Mitigation and adaptation strategies to offset the impacts of climate change on urban health

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Abstract

Climate change threatens urban health, whether that refers to the human or environmental aspects of urban life. At the same time, initiatives of city regeneration are envisioning alternative forms of the urban environment, where derelict spaces have the potential to be brought back to life in ways that would not compromise urban health. Regeneration processes should utilise mitigation and adaptation strategies that consider the future needs and anticipated role of cities within the context of the discourse about climate change, accounting for expected and unforeseen impacts and regarding the city as an agent of action rather than a static territory too complex to change. Nevertheless, literature implicating these three parameters synchronously, namely, climate change, cities, and health, has been scarce. This study aims to fill this gap through a systematic literature review, exploring adaptation and mitigation strategies that can be employed in urban regeneration efforts aiming to mitigate climate change and its impacts on urban health as well as identifying the main trends and opportunities overlooked. Findings show that even though the emphasis is given to the physical actions and impacts of climate change and urban health, an emerging theme is the need to engage civic society in co-designing urban spaces. Synergistic relationships, collaborations and avoidance of lock-in situations appears to be the most significant subtopic emerging from this literature review One main recommendation is to promote a community-driven, inclusive, participatory approach in regeneration projects. This will ensure that different vulnerabilities can be adequately addressed and different population groups will have equitable health benefits.

Keywords

Climate change; urban health; regeneration; systematic literature review; SWOT analysis; adaptive urban design

1. Introduction

People born in the past two decades have lived through extended crises – economic crunches, social disruptions, national or international conflicts, public health shocks and constant climate anxiety [1]. While some disasters can be alleviated and seem to have an expiration date, others are long-lasting. Climate change is such an affliction; it has been a research topic for decades, with each period being marked by a different focus [2]. Global warming is now such a critical matter that the anthropic dimension is being examined alongside its scientific basis. The latest IPCC report highlights the impacts of climate change observed in many ecosystems and human systems worldwide [3]. Notably, observed climate change in urban settings has affected human health, livelihoods and key infrastructure. Hot extremes, including heat waves, have intensified in cities, where they have also aggravated air pollution events and limited the functioning of key operative frameworks. Marked effects are concentrated amongst the economically and socially marginalised urban residents, e.g., in informal settlements, and the magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions.

The changing climate is no longer a niche topic intended to be known only to experts; it is today's lived reality, and major efforts are being observed on a coordinated plane to avoid worst-case scenarios. The science of climate change is well understood, and the challenge for the near future is to assimilate this knowledge into policymaking, promoting major transitions in lifestyles and systems to a more sustainable living experience. The epicentre of these changes is unavoidably cities, with more than half of the world's population already living in urban centres in 2018 [4] and the global population surpassing 8 billion in late 2022 [5]. The impact of climate change within densely populated and travelled urban centres is manifested in many ways, from the built environment to the patterns of energy consumption and the health of humans, living organisms or the urban environment.

A focal element to transferring the knowledge on the physical basis of climate change to practical applications at the city level is the co-participatory approach. Allowing and encouraging populations to be engaged in the shaping of urban spaces is an important step in the regeneration process [6]. It also enlightens citizens on the potential of cities to improve their mental and physical health, something which not everyone is aware of. Co-participation acknowledges the real needs of urban dwellers and integrates their own preferences in design solutions, forming contacts with nature, enhancing social interactions and creating co-benefits between the health of humans and urban habitats [7–9].

The scope of the “Climate change, Cities, Communities and Equity in health” (CliCCHE) project is to create and promote a fully-integrated transdisciplinary educational methodology, adopting unconventional tools to deal with the effects of climate change on urban health and equity in teaching urban regeneration of European cities. The project’s task is, therefore, to bridge gaps between the scientific and anthropic dimensions of climate change, with a special emphasis on design tools able to improve health in urban habitats. This work reflects the investigation into adaptation and mitigation strategies against climate change and its impacts on urban health, identifying the main trends as well as the opportunities that are overlooked. The main concepts of this review are therefore three: the first is climate change, referring to long-term changes in temperatures and weather patterns. Although climate change is a naturally occurring phenomenon, the industrial revolution and anthropogenic actgivity have accelerated it, primarily due to the burning of fossil fuels and the release of heat-trapping gases in the atmosphere. The second concept is the urban environment, referring to infrastructure, services and community encountered in cities, and the last concept is health, defined here as either human (wellbeing or disease) and environmental (declining or thriving).

Previous work has examined similar topics in a more narrow lens, for instance Villalbí and Ventayol (2016) have elaborated on the health challenges brought forward by climate change, but specifically for the city of Barcelona [10]. Moreover, recent reviews have tackled limited scopes of the city-health-climate change trio. For instance, Wang and He (2022) focused on the resilience of urban systems by examining the co-occurrence of urban heat and Covid-19, without further health considerations, while Arsad et al. (2022) also looked into heat-related health issues, assessing effects of extremes on mortality and morbidity, but not in an urban context [11,12]. Other reviews have focused more on the relationship between climate change and health, either in an intersectional approach [13] or in relation to distinct causes and effects [14], without expanding on the capacity of cities to act as agents of adaptation and mitigation and rarely with a connection to health equity. An integrated approach was developed by Nazarian et al. (2022) to study the effects of heat hazards in urban contexts, the factors that may increase vulnerability and impacts on health and energy [15]. The study also explored adaptive capacities and future outlook towards a more resilient built environment and governance frameworks, focusing only on the overheating aspect. Another overarching review published in 2022 advocates for combined risk mitigation and adaptation policies in urban areas for increased resilience to climate risk, through the perspective of IPCC’s assessment reports [16]. A plethora of publications has been produced in the last few years, reflecting the urgency posed by climate change impacts, however, most of these studies are focused on specific elements or combinations of the city-health-climate change nexus, but not quite covering all facets. In this review, climate change

challenges relating to various types of natural hazards, as well as human-exaggerated ones are analysed, as well as human and environmental health impacts and adaptation and mitigation strategies at the city level.
In order to increase the impact and replicability of this contribution, a systematic approach has been selected to collect, review and analyse information and a SWOT analysis has been chosen as a way to merge studies from different sciences and to to facilitate the discussion and the qualitative analysis of findings. The subsequent section therefore describes the methodological approach, followed by a quantitative description of the scientific landscape in section 3, and a qualitative analysis of the strengths, weaknesses, opportunities and threats identified through this systematic literature review in section 4. The final section offers concluding remarks, outlining the main findings and outlook resulting from this work.

2. Methodology

The systematic literature review approach is employed to summarise and synthesise the findings of existing research for a specific field. This approach is used to qualitatively assess manageable datasets, evaluating and interpreting findings. On the other hand, a bibliometric analysis is often used with large datasets in need of quantitative analysis of a broad subject [17]. Such guidelines seem clear and concise, but a considerable number of publications may need to be reviewed under a qualitative lens, which is often facilitated through quantitative approaches. The favourable method is, therefore, often a mixed methodology adjusted to the specific needs of a topic, with diverse fields of research already exploring these methodologies [18–20]. Studies adopting a mixed-methods approach selects and synthesizes elements that are most suited to their narratives; this study does the same, combining different elements of systematic literature review, bibliometrics and SWOT analysis to examine the specificities of urban health in relation to mitigation and adaptation strategies.
This study aims to analyse the mitigation and adaptation strategies to climate change effects on human health adopted in mostly European urban areas. Although this establishes a niche topic, which is most suitably addressed qualitatively through a systematic literature review, including a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, the relevant literature is not scarce. Therefore, a quantitative approach is also adopted through bibliometric analysis, used here to assess prevailing patterns, trends and possible gaps. Regarding the SWOT analysis, although it is used most commonly as a strategic planning tool, here it is treated as a tool for a structured critical analysis of the findings. Previous studies reviewing a body of literature have employed the SWOT analysis, either to point out different angles of a specific topic, or to identify overlooked issues that are secondary to the main ones [21–23].

2.1. Systematic literature review

In the last decades, several studies have dealt with the conditions related to global warming and the linked impacts caused by climate change. In order to study the implications of climate change’s impact on urban health, a systematic literature review was performed. To this purpose, the Preferred Reporting Items for Systematic Reviews and Meta-Analyse (PRISMA) scheme and the Context-Intervention-Mechanisms-Outcomes (CIMO) logic are used in tandem to explore existing knowledge. According to the most recent PRISMA scheme, three main steps are advised in the selection of documents: Identification, Screening and Inclusion [24]. In the first step, identification, the CIMO logic is applied to define the research question and the exact queries to be run in accessible databases of scientific publications (see Fig.1). For the purposes of this study, the Scopus and the PubMed databases are investigated, representing the former primarily natural sciences- and engineering-oriented sources and the latter primarily health and medical sources [25,26]. An iterative process and keywords review were crucial steps in the Identification phase to finalise the exact queries. Following the CIMO logic, the research question investigated in this work is: "*How can mitigation and adaptation strategies (M) mitigate climate change effects (I) to improve health (O) in urban contexts (C)?*"

Based on the formulated research question, keywords were identified for each component of CIMO, as presented in Fig.1. The keywords are connected with proper Boolean operators: OR within each of the four CIMO categories and AND between the four CIMO categories and a search query is built. Then, exclusion criteria are applied throughout the PRISMA process, including removing generic keywords and duplicate studies and selecting specific document types and language (English). Moreover, a restriction for European cities was imposed, because the number of results from the query was otherwise too high; in recent years, a global increase has been observed on topics relating to climate change and urban health, reflecting the urgency to address them. Nevertheless, some flexibility was allowed when very interesting work was identified for areas outside the EU. The process of query building and exclusion criteria is adjusted to the two databases used; Scopus and PubMed. A manual search of specific articles complements the query search (lastly accessed on 14/3/2022), and the ultimate pool of research documents includes 110 contributions.

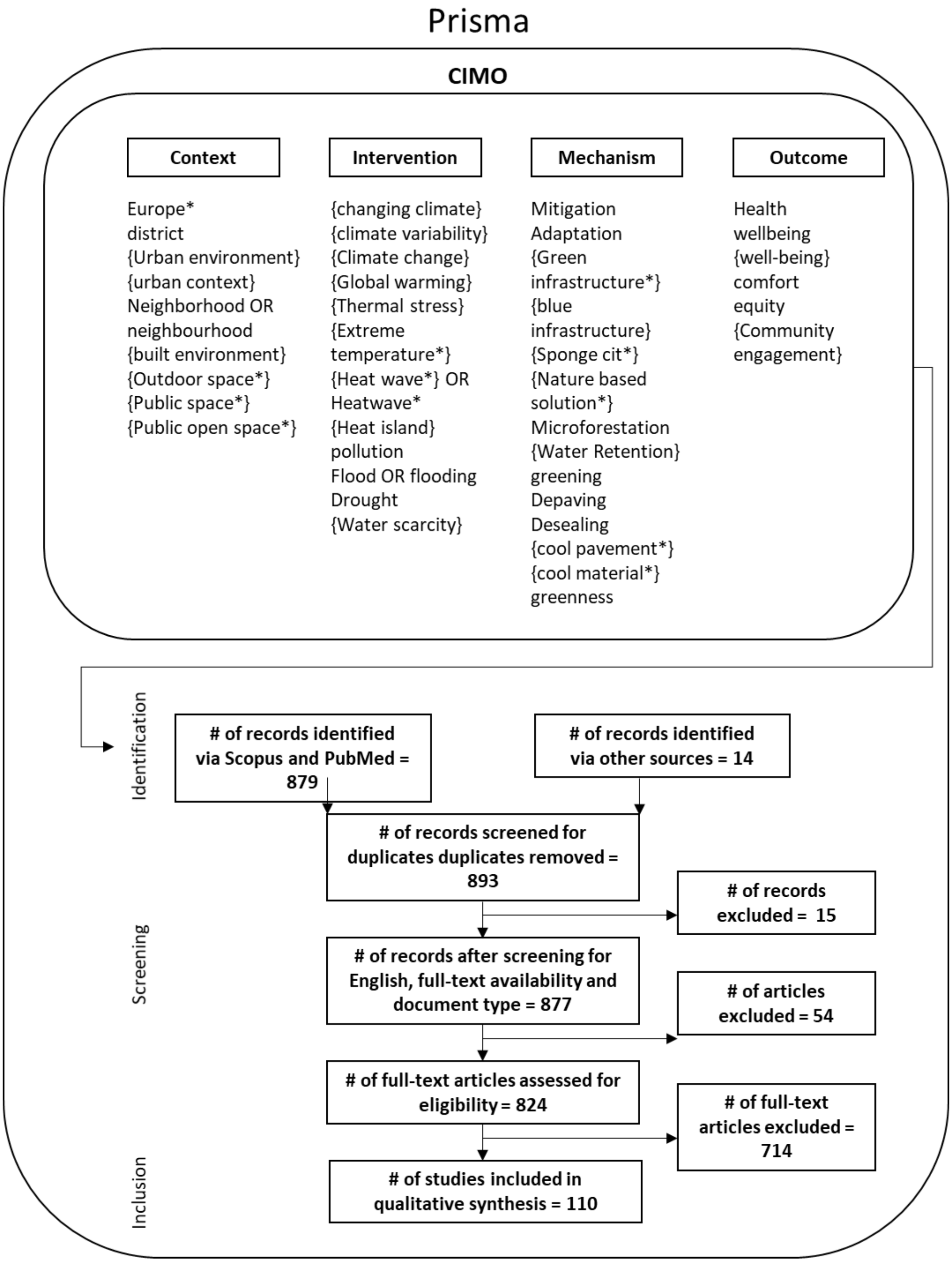

Figure 1. PRISMA and CIMO schemes.

2.2. Bibliometric analysis

Bibliometrics are explored through the free software VOSviewer 1.6.18 to analyse key bibliometric and meta-analysis features, in line with similar hybrid studies that have followed a systematic literature review approach [20,27,28]. Co-occurrence analysis detects the simultaneous occurrence of specific words, whether that refers to author or index keywords, institutions or thematic areas, helping identify research hotspots and trends in a field of literature [2]. In this study, co-occurrence analysis is conducted for author and index keywords.

2.3. SWOT analysis

With its origins traced back to the 1950s, the tool of SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis has been used for purposes of strategic analysis and development, commonly in corporate fields related to management and business [29]. However, its extended use in environmental academia also covers energy and renewables [30–33], sustainability and urban regeneration topics [34–38] and health [39–42], among others. Here it is employed concurrently with the systematic literature review, to facilitate qualitative analysis of an extended database of publications. In this study, the SWOT analysis is used to extract key topics from each of the elements: Strengths, Weaknesses, Opportunities and Threats, leading to the creation of a matrix. This identifies the frequency in which specific topics are discussed, as well as the SWOT elements each topic appears in, allowing for identification of the most and least explored themes in climate change and urban health literature.

3. Scientific landscape and emerging themes

The results of the systematic literature review are presented in subsections corresponding to key features of bibliometric analysis, the components of the CIMO approach and the SWOT analysis. These are discussed in a qualitative approach in subsequent sections. No time limits were imposed on the literature search, with the resulting timeline of publications spanning from 1996 to 2022, although only one publication fitting the search criteria was published between 1996-2007 (Fig. 2). The observed increment in publications post-2008 may serve as a reflection of the social and economic crises experienced globally, as well as the increased focus of international alliances on the urgency of climate change mitigation and urbanisation. The research query, therefore, successfully echoes the physical as well as the social dimensions related to adaptation and mitigation of climate change and health in cities. Still, it is notable that half of the publications responding to the formulated research question were published from 2018 onwards, with a remarkably low number of papers reaching the publication stage in 2019 and a corresponding increase in 2020.

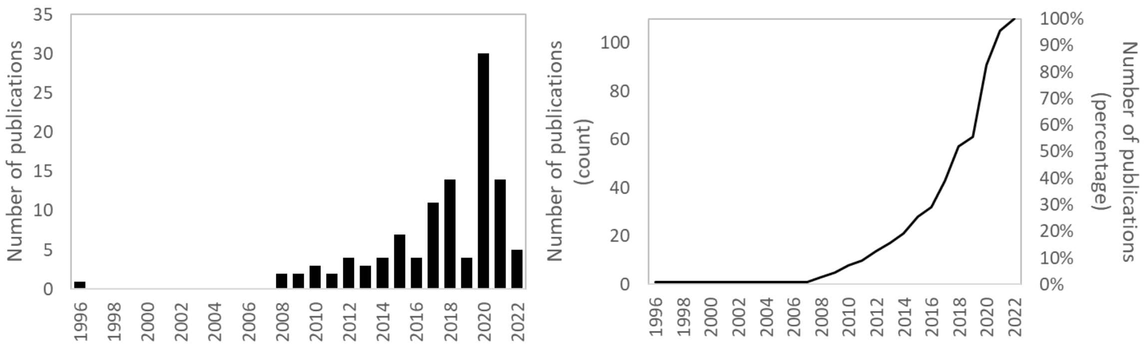

Figure 2. Timeline of publications per year (left) and cumulative publications (right).

As for the co-occurrence analysis, Fig. 3 presents the density visualisation indicating that climate change is the most frequently cited keyword. The most frequent keywords also include human(s), urban heat island(s), urban design, thermal comfort and adaptive management, illustrating the priorities of research so far. Moreover, health, mortality and vulnerability are highlighted, as well as policy, adaptation and decision-making.

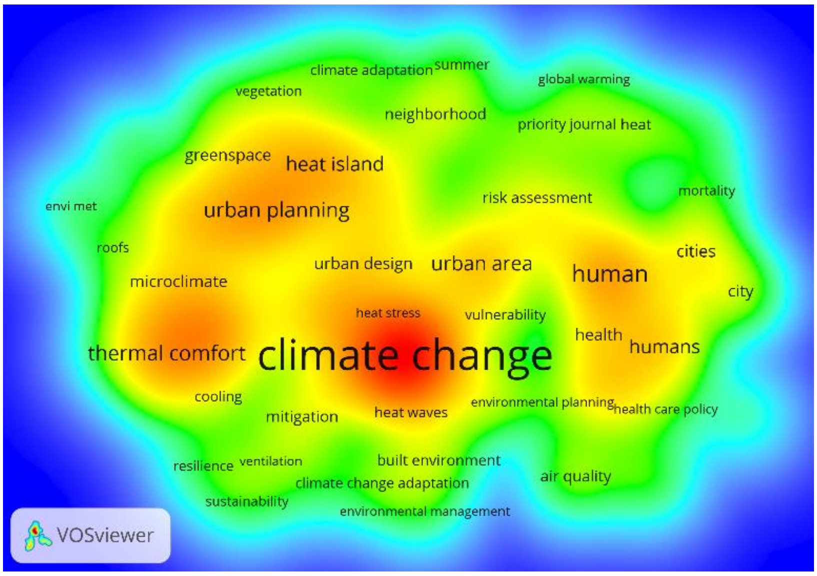

Figure 3. Co-occurrence of all keywords, with a minimum number of 5 occurrences. Source: own work via VOSviewer.

Each CIMO component was further partitioned into subcategories, presented throughout Figures 4-9. The Context (Fig. 4) where the intervention is embedded refers to the physical boundaries of cities, ranging from the scale of a single building to the higher level of territories overarching multiple cities. The city level is the most frequently examined spatial plane, although neighbourhoods, districts and clusters are also commonly examined. Singular buildings or overarching territories are less frequent but not rare. This distribution is not observed in the other two subcategories of the Context component since open spaces are by far more regularly studied in relation to closed ones, and the most common type of climate is related to locations with temperate humid subtropical or oceanic conditions.

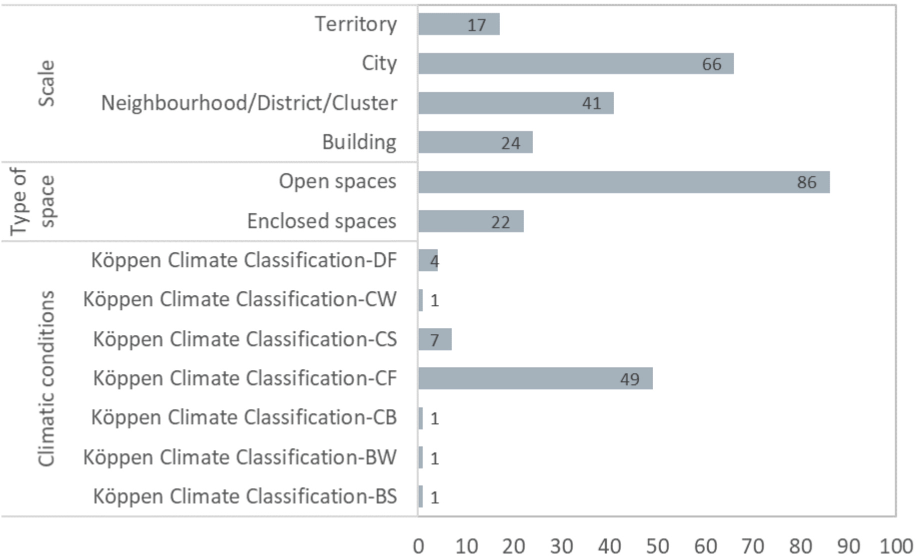

Figure 4. Subcategories of the Context component of CIMO.

Under Intervention (Fig. 5), only two subcategories exist: anthropogenic hazards and natural hazards. The first category refers to hazards that have developed due to human activity and are more frequently studied while the second category to ones that relate to naturally occurring phenomena that have no link to human interference. In both subcategories, heat is the most commonly studied hazard, whether that relates to heat stress due to global warming or heat island effects of urban centres. Under anthropogenic-induced hazards, the second highest occurrence refers to issues of pollution, whereas shortage of energy or other resources comes last. In terms of naturally occurring catastrophes, the subject most frequently studied following heat stress is related to flooding. Droughts and disease outbreaks are not so common, whereas dust storms are non-existent in this specific research field, something possibly owed to the European focus; such dust events are a major hindrance in other parts of the world, such as the Eastern Mediterranean and the Gulf Cooperation Council area [43].

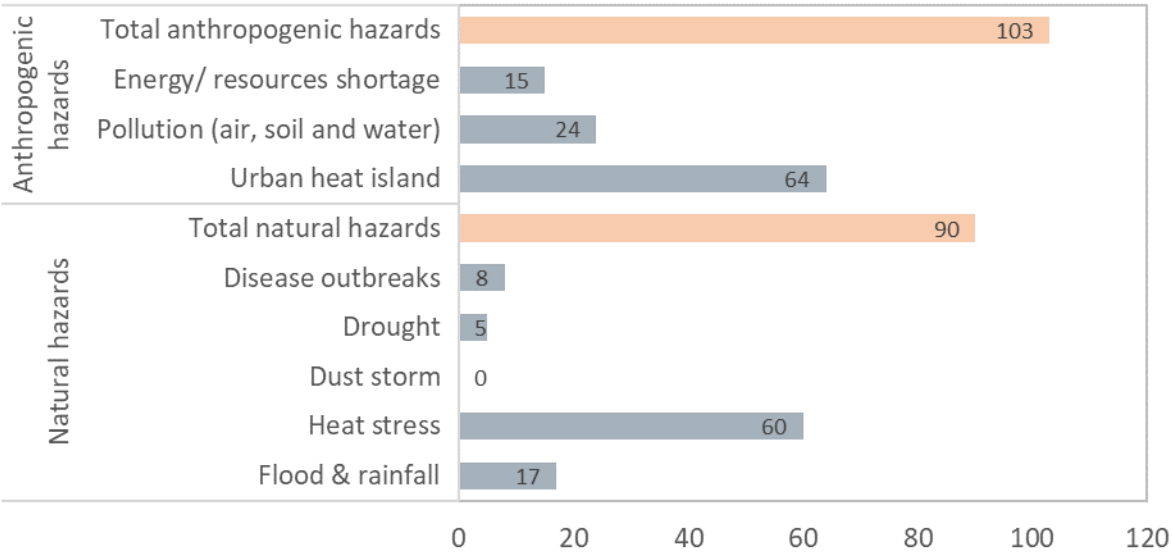

Figure 5. Subcategories of the Intervention component of the CIMO-logic.

The Mechanism component of CIMO contains two major subcategories, Mitigation and Adaptation strategies, each comprising multiple further subdivisions. Findings on the mitigation strategies detected in literature are shown in Fig.6. Urban design and land-use planning seem to be a preferred study subject, while investigations on circular economy issues such as carbon capture, low-carbon materials and material efficiency are considerably less common. Similarly, the low-energy, sustainable and resilient buildings and neighbourhoods' subdivision is mostly represented by the energy efficiency element, followed by energy conservation. Smart and renewable energy technologies are under-represented in the literature. The same can be said for the entire class of sustainable mobility, which is uniformly represented among subdivisions of modal shift, shared mobility, mobility services, traffic optimisation and smaller vehicles with high efficiency and low emissions.

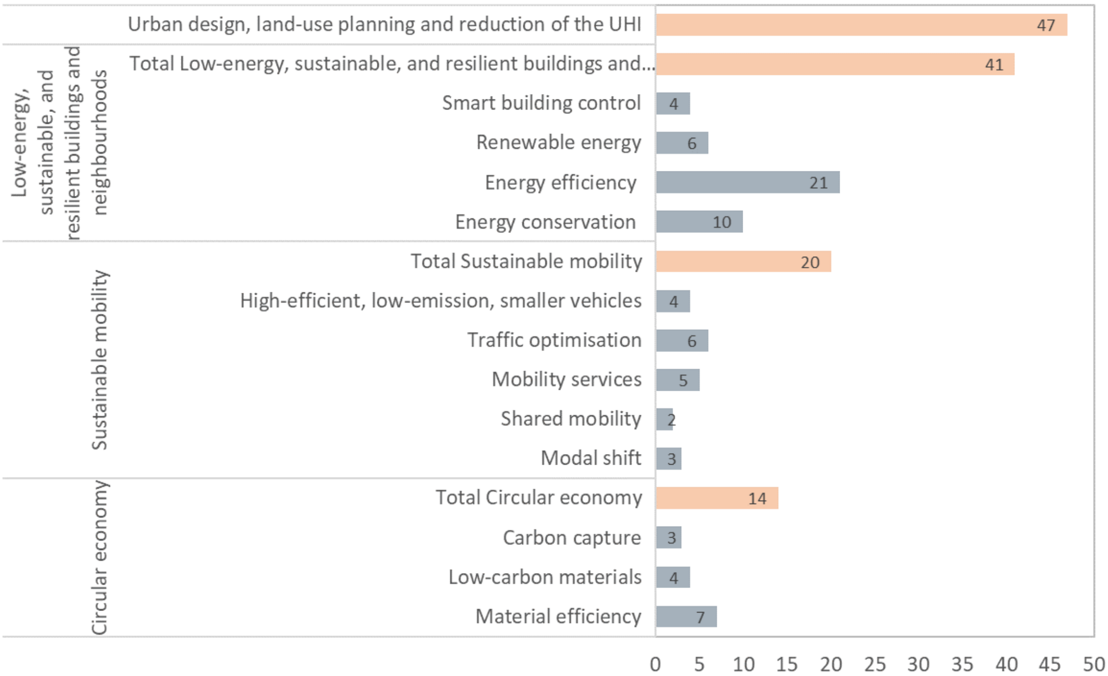

Figure 6. Subcategories of the mitigation strategies for the Mechanism component of the CIMO logic.

In Adaptation strategies (Fig.7), there is no significantly overshadowed component analogous to sustainable mobility; all subcategories are well embodied in research. Policy-based strategies form the strongest element, almost equally represented by design guidelines, urban planning, and zoning regulation.

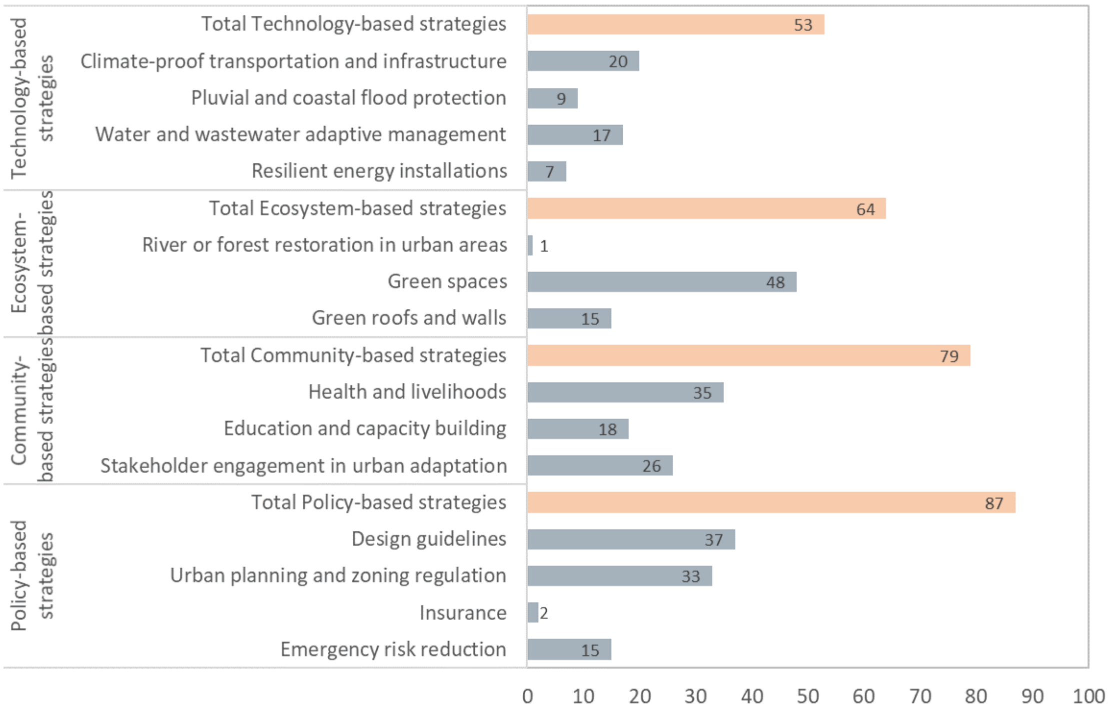

Figure7. Subcategories of the adaptation strategies for the Mechanism component of CIMO.

Although emergency risk reduction is far less echoed in literature, insurance-related policy strategies are almost absent. The category most closely following policy-based strategies is related to community-driven adaptive measures. The three divisions featured here, health and livelihoods, education and capacity building and stakeholder engagement, are well reflected in the research. In ecosystem-based strategies, one subdivision overpowers the rest, and another is poorly mirrored. Green spaces are the most significant aspect of ecosystem-driven approaches, possibly reflecting the importance of urban design.

On the other hand, urban rivers or forests are not a hotspot of research at the moment, with green roofs and walls being moderately studied in relation to other topics. The final category under adaptation is focused on technology-based strategies, mostly comprised of climate-proof transportation and infrastructure, as well as management of urban water resources. Pluvial and coastal flood protection and resilient energy installations have received little to moderate attention in this field of research.

The last component of the CIMO scheme is Output (Fig. 8), defined here by two categories: human and environmental urban health. The largest part is occupied by comfort, under human health, without, however, lessening the attention paid to other subdivisions. Under this main category, disease, fitness and mental health are uniformly investigated, unlike equity issues, which nevertheless are moderately reflected in relation to other elements. Under environmental health, improved urban ecosystems and resource use efficiency are well illustrated, with improved carbon footprints and reduced emissions being moderately examined.

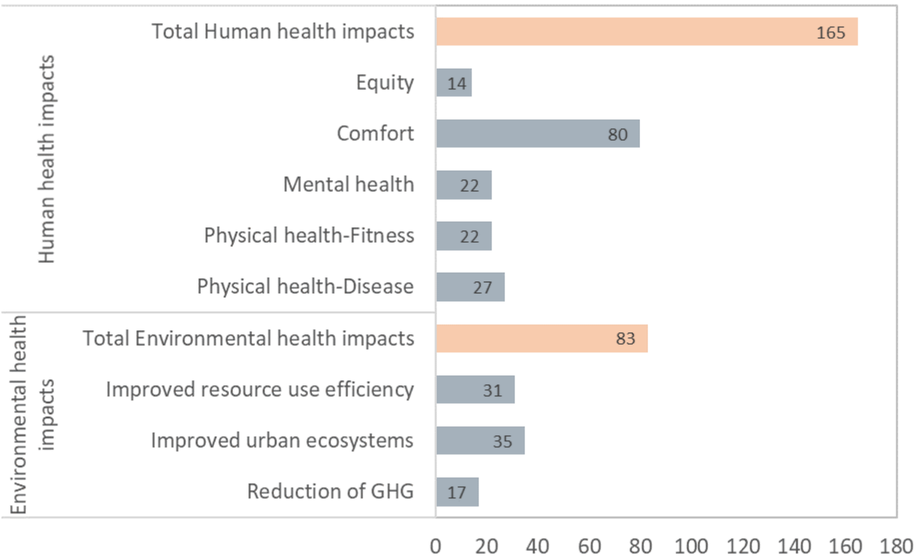

Figure 8. Subcategories of the Output component of CIMO.

A clear distinction is observed in the reported number of each element of the SWOT analysis, with a considerably higher amount of strengths and opportunities being identified relative to the number of weaknesses and threats. This may be due to the focus of the query search, aiming to detect adaptation and mitigation designs instead of simply the adverse impacts of cities on health (Fig. 9).

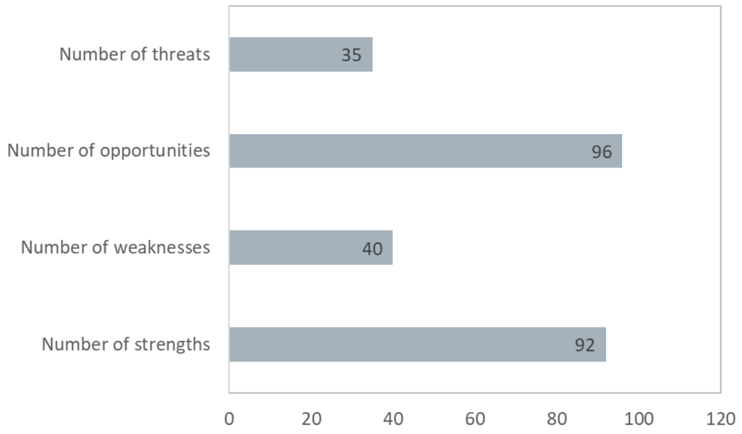

Figure 9. Metrics of the SWOT analysis.

4. Discussion

Adaptation and mitigation interventions that cities will be able to implement in the coming decades through urban regeneration plans represent an essential factor in the fight against climate change. The integration of different skills and the involvement of different stakeholders is a process that implies interdisciplinary paths and tools. These are applied towards the preventive assessment of health impacts from environmental changes to create more sustainable built environments. Moreover, tools for a global evaluation of the interconnections between climate and health, social, environmental, and economic vulnerabilities, and the quality of urban spaces are developed. Cities are at the forefront of the fight against climate change and must play a leading role in strategies for identifying adaptation and mitigation interventions. The SWOT analysis is used here as a tool to structure and facilitate the discussion on trends, emerging topics and gaps in current literature on the nexus of climate change-cities-health. The content of contributions is briefly discussed, but is not the focal point for this analysis, which rather presents a meta-analysis of the systematic literature review.

Qualitative analysis of the literature

An array of strategies has been identified to potentially improve urban centres for their residents, benefitting humans and the local environment simultaneously. Urban geometry and vegetation have been the most effective strategies that substantially contributed to reducing human thermal discomfort in outdoor spaces [44–47]. Urban green interventions, such as road trees, public and private gardens, parks, green roofs and walls, and urban gardens, contribute significantly to climate adaptation, the reduction of heat waves, to the improvement of surface runoff and absorption of water [48–51]. Humans also benefit from urban greenery and soft surfaces as these mitigate the effects of urban heat islands and contribute to air filtration, noise reduction, rainwater drainage and wastewater treatment [52]. Although water-related health problems are significant for urban living – the analysed literature does not reflect it and does not offer opportunities to overcome these problems. Moreover, greenery is also studied in the context of adequate water supply [53], while identification and quantification of the environmental benefits of nature based solutions (NBS) [54] and the co-benefits of urban green structures [55] are also examined. Some emerging topics in relation to adaptation and mitigation in this respect include the development of an “anti-gentrification” urban greening strategy through greening with the vertical system [56] and the Inclusion of psychological and social aspects in the research and implementation of NBS measures [57]. Nevertheless, green spaces are linked to health risks, mainly associated with exposure to allergens, such as plants and the emission of biogenic volatile organic compounds, which can act as air ozone precursors [58]. They may also provide fertile conditions for bacterial growth [59] but also for chronic diseases such as cancer, heart disease, mental illness, chronic respiratory disease, diabetes and obesity, especially present in the Global North [60].

Almost half of the papers refer to problems of overheating, with many studies focusing on UHIs and heatwaves [61–65]. Moreover, extreme temperatures and future warming are also reported as frequent threats [66,67], as well as heat stress affecting air quality and health [47,66,68]. Urban heat can also be investigated through scenario hypotheses for climate changes and design hypotheses through satellite maps, numerical simulation software, prognostic models based on fluid dynamics and thermodynamics, multi-criteria methodologies [69], often integrated and involving citizens, decision-makers, local planners and interested parties [70]. In addition to small-scale interventions, urban heat can be tackled at the policy level through guidelines for local authorities on where to focus the most sustainable actions [71]. It can also be addressed through policies to improve the shading function of roads [72] and by using a transdisciplinary approach for the joint framing of problems with the aim of developing shared design solutions [68]. Nevertheless, only a few studies analyse the effects of heat weaves on socio-demographic factors at the urban and neighbourhood scale [73].

Atmospheric emissions and air quality [70,74,75], pollution [62,76], exposure to allergens and the emission of biogenic volatile organic compounds [58] are also frequent research subjects. Pollution has been linked to human mortality and morbidity [46]. In response to its detrimental effect in cities and the well-being of residents, adaptive and mitigating topics emerging from the literature include mixed methods. These consider the role of citizen behaviour in creating future scenarios to improve urban environments [70], including innovative approaches to investigate health benefits as a motivator for climate action [77]. For example, built chimney systems are examined in their capacity to remove polluted air from the pedestrian level of the streets while generating clean electricity [74]. Evaluation models have been used to internalise health costs related to air pollution, as well as models that efficiently integrate environmental monitoring data and scenario modelling [78], but research could be further explored in the study of computational models for traffic management and urban planning, as well as in understanding pollution dispersion models within road canyons [46]. Moreover, interdisciplinary factors in assessing citizens' preferences for mitigation measures that may have practical implications for public health and climate policies are another underexplored topic [77].

With regards to the design and promotion of interventions for the bioclimatic control of buildings, by design but also with the use of innovative materials, these have been shown to have the capacity to improve thermal insulation, offer shading solutions for solar radiation, and increase natural ventilation and cooling [79–81]. Building design and configuration and occupant scenarios were found to have beneficial impacts on thermal comfort, energy consumption and emissions [82]. For instance, Bienvenido-Huertas et al. [83] found that according to adaptive thermal comfort conditions applied to new buildings, energy savings greater than 1000kWh/year can be achieved, while William et al. [84] estimated energy savings of up to 67% through energy refurbishment and sizing the HVAC system correctly. Solar reflective pavements have been exemplified as simple, cost-effective solutions to reduce surface temperature, while less understood is the effect of solar reflective coatings on radiant heat, which may affect human thermal exposure and comfort [72]. Nevertheless, reflective coatings of cool roofs may be helpful to limit the absorbed solar energy, leading to a decrease in the temperature of surfaces, air, and, thus, the surrounding environment. Indeed, reduced overheating periods have been observed due to the reduced values of the heat quantities [85].

Another key thematic area identified is the role of a participatory approach to the design of public space and active citizens. Engaging in ongoing research projects has allowed citizens to understand better the links in their daily lives related to urban infrastructure and land-use planning [86]. Community-based strategies allow for tailored solutions in relation to local contexts and needs, establishing new habits that can contribute to improved urban health [87,88]. Moreover, citizen-inclusive policy making is an essential focus point for future policy plans aiming to improve air quality and health benefits [70]. Attention is paid to the education and involvement of citizens that are concerned about heatwaves and climate change [89] and also to "citizen-inclusive policymaking" [70]. It is not only necessary to make cities interesting and attractive; they must mitigate climate change as well [90] and for this task, it is necessary to foster a co-design approach for climate change adaptation [68]. Synergies between different policy areas regarding the soil-water system have been investigated as the basis for a climate-proof and healthy urban environment [49], whereas careful planning is suggested for the reduction of overall air pollution-related risk [91]. Scheme and strategy development are also encountered when developing systematic procedures for implementing green interventions in the urban public fabric [90]. They are also met when combining measures in heat stress reduction and improvement of thermal comfort with design solutions that include vegetation, street orientation and aspect ratio [47], green areas, shadow zones and the maintenance of "street canyon ventilation" [92]. Besides individual domains, it has therefore been recognised that specific opportunities lie in combining different mitigation and adaptation measures [81] and domains of action [47], as well as in developing approaches that enable co-benefits [67,88,93,94].

When introducing novel approaches, even if the environmental advantage of the proposed methods is obvious, the economics, maintenance and management costs of the system to improve urban environmental conditions could create substantial implementation barriers and therefore need to be studied further [74]. Moreover, materials aiming to improve the urban fabric can prove to be worsening the situation if a series of conditions are not met. For instance, a study found that areas with high sky view factors do not benefit from the application of cool paving materials but instead suffer worse thermal comfort conditions in the daytime [80]. The conversion of cities into business hubs also leads to higher urban housing needs and an exponential increase in energy demands [95]. Massive urbanisation and human development, especially in areas with "uncontrolled" (illegal or irregular) expansion, a major threat is observed because of an increased risk of unplanned urban slums to landslides and flooding, also due to the excessive reduction of natural wooded areas [58]. A less tangible but equally critical threat is that of the equity chasm. The impacts of climate change are already experienced differently among different population classes and global locations, something predicted to progress over time. Climate change will aggravate any existing underlying social inequities and possibly create new ones, with direct and indirect repercussions on urban health [96]. One area where equity in health has been adequately recognised is on understanding the impacts of urban heat on vulnerable groups, with attention to certain socio-demographic factors [73,77,97].

One of the biggest risks cities and policymakers face is lock-ins created by the asynchronous implementation of adaptation and mitigation measures. It has been estimated that while there is an energy conservation potential of over 70% for the building sector of western Europe, the unrealised energy gains, reflecting the lock-in risk, is around 45% [98]. The result of these situations is often legacy infrastructure and carbon-intensive technologies that persist over long periods, which de facto hinder the reduction of energy intensity and the penetration of low-carbon technological alternatives [99]. On the other hand, focusing on isolated measure implementation could either lead to amplifying results or substantially reducing the overall impact [100]. It is, therefore vital for urban planners to acknowledge their limitations in predicting the exact future needs of cities and rather focus on the strategic development of a malleable urban design that avoids future negative lock-ins and enhances positive ones.

At the systemic level, opportunities for improving human health in urban areas rely not only on the knowledge that guides climate-related urban interventions and policies but also on factors that enable and support their implementation. For example, studies researched the effects of extreme heat events as a basis for preparing heat health action plans [101] and climate studies have examined reasonable planning alternatives in relation to bioclimatic effects and impacts on mortality [102,103]. Systemic action against climate change impacts also includes strategies to increase the resilience of the built environment through codes and standards [95] and incorporation of microclimate parameters in the revitalisation of cities [104]. Although the potential exists, often, there are hidden and apparent barriers to the proper implementation of adaptation and mitigation measures. For instance, dissemination strategies of design solutions are severely under-developed, resulting in low visibility of project and research outcomes [10]. Insufficient knowledge of climate change and its impacts may create situations where, though the political will exists, practical actions are not taken due to a lack of suitable expertise and/or resources. Furthermore, institutional hurdles, mismatches between local and national governments, lack of engagement of stakeholders from the public and private domains and limited resources to promote green infrastructure works are some of the concealed fences found at the policy level.

Meta-analysis of the literature

Each element, namely Strengths, Weaknesses, Opportunities and Threats is characterised by a number of unique or common topics. These are presented in Table 1 in the form of a matrix, which identifies the frequency with which each topic has been discussed, and the coverage of SWOT elements each topic is found in. The matrix identifies five main thematic categories (Greenery and Urban fabric, Resource management, Hazards, Community and Governance and Health), each of which includes a number of sub-categories. The smallest category is Resource management and the biggest one is Community and administration and under each category is a parenthesis, which indicates the number of papers focusing on it. As expected, the smaller categories such as Resource management and Health are less represented in literature, in relation to the other three. The subject with the most emphasis seems to be Community and Governance, with the subtopic of Collaboration and Lock-ins being the most popular single subtopic. It includes aspects of international, national and regional synergies, multi-disciplinary action and co-benefits resulting from such interactions, as well as possible lock-in situations that can be created if there is no concerted effort. Publications from diverse fields are found in this category: urban planning, green public spaces, urban overheating, climate adaptation policies, human and environmental wellbeing [55,63,68,78,89,90] are only a few. Other popular subtopics include Vegetation and NBS and Heat and UHIs. These possibly reflect the most urgent needs of cities, suggesting that overheating is a critical issue that can be addressed through “greening” the city. The least examined subtopics are Urbanization and Guidelines and standards, which can present gaps in literature on the nexus of urban health-climate change-adaptation.

From the lens of the SWOT components (strengths, weaknesses, opportunities and threats), the coverage colour gradient presented in Table 1 depicts which categories and subtopics have been analysed across the board, and which have been examined in limited view. The majority of subtopics (11) have contributions in all aspects, several (8) have extended coverage, a few (5) have limited coverage and only 1 subtopic has been examined from a single lens. There is, therefore, a linear relationship between coverage and the number of subtopics included in coverage classes. The only subtopic to be examined from a single perspective is Urbanization, observed only as a threat to urban health. Although this is rational, it also represents a prospect for further research into not only the weaknesses created in cities by urbanization, but also the strengths and opportunities that may arise as a result of concentrated population in urban centres.

Table 1. Matrix of SWOT elements in relation to main topics discussed for each paper. In "Topic discussed" legend, Never corresponds to 0 papers, Rarely to 1-3 papers, Sometimes to 4-6 papers, Often to 7-10 papers and Usually to more than 11 papers. In "Coverage-Subtopics", Very limited corresponds to the subtopic being mentioned with respect to 1 SWOT element, Limited to 2, Extended to 3 and Very extended to 4. In "Coverage-Categories", Very limited corresponds to less than 25 papers covering that topic, Limited to 26-65, Extended to 66-100 and Very extended to more than 100 paper.

Category	Subtopics	Strengths	Weaknesses	Opportunities	Threats
Greenery & Urban fabric	Vegetation & NBS	[44–47,52,81,89]		[45,48,92,105–111,49–55,81]	[112]
	Spaces (outdoor, public)	[48–51,55,63,90,94,113,114]	[115]	[55,63,64,68,94,105,113]	[58–60,94]
	Greening architecture	[80,116]		[44,48,50,56,90,116–119]	
	Urban geometry	[44–47,81]	[46,72,75,110,119]	[66,92,111]	[80,92]
	Materials	[72,79–81,85,120]	[119]	[44,79,111,121]	[80]
	Building design	[79,81]	[122]	[69,74,82,85,111,115,123,124]	[61,125]
Resource management	Water management	[52,80]	[49,126,127]	[53,66,86,126,128–130]	
	Energy	[78]		[82–84,106,107]	[56,95,98]
Hazards	Air quality	[52]	[46,75]		[47,58,59,66,68,70,74,75,131]
	Pollution		[46,74]	[74,91,132,133]	[62,70,74–76]
	Heat & UHIs	[52,63,116,120,134,135]	[68,69,71–73,110,119,127,136]	[101,108,111,137,138]	[61–67,112,131,139]
	Flooding		[127,140,141]		[58,65,142]
	Urbanization				[58,95,143]
Community & Governance	Policy	[89,134]	[71,72,77,141]	[127]	
	Implementation			[111,127,134]	[10,74,144]
	Guidelines & Standards		[71,122]	[95]	
	Society & Citizens	[63,70,86–88,90,113,145]	[77,101,115,141]	[68,73,77,86,91,97,105,146,147]	[68,89]
	Stakeholders	[147]		[68,91,126,148]	
	Collaboration & lock-ins	[55,63,65,71,78,89,90,94,134,145]	[68,126,136,141]	[47,49,127,135,67,68,81,88,91,93,94,104]	[56,98–100,149]
	Planning & Strategy	[70,94,134,135]	[75,115,140,141]	[65,86,90,91,96,101–103,127]	[149]
	Inequalities	[97,105,108]	[73,122]	[63,111,127,139]	[92,96,139]
Health	Heat stress & Thermal comfort	[71,97,105,108,114,134]	[115,122,136]	[136]	[47,66,68,80,92,103]
	Physical	[70,87,88,90,94,113]	[119,141]		[60]
	Mental	[70,87,88,94]		[57,78,90,133]	[60]

Legend	
Topic discussed	
Never	
Rarely	
Sometimes	
Often	
Usually	
Coverage-Subtopics	
Very limited	
Limited	
Extended	
Very extended	
Coverage-Categories	
Very limited	
Limited	
Extended	
Very extended	

	Morbidity & Mortality	[134]	[46,73,74]	[103,134,137]	[70,103]

5. Conclusions

Living in and moving around urban areas can be both a privilege and a risk; a user-friendly and sustainable city has the capacity to offer shelter, livelihood and high-quality services to its residents, maintaining its present and future integrity. Nevertheless, the lived reality of most urban centres is far from this utopian outlook, featuring high levels of air, soil, water and noise pollution, periodic intense thermal discomfort, unaffordability issues and limited mobility options. This work aims to bring forth existing design solutions that allow urban dwellers to adapt to the new realities and mitigate the negative impacts of climate change, bridging the concepts of urban design and urban health. The methodological approach followed highlighted that the vast majority of research output studying all the elements of our research question was only published over the past few years (since 2018). This increase in research interest most likely reflects the urgency of making cities liveable and enjoyable, especially after the space and movement restrictions imposed on residents of dense centres due to the pandemic. The use of urban spaces and greenery to improve climatic conditions for optimal human comfort appear to be the most popular options for adaptive design solutions. Overall, it can be said that the focus of research on green urban spaces reflects the multiple facets of urban health, in a nexus of human physical and psychological wellbeing as well as that of the urban environment.

The co-occurrence bibliometric analysis indicates that the research focus is on climate change, human health, comfort and urban design, and although policy and decision-making are also indicated as most frequent among all the papers reviewed, topics relating to social aspects, such as community or participatory processes, are not listed as top keywords. It would be expected that an increase in the socio-economic dimensions of climate change and urban health should be observed in the coming years, accounting also for the preference for studying open public spaces and their utility in urban centres. Nevertheless, it would be misconceived to assume that the prominence of social sciences will overcome physical actions towards addressing urban challenges.

Findings of the qualitative and meta-analysis show that different perspectives can be obtained from common denominators, exposing both the benefits and the risks of specific design options. Under-represented topics of significance for the nexus of climate change-health-cities include the participatory approach and citizen action. Community-based adaptation and co-participation in planning and public space co-management are important components of handling climate change regionally and reinforcing a co-benefits approach. Although community and citizen related issues have not been extensively investigated, their gravity is reflected by their presence across all elements of the matrix. This mode of operation has a higher capacity for local action, making up for the limitations or inadequacies of central government intervention in a democratic governance framework. Research has shown that a participatory process can be used to describe the collective intangible heritage and allows citizens to engage and have a voice in the decision-making process. This literature review further suggests that urban planning and the decision-making process should consider the experiences and preferences of local habitants, integrating bottom-up and top-down approaches. Following a community-driven participatory approach that is inclusive also ensures that different vulnerabilities can be adequately addressed and different population groups may have equitable health benefits.

Synergistic relationships, collaborations and avoidance of lock-in situations appears to be the most significant subtopic emerging from this literature review, and moving beyond the realm of theoretical solutions and recommendations, what is lacking most is practical answers to real problems. This is profoundly important for the most vulnerable portions of populations, whose voices may not be echoed in the implementation stages of policies. Ultimately, equity in urban health can be achieved through a variety of technical and non-technical approaches addressing climate change and its impacts, but the possibility of lock-ins should never be neglected. Regeneration of cities should therefore aim at improved physical designs able to reinforce the efficiency of the built environment, considering present conditions and allowing flexibility for different future ones, while promoting stronger, more cohesive, social structures.

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