from past experiences and to apply more healthy and sustainable approaches – especially regarding resilience to climate change and climate-related events in urban areas. Health should be thought of as an essential input into the process as well as an outcome (UN-Habitat & WHO, 2020), and local actors are in the best position to activate change (WHO, 2021b). The findings point to two main areas for improvement that have a direct impact on urban resilience:

- further implementing global goals and commitments in the local context, embedding their principles in policy and action; and
- further integrating health protection considerations into mainstream urban planning and management.

Such action will contribute to healthier and more sustainable cities in general, and will increase specific coping capacities and resilience at the local level.

This report examines a wide array of strategies to respond to the challenges raised by different types of hazards, which may also contribute to working on these two areas of improvement. Multiple strategies extracted from the literature (such as institutional innovation, improving early warning systems, raising awareness and understanding risks and cascading effects) are important for all hazards, while other strategies have synergies and co-benefits across multiple hazard types. Thus, individual and sectoral urban planning solutions are probably not the best method to achieve healthier and more resilient cities. Urban strategies (even hazard-specific ones) must be integrated to enable structural or systemic transformation, based on an all-hazards and multirisk approach, ensuring that unforeseen consequences are minimized and that the benefits derived are multidimensional.

One good example of such synergetic effect are NBSs (such as wetlands and waterfront renaturing); these complement and enhance pre-existing grey infrastructure (such as dikes and pumping stations) to manage floodwater; mitigate the impacts of storms; improve air quality; provide green space for recreation; and protect health overall. Similarly, a public and active transport system can use pervious pavements for its pedestrian and cycle lanes and be shaded by tree canopy throughout its pathways, thereby combining stormwater management with cooling measures to mitigate heat exposure, reducing car dependency (and consequently GHG emissions), promoting physical activity and again protecting human health and the environment overall.

Thus, when synergies among strategies are found and unwanted consequences are controlled, resilient planning and preparedness for emergencies and disasters can also make for better and healthier cities in general.

References[22]

Akerlof KL, Rowan KE, La Porte T, Batten BK, Ernst H, Sklarew DM (2016). Risky business: engaging the public on sea level rise and inundation. Environ Sci Policy. 66:314–23. doi:10.1016/j.envsci.2016.07.002.

Allam Z, Jones DS (2020). Pandemic stricken cities on lockdown. Where are our planning and design professionals [now, then and into the future]? Land Use Policy. 97:104805. doi:10.1016/j.landusepol.2020.104805.

Almeida MC, Telhado MJ, Morais M, Barreiro J, Lopse R (2020). Urban resilience to flooding: Triangulation of methods for hazard identification in urban areas. Sustainability. 12(6):2227. doi:10.3390/su12062227.

Andersson E, Borgström S, McPhearson T (2017). Double insurance in dealing with extremes: ecological and social factors for making nature-based solutions last. In: Kabisch N, Korn H, Stadler J, Bonn A, editors. Nature-based solutions to climate change adaptation in urban areas. Cham: Springer:51–64. doi:10.1007/978-3-319-56091-5.

Andres L, Bryson JR, Moawad P (2021). Temporary urbanisms as policy alternatives to enhance health and well-being in the post-pandemic city. Curr Environ Health Rep. 8(2):167–76. doi:10.1007/s40572-021-00314-8.

Anglade E, Giatreli AM, Blyth A, Di Napoli B, Parisse F, Namourah Z et al. (2020). Seismic damage scenarios for the historic city center of Leiria, Portugal: analysis of the impact of different seismic retrofitting strategies on emergency planning. Int J Disaster Risk Reduct. 44:101432. doi:10.1016/j.ijdrr.2019.101432.

Anguelovski I, Shi L, Chiu E, Gallagher D, Goh K, Lamb Z et al. (2016). Equity impacts of urban land use planning for climate adaptation: critical perspectives from the Global North and South. J Plan Educ Res. 36(3):333–48. doi:10.1177/0739456X16645166.

Araos M, Austin SE, Berrang-Ford L, Ford JD (2016). Public health adaptation to climate change in large cities: a global baseline. Int J Health Serv. 46(1):53–78. doi:10.1177/0020731415621458.

Araos M, Berrang-Ford L, Ford JD, Austin SE, Biesbroek R, Lesnikowski A (2016). Climate change adaptation planning in large cities: a systematic global assessment. Environ Sci Policy. 66:375–82. doi:10.1016/j.envsci.2016.06.009.

Armaghan N, Pazani MY (2019). A model for designing a blood supply chain network to earthquake disasters (case study: Tehran City). Int J Qual Res. 13(3):605–24. doi:10.24874/IJQR13.03-07.

Atalan-Helicke N, Abiral B (2021). Alternative food distribution networks, resilience, and urban food security in Turkey during the COVID-19 pandemic. J Agric Food Syst Commun Dev. 10(2):1–16. doi:10.5304/jafscd.2021.102.021.

Axelsson C, Soriani S, Culligan P, Marcotullio P (2021). Urban policy adaptation toward managing increasing pluvial flooding events under climate change. J Environ Plan Manag. 64(8):1408–27. doi:10.1080/09640568.2020.1823346.

Azzopardi-Muscat N, Brambilla A, Caracci F, Capolongo S (2020). Synergies in design and health. The role of architects and urban health planners in tackling key contemporary public health challenges. Acta Biomed. 91(7): 9–20. doi:10.23750/abm.v91i3-S.9414.

Banai R (2020). Pandemic and the planning of resilient cities and regions. Cities. 106:102929. doi:10.1016/j.cities.2020.102929.

Bastin JF, Clark E, Elliott T, Hart S, van den Hoogen J, Hordijk I et al. (2019). Understanding climate change from a global analysis of city analogues. PLoS One. 14(7):1–13. doi:10.1371/journal.pone.0217592.

Batsaris M, Kavroudakis D, Soulakellis N, Kontos T (2019). Location-allocation modeling for emergency evacuation planning in a smart city context: the case of earthquake in Mytilini, Lesvos, Greece. Int J Appl Geospat Res. 10(4):28–43. doi:10.4018/IJAGR.2019100103.

Behnam B, Skitmore M, Ronagh HR (2015). Risk mitigation of post-earthquake fire in urban buildings. J Risk Res. 18(5):602–21. doi:10.1080/13669877.2014.910686.

Bereitschaft B, Scheller D (2020). How might the COVID-19 pandemic affect 21st century urban design, planning, and development? Urban Sci. 4(4):56. doi:10.3390/urbansci4040056.

Berkowitz RL, Gao X, Michaels EK, Mujahid MS (2020). Structurally vulnerable neighbourhood environments and racial/ethnic COVID-19 inequities. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1792069.

Birkmann J, Sauter H, Garschagen M, Fleischhauer M, Puntub W, Klose C et al. (2021). New methods for local vulnerability scenarios to heat stress to inform urban planning – case study City of Ludwigsburg/Germany. Clim Change. 165:37. doi:10.1007/s10584-021-03005-3.

Born CT, Cullison TR, Dean JA, Hayda RA, McSwain N, Riddles LM et al. (2011). Partnered disaster preparedness: lessons learned from international events. J Am Acad Orthop Surg. 19(Suppl 1):S44–8. doi:10.5435/00124635-201102001-00010.

Bowen KJ, Ebi KL (2015). Governing the health risks of climate change: towards multi-sector responses. Curr Opin Environ Sustain. 12:80–5. doi:10.1016/j.cosust.2014.12.001.

Broz D, Levin EC, Mucha AP, Pelzel D, Wong W, Persky VW et al. (2009). Lessons learned from Chicago's emergency response to mass evacuations caused by Hurricane Katrina. Am J Public Health. 99(8):1496–504. doi:10.2105/AJPH.2007.126680.

Capolongo S, Rebecchi A, Dettori M, Appolloni L, Azara A, Buffoli M et al. (2018). Healthy design and urban planning strategies, actions, and policy to achieve salutogenic cities. Int J Environ Res Public Health. 15(12):2698. doi:10.3390/ijerph15122698.

Carter JG, Handley J, Butlin T, Gill S (2018). Adapting cities to climate change – exploring the flood risk management role of green infrastructure landscapes. J Environ Plan Manag. 61(9):1535–52. doi:10.1080/09640568.2017.1355777.

CDP Worldwide (2021). Cities on the route to 2030: building a zero emissions, resilient planet for all. London: CDP Worldwide (https://www.cdp.net/en/research/global-reports/cities-on-the-route-to-2030).

Cerra JF (2016). Inland adaptation: developing a studio model for climate-adaptive design as a framework for design practice. Landsc J. 35(1):37–55. doi:10.3368/lj.35.1.37.

Chan EYY, Man AYT, Lam HCY, Chan GKW, Hall BJ, Hung KKC (2019). Is urban household emergency preparedness associated with short-term impact reduction after a super typhoon in subtropical city? Int J Environ Res Public Health. 16(4):596. doi:10.3390/ijerph16040596.

Chen C, Doherty M, Coffee J, Wong T, Hellmann J (2016). Measuring the adaptation gap: a framework for evaluating climate hazards and opportunities in urban areas. Environ Sci Policy. 66(2015):403–19. doi:10.1016/j.envsci.2016.05.007.

Chu E, Anguelovski I, Roberts D (2017). Climate adaptation as strategic urbanism: assessing opportunities and uncertainties for equity and inclusive development in cities. Cities, 60:378–87. doi:10.1016/j.cities.2016.10.016.

Cole TA, Wanik DW, Molthan AL, Román MO, Griffin RE (2017). Synergistic use of nighttime satellite data, electric utility infrastructure, and ambient population to improve power outage detections in urban areas. Remote Sens. 9(3):286. doi:10.3390/rs9030286.

Comfort LK (2006). Cities at risk: Hurricane Katrina and the drowning of New Orleans. Urban Aff Rev. 41(4):501–16. doi:10.1177/1078087405284881.

[22] All URLs accessed 25–31 March 2022.

Costa S, Peters R, Martins R, Postmes L, Keizer JJ, Roebeling P (2021). Effectiveness of nature-based solutions on pluvial flood hazard mitigation: the case study of the city of Eindhoven (the Netherlands). Resources. 10(3):24. doi:10.3390/resources10030024.

Depietri Y, McPhearson T (2017). Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. In: Kabisch N, Korn H, Stadler J, Bonn A, editors. Nature-based solutions to climate change adaptation in urban areas. Cham: Springer:91–109. doi:10.1007/978-3-319-56091-5.

De Nicola A, Giovinazzi S, Guarascio M, Rizzi P, Villani ML (2020). Gamified decision making for a participatory post-crisis recovery: a model based process. In: Proceedings. 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference, Venice, Italy, 1–5 November 2020. Chennai: Research Publishing Services: 1937–43. doi:10.3850/978-981-14-8593-0_5012-cd.

Di Ludovico D, Rizzi P (2019). Walkability and urban design in a post-earthquake city. TeMA – J Land Use, Mobility Environ. 12(2): 191–6. doi:10.6092/1970-9870/6135.

Dominianni C, Ahmed M, Johnson S, Blum M, Ito K, Lane K (2018). Power outage preparedness and concern among vulnerable New York City residents. J Urban Health. 95(5):716–26. doi:10.1007/s11524-018-0296-9.

EEA (2020). Urban adaptation in Europe: how cities and towns respond to climate change. Copenhagen: European Environment Agency (EEA Report No. 12/2020; https://www.eea.europa.eu/publications/urban-adaptation-in-europe).

EEA (2021). Nature-based solutions in Europe: policy, knowledge and practice for climate change adaptation and disaster risk reduction. Copenhagen: European Environment Agency (EEA Report No. 1/2021; https://www.eea.europa.eu/publications/nature-based-solutions-in-europe).

EEA (2022). What is the difference between adaptation and mitigation? In: European Environment Agency [website]. Copenhagen: European Environment Agency (https://www.eea.europa.eu/help/faq/what-is-the-difference-between).

Elwood K, Filippova O, Noy I, Paz JP (2020). Seismic policy, operations, and research uses for a building inventory in an earthquake-prone city. Int J Disaster Risk Sci. 11(6):709–18. doi:10.1007/s13753-020-00313-7.

Faivre N, Fritz M, Freitas T, de Boissezon B, Vandewoestijne S (2017). Nature-based solutions in the EU: innovating with nature to address social, economic and environmental challenges. Environ Res. 159:509–18. doi:10.1016/j.envres.2017.08.032.

FEMA (2021). Building community resilience with nature-based solutions: a guide for local communities. Washington DC: Federal Emergency Management Agency (https://toolkit.climate.gov/reports/building-community-resilience-nature-based-solutions-guide-local-communities).

Ferreira TM, Vicente R, Raimundo Mendes da Silva JA, Varum H, Costa A, Maio R (2016). Urban fire risk: evaluation and emergency planning. J Cult Herit. 20(426):739–45. doi:10.1016/j.culher.2016.01.011.

Fezi BA (2020). Health engaged architecture in the context of COVID-19. J Green Build. 15(2):185–212. doi:10.3992/1943-4618.15.2.185.

Francesch-Huidobro M, Dabrowski M, Tai Y, Chan F, Stead D (2017). Governance challenges of flood-prone delta cities: integrating flood risk management and climate change in spatial planning. Prog Plan. 114:1–27. doi:10.1016/j.progress.2015.11.001.

Francini M, Artese S, Gaudio S, Palermo A, Viapiana MF (2018). To support urban emergency planning: a GIS instrument for the choice of optimal routes based on seismic hazards. Int J Disaster Risk Reduct. 31:121–34. doi:10.1016/j.ijdrr.2018.04.020.

Frantzeskaki N, McPhearson T, Collier MJ, Kendal D, Bulkeley H, Dumitru A et al. (2019). Nature-based solutions for urban climate change adaptation: linking science, policy, and practice communities for evidence-based decision-making. BioScience. 69(6):455–46. doi:10.1093/biosci/biz042.

Frumkin H, Das MB, Negev M, Rogers BC, Bertollini R, Dora C et al. (2020). Protecting health in dry cities: considerations for policy makers. BMJ. 371:m2936. doi:10.1136/bmj.m2936.

Furuta N, Shimatani Y (2018). Integrating ecological perspectives into engineering practices – Perspectives and lessons from Japan. Int J Disaster Risk Reduct. 32:87–94. doi:10.1016/j.ijdrr.2017.12.003.

Garschagen M, Sandholz S (2018). The role of minimum supply and social vulnerability assessment for governing critical infrastructure failure: current gaps and future agenda. Nat Hazards Earth Syst Sci. 18(4):1233–46. doi:10.5194/nhess-18-1233-2018.

Goh K (2019). Flows in formation: the global-urban networks of climate change adaptation. Urban Stud. 57(11):2222–40. doi:10.1177/0042098018807306.

Gondhalekar D, Ramsauer T (2017). Nexus city: operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany. Urban Clim. 19:28–40. doi:10.1016/j.uclim.2016.11.004.

Göpfert C, Wamsler C, Lang W (2019). A framework for the joint institutionalization of climate change mitigation and adaptation in city administrations. Mitig Adapt Strateg Glob Chang. 24:1–21. doi:10.1007/s11027-018-9789-9.

Grafakos S, Viero G, Reckien D, Trigg K, Viguie V, Sudmant A et al. (2020). Integration of mitigation and adaptation in urban climate change action plans in Europe: a systematic assessment. Renew Sust Energ Rev. 121:109623. doi:10.1016/j.rser.2019.109623.

Graham DA, Vanos JK, Kenny NA, Brown RD (2016). The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada. Urban For Urban Green. 20:180–6. doi:10.1016/j.ufug.2016.08.005.

Graham DA, Vanos JK, Kenny NA, Brown RD (2017). Modeling the effects of urban design on emergency medical response calls during extreme heat events in Toronto, Canada. Int J Environ Res Public Health. 14(7):778. doi:10.3390/ijerph14070778.

Grappasonni I, Petrelli F, Traini E, Grifantini G, Mari M, Signorelli C (2017). Psychological symptoms and quality of life among the population of L'Aquila's "new towns" after the 2009 earthquake. Epidemiol Biostat Public Health. 14(2). doi:10.2427/11690.

Greenwalt J, Raasakka, N, Alverson K (2018). Building urban resilience to address urbanization and climate change. In: Zommers Z, Alverson K, editors. Resilience: the science of adaptation to climate change. Amsterdam: Elsevier: 151–64. doi:10.1016/B978-0-12-811891-7.00012-8.

Gunawardena KR, Wells MJ, Kershaw T (2017). Utilising green and bluespace to mitigate urban heat island intensity. Sci Total Environ. 584–5:1040–55. doi:10.1016/j.scitotenv.2017.01.158.

Gutiérrez A, Miravet D, Domènech A (2020). COVID-19 and urban public transport services: emerging challenges and research agenda. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1804291.

Hamidi S, Sabouri S, Ewing R (2020). Does density aggravate the COVID-19 pandemic? Early findings and lessons for planners. J Am Plann Assoc. 86(4):495–509. doi:10.1080/01944363.2020.1777891.

Hanzl M (2020). Urban forms and green infrastructure – the implications for public health during the COVID-19 pandemic. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1791441.

Hatvani-Kovacs G, Bush J, Sharifi E, Boland J (2018). Policy recommendations to increase urban heat stress resilience. Urban Clim. 25:51–63. doi:10.1016/j.uclim.2018.05.001.

Honey-Rosés J, Anguelovski I, Chireh VK, Daher C, Konijnendijk van den Bosch C, Litt JS et al. (2020). The impact of COVID-19 on public space: an early review of the emerging questions – design, perceptions and inequities. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1780074.

Houghton A, Castillo-Salgado C (2017). Health co-benefits of green building design strategies and community resilience to urban flooding: a systematic review of the evidence. Int J Environ Res Public Health. 14(12):1519. doi:10.3390/ijerph14121519.

Huang-Lachmann JT, Lovett JC (2016). How cities prepare for climate change: comparing Hamburg and Rotterdam. Cities. 54:36–44. doi:10.1016/j.cities.2015.11.001.

Huxley M, Inch A (2020). Urban planning. In: Kobayashi, A. International Encyclopedia of Human Geography, second edition. Amsterdam: Elsevier:87–92.

ICLEI (2019). Resilient cities, thriving cities: the evolution of urban resilience. Bonn: Local Governments for Sustainability (https://www.iclei.org/en/publication/resilient-cities-thriving-cities-the-evolution-of-urban-resilience).

Imperiale AJ, Vanclay F (2020). Top-down reconstruction and the failure to "build back better" resilient communities after disaster: lessons from the 2009 L'Aquila Italy earthquake. Disaster Prev Manag. 29(4):541–55. doi:10.1108/DPM-11-2019-0336.

Imran HM, Kala J, Ng AWM, Muthukumaran S (2019). Effectiveness of vegetated patches as green infrastructure in mitigating urban heat island effects during a heatwave event in the city of Melbourne. Weather Clim Extremes. 25:100217. doi:10.1016/j.wace.2019.100217.

IPCC (2014). Summary for policymakers. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press: 1–32 (https://www.ipcc.ch/report/ar5/wg2/).

IPCC (2021). Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press (https://www.ipcc.ch/report/ar6/wg1/#FullReport).

James P, Das R, Jalosinska A, Smith L (2020). Smart cities and a data-driven response to COVID-19. Dialogues Hum Geogr. 10(2):255–9. doi:10.1177/2043820620934211.

Kim Y, Newman G (2019). Climate change preparedness: comparing future urban growth and flood risk in Amsterdam and Houston. Sustainability. 11(4):1048. doi:10.3390/su11041048.

Klein J, Araos M, Karimo A, Heikkinen M, Ylä-Anttila T, Juhola S (2018). The role of the private sector and citizens in urban climate change adaptation: evidence from a global assessment of large cities. Glob Environ Change. 53:127–36. doi:10.1016/j.gloenvcha.2018.09.012.

Kocabaş HM (2019). The necessity of integration of flood risk reduction strategies with spatial planning decisions in Turkey, by comparing exemplary practices in developed countries. Iconarp Int J Archit Plan. 7(1):136–67. doi:10.15320/iconarp.2019.70.

Koch K, Ysebaert T, Denys S, Samson R (2020). Urban heat stress mitigation potential of green walls: a review. Urban For Urban Green. 55:126843. doi:10.1016/j.ufug.2020.126843.

Kourgialas NN, Karatzas GP (2017). A national scale flood hazard mapping methodology: the case of Greece – protection and adaptation policy approaches. Sci Total Environ. 601–2:441–52. doi:10.1016/j.scitotenv.2017.05.197.

Kousky C (2017). Disasters as learning experiences or disasters as policy opportunities? Examining flood insurance purchases after hurricanes. Risk Anal. 37(3):517–30. doi:https://doi.org/10.1111/risa.12646.

Kyriazis A, Mews G, Belpaire E, Aerts J, Malik SA (2020). Physical distancing, children and urban health. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1809787.

Laaidi K, Economopoulou A, Wagner V, Pascal M, Empereur-Bissonnet P, Verrier A et al. (2013). Cold spells and health: prevention and warning. Public Health. 127(5):492–9. doi:10.1016/j.puhe.2013.02.011.

Larsen L (2015). Urban climate and adaptation strategies. Front Ecol Environ. 13(9):486–92. doi:10.1890/150103.

Leandro J, Chen KF, Wood RR, Ludwig R (2020). A scalable flood-resilience-index for measuring climate change adaptation: Munich city. Water Res. 173:115502. doi:10.1016/j.watres.2020.115502.

Lennon M (2020). Green space and the compact city: planning issues for a "new normal". Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1778843.

Li C, Cheng X, Li N, Du X, Yu Q, Kan G (2016). A framework for flood risk analysis and benefit assessment of flood control measures in urban areas. Int J Environ Res Public Health. 13(8). doi:10.3390/ijerph13080787.

Lin BB, Ossola A, Alberti M, Andersson E, Bai X, Dobbs C et al. (2021). Integrating solutions to adapt cities for climate change. Lancet Planet Health. 5(7):e479–86. doi:10.1016/S2542-5196(21)00135-2.

Lindberg F, Thorsson S, Rayner D, Lau K (2016). The impact of urban planning strategies on heat stress in a climate-change perspective. Sustain Cities Soc. 25:1–12. doi:10.1016/j.scs.2016.04.004.

Long N, Cornut P, Kolb V (2021). Strategies for adapting to hazards and environmental inequalities in coastal urban areas: what kind of resilience for these territories? Nat Hazards Earth Syst Sci. 21(3):1087–1100. doi:10.5194/nhess-2020-323.

López-Bueno JA, Linares C, Sánchez-Guevara C, Martinez GS, Mirón IJ, Núñez-Peiró M et al. (2020). The effect of cold waves on daily mortality in districts in Madrid considering sociodemographic variables. Sci Total Environ. 749:142364. doi:10.1016/j.scitotenv.2020.142364.

Lovreglio R, Gonzalez V, Feng Z, Amor R, Spearpoint M, Thomas J et al. (2018). Prototyping virtual reality serious games for building earthquake preparedness: the Auckland City Hospital case study. Adv Eng Inform. 38:670–82. doi:10.1016/j.aei.2018.08.018.

Lu P, Stead D (2013). Understanding the notion of resilience in spatial planning: a case study of Rotterdam, the Netherlands. Cities. 35:200–12. doi:10.1016/j.cities.2013.06.001.

Mabon L (2019). Enhancing post-disaster resilience by "building back greener": evaluating the contribution of nature-based solutions to recovery planning in Futaba County, Fukushima Prefecture, Japan. Landsc Urban Plan. 187:105–18. doi:10.1016/j.landurbplan.2019.03.013.

Maggiotto G, Miani A, Rizzo E, Castellone MD, Piscitelli P (2021). Heat waves and adaptation strategies in a Mediterranean urban context. Environ Res. 197:111066. doi:10.1016/j.envres.2021.111066.

Mammarella MC, Grandoni G (2011). Resilience actions to counteract the effects of climate change and health emergencies in cities: the role of artificial neural networks. Ann Ist Super Sanità. 47(4):363–72. doi:10.4415/ANN_19_04_14.

Meerow S, Woodruff SC (2020). Seven principles of strong climate change planning. J Am Plann Assoc. 86(1):39–46. doi:10.1080/01944363.2019.1652108.

Mera AP, Balijepalli C (2020). Towards improving resilience of cities: an optimisation approach to minimising vulnerability to disruption due to natural disasters under budgetary constraints. Transportation. 47(4):1809–42. doi:10.1007/s11116-019-09984-8.

Mir V (2020). Post-pandemic city: historical context for new urban design. Transylv Rev Adm Sci. (Special Issue):94–108. doi:10.24193/tras.SI2020.6.

Mitsova D, Esnard AM, Sapat A, Lai BS (2018). Socioeconomic vulnerability and electric power restoration timelines in Florida: the case of Hurricane Irma. Nat Hazards, 94(2):689–709. doi:10.1007/s11069-018-3413-x.

Mitsova D, Escaleras M, Sapat A, Esnard AM, Lamadrid AJ (2019). The effects of infrastructure service disruptions and socio-economic vulnerability on hurricane recovery. Sustainability. 11(2):1–16. doi:10.3390/su11020516.

Moore TL, Gulliver JS, Stack L, Simpson MH (2016). Stormwater management and climate change: vulnerability and capacity for adaptation in urban and suburban contexts. Clim Change. 138(3–4):491–504. doi:10.1007/s10584-016-1766-2.

Morakinyo TE, Ouyang W, Lau KK, Ren C, Ng E (2020). Right tree, right place (urban canyon): tree species selection approach for optimum urban heat mitigation – development and evaluation. Sci Total Environ. 719:137461. doi:10.1016/j.scitotenv.2020.137461.

Najarian LM, Majeed MH, Gasparyan K (2017). Effect of relocation after a natural disaster in Armenia: 20-year follow-up. Asian J Psychiatr. 29:8–12. doi:10.1016/j.ajp.2017.03.030.

Narayan S, Beck MW, Wilson P, Thomas CJ, Guerrero A, Shepard CC et al. (2017). The value of coastal wetlands for flood damage reduction in the northeastern USA. Sci Rep. 7(1):9463. doi:10.1038/s41598-017-09269-z.

Nasrollahi Y, Behnam B (2018). Evacuation-based design of urban regions for earthquake disaster. Int J Civ Eng. 16(7):769–82. doi:10.1007/s40999-017-0214-7.

Neiderud CJ (2015). How urbanization affects the epidemiology of emerging infectious diseases. Infect Ecol Epidemiol. 5:27060. doi:10.3402/iee.v5.27060.

Newell R, Dale A (2020). COVID-19 and climate change: an integrated perspective. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1778844.

Newman P (2020). Cool planning: how urban planning can mainstream responses to climate change. Cities. 103:102651. doi:10.1016/j.cities.2020.102651.

OECD (2009). Eco-innovation in industry: enabling green growth. Paris: OECD (https://www.oecd-ilibrary.org/environment/eco-innovation-in-industry_9789264077225-en).

Park CY, Yoon EJ, Lee DK, Thorne JH (2020). Integrating four radiant heat load mitigation strategies is an efficient intervention to improve human health in urban environments. Sci Total Environ. 698:134259. doi:10.1016/j.scitotenv.2019.134259.

Patterson JJ (2021). More than planning: diversity and drivers of institutional adaptation under climate change in 96 major cities. Glob Environ Change. 68:102279. doi:10.1016/j.gloenvcha.2021.102279.

Patterson JJ, Huitema D (2019). Institutional innovation in urban governance: the case of climate change adaptation. J Environ Plan Manag. 62(3):374–98. doi:10.1080/09640568.2018.1510767.

Paz S, Negev M, Clermont A, Green MS (2016). Health aspects of climate change in cities with Mediterranean climate, and local adaptation plans. Int J Environ Res Public Health. 13(4):438. doi:10.3390/ijerph13040438.

Pirlone F, Spadaro I (2020). Scenarios, insights, reasoning and research. The resilient city and adapting to the health emergency. TeMA – J Land Use, Mobility Environ (Special Issue on COVID-19 vs City-20). 305–14. doi:10.6092/1970-9870/6856.

Pour SH, Wahab AKA, Shahid S, Asaduzzaman M, Dewan A (2020). Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: current trends, issues and challenges. Sustain Cities Soc. 62:102373. doi:10.1016/j.scs.2020.102373.

Pourezzat AA, Nejati M, Mollaee A (2010). Dataflow model for managing urban disasters: the experience of Bam earthquake. Int J Disaster Resil Built Environ. 1(1):84–102. doi:10.1108/17595901011026490.

Pourghasemi HR, Kariminejad N, Amiri M, Edalat M, Zarafshar M, Blaschke T et al. (2020). Assessing and mapping multi-hazard risk susceptibility using a machine learning technique. Sci Rep. 10(1):3203. doi:10.1038/s41598-020-60191-3.

Rastandeh A, Jarchow M (2020). Urbanization and biodiversity loss in the post-COVID-19 era: complex challenges and possible solutions. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1788322.

Reckien D, Salvia M, Heidrich O, Church JM, Pietrapertosa F, De Gregorio-Hurtado S et al. (2018). How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. J Clean Prod. 191:207–19. doi:10.1016/j.jclepro.2018.03.220.

Richards DR, Edwards PJ (2018). Using water management infrastructure to address both flood risk and the urban heat island. Int J Water Resour Dev. 34(4):490–98. doi:10.1080/07900627.2017.1357538.

Rychetnik L, Sainsbury P, Stewart G (2019). How local health districts can prepare for the effects of climate change: an adaptation model applied to metropolitan Sydney. Aust Health Rev. 43(6):601–10. doi:10.1071/AH18153.

Ryti NRI, Guo Y, Jaakkola, JJK (2016). Global association of cold spells and adverse health effects: A systematic review and meta-analysis. Environ Health Perspect. 124(1):12–22. doi:10.1289/ehp.1408104.

Santamouris M, Cartalis C (2015). Building resilient cities to climate change. In: Rassia ST, Pardalos PM, editors. Future city architecture for optimal living. Cham: Springer: 141–59. doi:10.1007/978-3-319-15030-7_8.

Sharifi A (2021). Co-benefits and synergies between urban climate change mitigation and adaptation measures: a literature review. Sci Total Environ. 750:141642. doi:10.1016/j.scitotenv.2020.141642.

Sharifi A, Khavarian-Garmsir AR (2020). The COVID-19 pandemic: impacts on cities and major lessons for urban planning, design, and management. Sci Total Environ. 749:142391. doi:10.1016/j.scitotenv.2020.142391.

Silva MM, Costa JP (2018). Urban floods and climate change adaptation: the potential of public space design when accommodating natural processes. Water. 10(2):180. doi:10.3390/w10020180.

Sinha M, Kumar M, Zeitz L, Collins PY, Kumar S, Fisher S et al. (2020). Towards mental health friendly cities during and after COVID-19. Cities Health (Special Issue on COVID-19). doi:10.1080/23748834.2020.1790251.

Soleimani H, Poorzahedy H (2021). Multi-agent programming to enhance resiliency of earthquake-prone old metropolitan areas by transit-oriented development under public-private partnership. Eur J Transp Infrastruct Res. 21(1):19–52. doi:10.18757/ejtir.2021.21.1.4304.

Stone B, Hess JJ, Frumkin H (2010). Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Environ Health Perspect. 118(10):1425–8. doi:10.1289/ehp.0901879.

Sturiale L, Scuderi A (2019). The role of green infrastructures in urban planning for climate change adaptation. Climate. 7(10):1–24. doi:10.3390/cli7100119.

Szewrański S, Świąder M, Kazak JK, Tokarczyk-Dorociak K, van Hoof J (2018). Socio-environmental vulnerability mapping for environmental and flood resilience assessment: the case of ageing and poverty in the city of Wrocław, Poland. Integr Environ Assess Manag. 14(5):592–7. doi:10.1002/ieam.4077.

Tang P, Xia Q, Wang Y (2019). Addressing cascading effects of earthquakes in urban areas from network perspective to improve disaster mitigation. Int J Disaster Risk Reduct. 35:101065. doi:10.1016/j.ijdrr.2019.101065.

UNDRR (2017). How to make cities more resilient: a handbook for local government leaders. Geneva: United Nations Office for Disaster Risk Reduction (https://www.undrr.org/publication/how-make-cities-more-resilient-handbook-local-government-leaders-2017).

UNDRR (2019). Words into action: local disaster reduction and resilience strategies. Geneva: United Nations Office for Disaster Risk Reduction (https://www.undrr.org/publication/words-action-guidelines-implementation-guide-local-disaster-risk-reduction-and).

UNDRR (2021). Poorly planned urban development. In: PreventionWeb [website]. Geneva: United Nations Office for Disaster Risk Reduction (https://www.preventionweb.net/understanding-disaster-risk/risk-drivers/poorly-planned-urban-development).

UNDRR (2022). Making Cities Resilient 2030 [website]. Geneva: United Nations Office for Disaster Risk Reduction (https://mcr2030.undrr.org/).

UNECE (2020). A handbook on sustainable urban mobility and spatial planning: promoting active mobility. Geneva: United Nations Economic Commission for Europe (https://unece.org/transport/publications/handbook-sustainable-urban-mobility-and-spatial-planning).

UNEP DTU (2021). Climate technologies in an urban context. Copenhagen: UNEP DTU Partnership (https://tech-action.unepdtu.org/publications/climate-technologies-in-an-urban-context/).

UN-Habitat, WHO (2020). Integrating health in urban and territorial planning: a sourcebook. Geneva: United Nations Human Settlements Programme and World Health Organization (https://apps.who.int/iris/handle/10665/331678).

United Nations (2015a). Sendai Framework for Disaster Risk Reduction 2015–2030. New York: United Nations (https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030).

United Nations (2015b). Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations (https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981).

United Nations (2015c). Paris Agreement. New York: United Nations (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement).

United Nations (2017). New Urban Agenda. New York: United Nations (https://habitat3.org/the-new-urban-agenda/).

Vahmani P, Jones AD, Patricola CM (2019). Interacting implications of climate change, population dynamics, and urban heat mitigation for future exposure to heat extremes. Environ Res Lett. 14(8):084051. doi:10.1088/1748-9326/ab28b0.

Vamvakeridou-Lyroudia LS, Chen AS, Khoury M, Gibson MJ, Kostaridis A, Stewart D et al. (2020). Assessing and visualising hazard impacts to enhance the resilience of critical infrastructures to urban flooding. Sci Total Environ. 707:136078. doi:10.1016/j.scitotenv.2019.136078.

Vargo J, Stone B, Habeeb D, Liu P, Russell A (2016). The social and spatial distribution of temperature-related health impacts from urban heat island reduction policies. Environ Sci Policy. 66(C):366–74. doi:10.1016/j.envsci.2016.08.012.

Venter ZS, Krog NH, Barton DN (2020). Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. Sci Total Environ. 709:136193. doi:10.1016/j.scitotenv.2019.136193.

Vona M, Harabaglia P, Murgante B (2016). Thinking about resilient cities: studying Italian earthquakes. Proc Inst Civ Eng Urban Des Plan. 169(4):185–99. doi:10.1680/udap.14.00007.

Wamsler C (2016). From risk governance to city–citizen collaboration: capitalizing on individual adaptation to climate change. Environ Policy Gov. 26(3):184–204. doi:10.1002/eet.1707.

Wamsler C, Pauleit S, Zölch T Schetke, S, Mascarenhas A (2017). Mainstreaming nature-based solutions for climate change adaptation in urban governance and planning. In: Kabisch N, Korn H, Stadler J, Bonn A, editors. Nature-based solutions to climate change adaptation in urban areas. Cham: Springer:257–73. doi:10.1007/978-3-319-56091-5.

Watts N, Adger WN, Agnolucci P, Blackstock J, Byass P, Cai W et al. (2015). Health and climate change: policy responses to protect public health. Lancet. 386(10006):1861–914. doi:10.1016/S0140-6736(15)60854-6.

WHO (2020). WHO manifesto for a healthy recovery from COVID-19: prescriptions and actionables for a healthy and green recovery. Geneva: World Health Organization (https://www.who.int/news-room/feature-stories/detail/who-manifesto-for-a-healthy-recovery-from-covid-19).

WHO (2021a). Advancing health emergency preparedness in cities and urban settings in COVID-19 and beyond: report on a series of global technical working group meetings. Geneva: World Health Organization (https://www.who.int/publications/i/item/9789240031265).

WHO (2021b). Framework for strengthening health emergency preparedness in cities and urban settings. Geneva: World Health Organization (https://www.who.int/publications/i/item/9789240037830).

WHO Regional Office for Europe (2021a). Effective risk communication for environment and health: a strategic report on recent trends, theories and concepts. Copenhagen: WHO Regional Office for Europe (https://apps.who.int/iris/handle/10665/349338).

WHO Regional Office for Europe (2021b). Heat and health in the WHO European Region: updated evidence for effective prevention. Copenhagen: WHO Regional Office for Europe (https://apps.who.int/iris/handle/10665/339462).

World Bank, International Finance Corporation, Multilateral Investment Guarantee Agency (2008). Development and climate change: a strategic framework for the World Bank Group – technical report. Washington DC: World Bank (https://openknowledge.worldbank.org/handle/10986/28201).

Xu J, Yin X, Chen D, An J, Nie G (2016). Multi-criteria location model of earthquake evacuation shelters to aid in urban planning. Int J Disaster Risk Reduct. 20:51–62. doi:10.1016/j.ijdrr.2016.10.009.

Xu L, Wang X, Liu J, He Y, Tang J, Nguyen M et al. (2019). Identifying the trade-offs between climate change mitigation and adaptation in urban land use planning: an empirical study in a coastal city. Environ Int. 133(Pt B):105162. doi:10.1016/j.envint.2019.105162.

Yamashita S, Matsuda S, Watanabe R, Shimatani Y, Moriyama T, Hayashi H et al. (2016). A registration system for preventing/mitigating urban flood disasters as one way to smartly adapt to climate change in Japanese cities. Int Rev Spat Plan Sustain Dev. 4(2):18–29. doi:10.14246/irspsd.4.2_18.

Zhao Q, Guo Y, Ye T, Gasparrini A, Tong S, Overcenco A et al. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. Lancet Planet Health. 5(7):e415–25. doi:10.1016/S2542-5196(21)00081-4.

Zhu W, Yao N, Guo Q, Wang F (2020). Public risk perception and willingness to mitigate climate change: city smog as an example. Environ Geochem Health. 42(3):881–93. doi:10.1007/s10653-019-00355-x.

The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

Member States

Albania
Andorra
Armenia
Austria
Azerbaijan
Belarus
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czechia
Denmark
Estonia
Finland
France
Georgia
Germany
Greece
Hungary
Iceland
Ireland
Israel
Italy
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Luxembourg
Malta
Monaco
Montenegro
Netherlands
North Macedonia
Norway
Poland
Portugal
Republic of Moldova
Romania
Russian Federation
San Marino
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Tajikistan
Türkiye
Turkmenistan
Ukraine
United Kingdom
Uzbekistan

WHO/EURO:2022-5647-45412-64987

WHO European Centre for Environment and Health
Platz der Vereinten Nationen 1
D-53113 Bonn, Germany
Tel.: +49 228 815 0400
Fax: +49 228 815 0440
E-mail: euroeceh@who.int
Website: www.euro.who.int