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Original
Cities in the times of COVID-19: Trends, impacts, and challenges for urban sustainability and resilience / ESCORCIA HERNANDEZ, J.R., TORABI MOGHADAM, S., Sharifi, A., Lombardi, P.. - In: JOURNAL OF CLEANER PRODUCTION. - ISSN 0959-6526. - ELETTRONICO. - (2023). [10.1016/j.jclepro.2023.139735]

Availability:
This version is available at: 11583/2983995 since: 2025-02-06T15:08:14Z

Publisher:
ELSEVIER

Published
DOI:10.1016/j.jclepro.2023.139735

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(Article begins on next page)

25 November 2026

Journal of Cleaner Production 432 (2023) 139735

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

Cities in the times of COVID-19: Trends, impacts, and challenges for urban sustainability and resilience

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ARTICLE INFO

Handling Editor: Xin Tong

Keywords:
Urban sustainability
Sustainable cities
COVID-19
Post-pandemic
Resilient urban planning
Literature review

ABSTRACT

Since the beginning of the COVID-19 outbreak, understanding its impacts on cities has received much attention in science and policy circles. This paper systematically reviews the literature on the interface of the pandemic and urban sustainability. The objective is to portray the impacts brought by the COVID-19 outbreak in urban environments within the sustainability framework and to detect trends and challenges for future research. The paper follows a methodology that integrates both bibliometric and systematic review approaches. The first approach relies on bibliometric analysis to provide an overview of the landscape of main trends on this nexus. The second approach presents a content analysis that deepens the work by outlining the impacts of the pandemic and the challenges that emerged on five different key topics for urban sustainability. The role of resilient urban planning is discussed as an integrative concept to face diverse challenges in the construction of sustainable cities in a post-pandemic scenario. Likewise, the study deliberates on future research topics related to resilient urban planning, social equity, healthy urban environments, sustainable mobility, and circular economy. This review serves as a guide for researchers and urban planners to understand emerging challenges and future research trends in urban sustainability.

1. Introduction

The COVID-19 pandemic has caused tremendous distress and loss but has also produced an opportunity to re-evaluate the approach to urban planning and development. Extensive research has been conducted on the different impacts of the pandemic on cities at the operational, organizational, and social levels (Sharifi and Khavarian-Garmsir, 2020; Ranjbari et al., 2021a; Megahed and Ghoneim, 2020). Among these, it has been analyzed that the conditions of the built environment were critical during the pandemic (Megahed and Ghoneim, 2020), for key aspects like social equity (Benita et al., 2022), livability conditions during the lockdown (Corburn et al., 2020), or the spread of the virus (Sahasranaman and Jensen, 2021). For instance, the importance of public space in the well-being of people (Honey-Rosés et al., 2020) and its influence on resilience to biological and environmental risk factors (Auerbach and Thachil, 2021). As well as the effects of extended quarantine periods on environmental pollution (Saadat et al., 2020), like the improvement in air quality in some cities due to the disruption of industries and the reduction in transport demand (Fu et al., 2020).

Different scholars have also concluded that vulnerable groups such as low-income people and minorities were the most affected during the outbreak (Corburn et al., 2020). High contagion rates have affected these groups due to a multitude of factors such as the problem of mitigating the proliferation of the virus (Corburn et al., 2020; Bhattacharjee and Sattar, 2021), high mortality rates due to inaccessibility or lack of infrastructure and health services for appropriate treatment (Auerbach and Thachil, 2021), social problems such as unemployment (Truong and Asare, 2021), an increase in poverty in households (Francis and Weller, 2022), and mental health issues (Truong and Asare, 2021). These factors have worsened the living conditions of vulnerable groups by exacerbating already existing socioeconomic disparities.

It has been claimed that the outbreak and post-pandemic effects have had the greatest impact on developing countries, affecting their macro to micro affairs (Bong et al., 2020; Barbier and Burgess, 2020).

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https://doi.org/10.1016/j.jclepro.2023.139735
Received 21 August 2023; Received in revised form 30 October 2023; Accepted 10 November 2023
Available online 15 November 2023
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Consequently, following and supporting short- and long-term recovery plans are crucial. It is important to emphasize the importance of incorporating sustainable development goals into these plans, ensuring that no one is left behind, and leveraging the lessons learned from cities' responses to the pandemic to create resilient urban environments. Likewise, given that urban areas have been recognized as significant contributors to greenhouse gas emissions, these strategies should also be aligned with the goal of carbon neutrality to address climate change.

These issues have been broadly studied during the two years of the pandemic and are currently the focus of extensive research worldwide. Some of these studies remark that, in the post-pandemic scenario, it will be necessary to face different challenges in the design of recovery policies, plans, and strategies, together with the criteria of sustainable development (Echegaray, 2021; Sharifi and Alizadeh, 2023). Due to the multidimensionality of urban areas, the associated literature addresses various topics and the possible impacts of the pandemic (Sharifi and Khavarian-Garmsir, 2020; Benita et al., 2022).

In the existing literature is possible to find several reviews that have explored the impacts of the COVID-19 pandemic from various angles. These reviews have addressed specific dimensions such as the built environment (Megahed and Ghoneim, 2020), housing (Kaklauskas et al., 2021), smart cities solutions (Sharifi and Alizadeh, 2023), social equity (Benita et al., 2022), livability conditions during lockdowns (Pierantoni et al., 2020), and urban mobility (Tirachini and Cats, 2020), providing valuable insights into these specific aspects. Also, there have been some reviews with a more comprehensive approach dealing with an analysis of the implications of the pandemic on the sustainability agenda (Ranjbari et al., 2021a), the impacts on cities' life (Sharifi, 2022), and perspectives for future pandemic-resilient cities (Amirzadeh et al., 2023). However, there is a distinct gap in synthesizing the overall impact of the pandemic on the urban sustainability paradigm, specifically focusing on the core aspects of this concept rather than sustainability as a whole or broader urban matters. This highlights the need for an updated review that provides a comprehensive analysis of the effects of the COVID-19 pandemic on urban sustainability, with a particular emphasis on key aspects for future research. The concept of urban sustainability is framed by the sustainability agenda regarding human settlements (SDG11) which aims to develop environments that are inclusive, safe, resilient, and sustainable (United Nation-HLPF, 2018). As well, urban resilience is defined as the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity (Meerow et al., 2016). By examining the existing reviews, and incorporating the relevant literature, this study presents a systematic literature review that aims to identify the most relevant effects highlighted in the literature, as well as, to identify topics that need further research towards the development of more sustainable cities. The questions guiding this review are:

- What are the current trending topics and the impacts of the COVID-19 pandemic in the literature regarding urban sustainability?
- What are the future challenges to be further developed towards more sustainable cities?

To address the questions, this review relies on a methodology that integrates bibliometric and systematic review approaches. To answer the first question, we adopted a bibliometric analysis, which allowed us to comprehensively explore large volumes of information and analyze the main trends in the consulted literature. Further, to answer the second question, the systematic approach summarizes the state-of-the-art to analyze key topics and issues that might be relevant in the development of future research regarding urban sustainability in the current post-pandemic paradigm. Overall, this review identifies important topics for future research in urban sustainability. It is expected to help urban stakeholders, researchers, and decision-makers toward the achievement of the sustainability agenda. After this section, this paper is organized as follows: Section 2 describes the methodology used to perform the literature review; Section 3 presents the results and discussion of the review; Section 4 includes the future research challenges; Section 5 illustrates the major findings; and Section 5 presents the conclusions of the study.

2. Methodology

The methodological approach adopted in this review, illustrated in Fig. 1, follows a three-stage framework (Torabi Moghadam et al., 2017): (i) Literature search and selection, (ii) Analysis of the main trends, and (iii) Analysis of key impacts. Stage 1 follows the search and selection protocol illustrated in Fig. 2. Stage 2 relies on bibliometric analysis based on an extensive set of published works, to provide the analysis of the current main trends, and Stage 3 provides the analysis of key impacts based on contents analysis from the full-text-reading of the most relevant works in the field, and an analysis of future research trends.

2.1. Stage 1 - literature search and selection

In the first stage, the goal was to search for literature related to the nexus between urban sustainability and the COVID-19 pandemic. The focus was on selecting the most relevant works to describe this paradigm. In February 2023 we searched for relevant documents in Scopus. Among various academic databases, Scopus was selected for its broad coverage of quality peer-reviewed publications. According to the theoretical framework, the review should focus on the state of the art of the impact of the COVID-19 pandemic on cities within the sustainability paradigm. Initially, the following combination of terms and logical operators were used to define the search query for titles, keywords, and abstracts: ((“Covid” OR “Covid-19” OR “Coronavirus” OR “SARS-COV-2") AND (“Sustainability” OR “Sustainable” OR “Sustainable cities” OR “SDG 11" OR “Cities” OR “City” OR “Urban Development” OR “Urban")). The search using this combination yielded more than 35,000 documents published between 2020 and 2023. Such literature comprises a broad assessment of the effects of the pandemic on the sustainability agenda; however, the scope of this review focuses on the urban sustainability paradigm. Therefore, to get a selection of documents focused on the issues related to the cities, the search query was redefined as ((“Covid” OR “Covid-19" OR “Coronavirus” OR “SARS-COV-2") AND (“Sustainability” OR “Sustainable” OR “Sustainable cities” OR “SDGS” OR “SDG 11" OR “SDG-11" OR “Sustainable development goals”) AND (“Cities” OR “City” OR “Urban Development” OR “Urban")). This string yielded 1854 documents. As Fig. 2 illustrates, we used the filtering function of Scopus to exclude literature from irrelevant subject areas. After exclusion, a bibliometric database with 1439 entries was developed. This database served as the input for bibliometric analysis.

A second round of exclusion was conducted based on article titles, in which only documents directly relevant to the review questions were retained for in-depth analysis and full-text reading. Articles written in languages other than English were also excluded. Following this, abstracts and keywords of the remaining articles were screened to retain only those with approaches that evaluated one or more dimensions of urban sustainability (i.e., issues with explicit implications for the spatialization of phenomena affecting cities). Ultimately, 119 documents were selected for full-text reading.

2.2. Stage 2 - analysis of main trends

This stage aims to answer the first research question by providing an overview of the general paradigm of urban sustainability since the beginning of the COVID-19 outbreak in 2020 based on an analysis of the existing literature, including countries of affiliation, top-cited sources, and top-cited documents. Also, the main topics of interest in the body of



Fig. 1. Flowchart of the review.

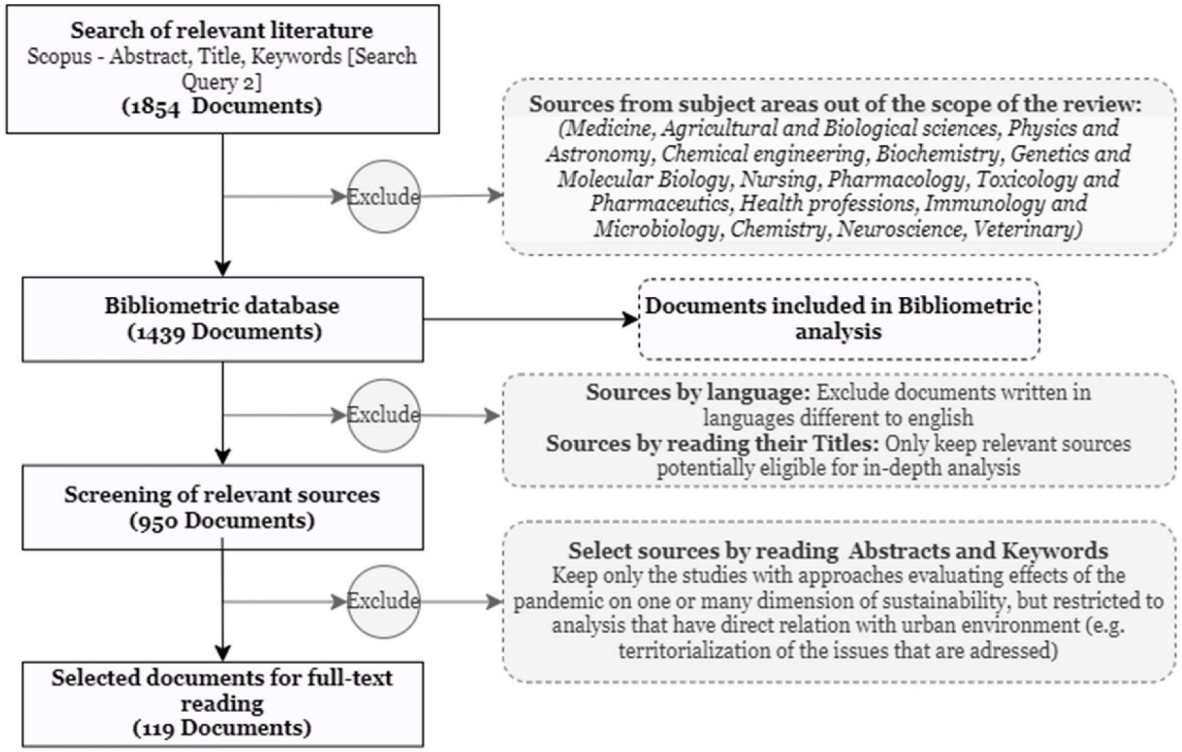


Fig. 2. Workflow of Stage 1 - Literature search and selection.

research and their mutual connections were explored. Over the years, a broad range of tools have been developed to support the systematic analysis of bibliographic materials (Cobo et al., 2011). These tools typically implement various analysis and visualization techniques to help understand the thematic focus and trends in the literature by revealing the complex interactions between a set of academic publications (Cobo et al., 2011). The analysis included keywords, terms, co-references, author citations, journals, and countries. Such items can be related to co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation (van Eck and Waltman, 2020). Cobo, López-Herrera, Herrera-Viedma, and Herrera (2011) conducted a comparative study of these tools, providing further details on their unique features.

In this study, VOSviewer (version 1.6.16) was selected for bibliometric analysis. VOSviewer is a free-access Java application developed at the University of Leiden that creates maps based on network data and visualizes and analyzes them (van Eck and Waltman, 2020). The tool was used to map the thematic trends of literature and to highlight key knowledge areas regarding the impacts of the pandemic on the paradigm of sustainable cities. A thesaurus file was created before each analysis and added to the VOSviewer database to avoid separate counting of synonyms referring to the same concept (e.g., COVID-19, Covid 19, Coronavirus, and SARScov2). The thematic analysis was done through term co-occurrence networks using "full counting" as a counting method and "author keywords" as the unit of analysis. A term co-occurrence analysis presents frequently occurring terms and their connections. In addition, to complement this analysis, it was performed a bibliographic coupling of documents, also using "full counting" as a counting method. This approach generally highlights major thematic areas and clusters, as will be presented in this study (van Eck and Waltman, 2020).

2.3. Stage 3 - analysis of key topics

The third step of the research involved a detailed qualitative examination of the chosen literature to address the second research question. This stage involved thoroughly reading the selected documents (as shown in Fig. 2) to gain a comprehensive understanding of the topic being reviewed. The contents of the documents were analyzed and categorized from the perspective of five key topics (Resilient urban planning, Sustainable transportation, Healthy urban environments,

Social equity, and Circular economy) which were defined starting from the overview of the previous stage, and the content analysis of the papers subject of full-text reading. Initially, the main concepts of the trending topics analysis served as a base for potential categories to summarize the state of the art. These were used to guide the in-depth summary implementing an inductive content analysis (Moldavska and Welo, 2017), enabling a more focused and targeted approach to understanding the existing literature.

This method allows us to take insights from a set of documents within a common context and still differentiate the topics within the literature (Moldavska and Welo, 2017; Sharifi et al., 2021). The methodology consisted of the identification, definition, and categorization of the main issues highlighted in each reviewed document. Initially, the documents were summarized and categorized into several potential categories, and further when the topics were tabulated were cross-analyzed to define the final categorization and analysis of the main topics. The most frequent topics were defined to summarize as comprehensively as possible the state-of-the-art from the selected literature. The qualitative nature of these kinds of analyses makes them prone to a bias given by the subjectivity of the author (Sharifi et al., 2021). However, due to the segmentation of the literature dealing with the impacts of the pandemic, the inductive content analysis allows us to perform a comprehensive review based on the key topics for urban sustainability in the post-pandemic (Moldavska and Welo, 2017; Sharifi et al., 2021). Through this approach, later, the set of key issues and topics were further discussed to propose future research needs. This analysis aimed to provide insights into the current state of research in the field of urban sustainability and to identify areas where further research is needed. Based on these findings, recommendations for future research directions and potential research questions are developed to guide future work in this area.

3. Results and discussion

This section presents the results of the literature review based on the two approaches stated in the previous section. Section 3.1 introduces the analysis of the main trends, developed based on a bibliometric approach. Section 3.2 presents the analysis of key topics based on the full-text reading of the most relevant documents. The information was classified into thematic categories based on the clusters defined in Section 3.1, describing different topics in the literature dealing with urban sustainability during the pandemic and trends for future work.

3.1. Analysis of main trends

This phase comprised a bibliometric analysis of 1439 documents. This was mainly performed using data management and VOSViewer software. This approach integrates the evaluation of the number of related publications made each year since the beginning of the pandemic, visualization of the countries that contributed to the state of the art, list of the most relevant sources of literature, top-cited documents, and analysis of the most relevant topics based on keywords. The analysis was based on a co-occurrence network of keywords, integrating a cluster-based analysis of the main topics and the interlinkages highlighted in the literature within the urban sustainability paradigm.

3.1.1. Description of the literature

Documents used for this review were published between the year 2020, after the declaration of the pandemic, and February 2023. Fig. 3 illustrates that, during the first year, 157 documents regarding this topic were published, followed by an increase in the production of literature by approximately 250% in 2021 relative to the previous year. The year with the most publications is 2022, with 609 documents available. Of the 1439 documents included in the bibliometric analysis, 68.7% were journal articles (988), 15.4% were conference papers (222), 6.5% were book chapters (93), and the remaining 9,4% (136 documents) were

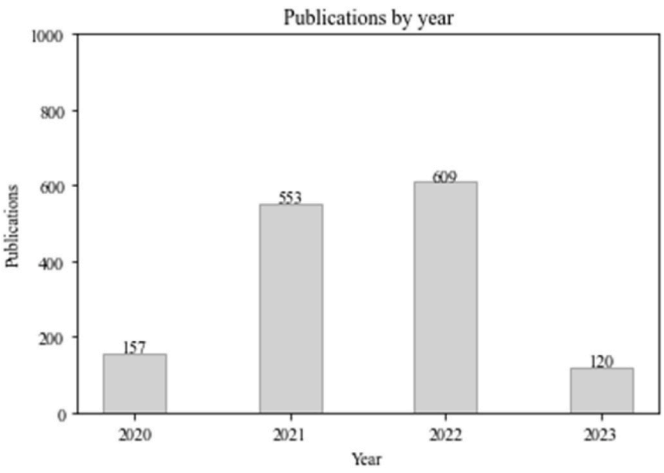


Fig. 3. The annual number of publications.

books, conference reviews, editorials, short surveys, and letters.

Bibliographic coupling was performed to understand the geographical distribution of the contributions. This is used to indicate where most research has originated from. The map presented in Fig. 4 shows the location of the publications, with an indicator of the number of publications by country. Most of the published research on this topic has been developed in the Global North, and Eastern countries such as China, India, and Japan. Italy, China, the United States, India, and the United Kingdom, respectively, are the five countries with the highest contributions. According to the map, very limited research has originated from Africa. Moreover, in Latin America, nearly all countries have contributed to publications; however, all have produced less than 50 contributions.

3.1.2. Main sources of literature

Table 1 presents the main sources based on the number of publications. This ranking included the 10 sources with the most production of documents. It also provides information about the 2021 Citescore and Scimago Journal Ranking (SJR) indicators, as well as source types and publishers. It can be seen that six of the ten sources are journals, followed by two book series, and two conference proceedings.

According to the findings, the journal "Sustainability" (MDPI) leads the ranking with 212 available articles, around 15% of the references included in the analysis, and more than three times the papers published by the next source in the ranking. This source, however, ranks sixth in terms of the Citescore indicator, which computes the ratio of citations to articles. The source in the ranking with the highest value in this regard was "Sustainable Cities and Society" (ELSEVIER), which takes third place in the ranking of publications (44 publications). This makes this source one of the most relevant on the topic, with a high impact on the knowledge paradigm with a considerable number of published documents and citations. Likewise, the journal "Science of the Total Environment", even if it takes eighth place based on the number of publications (19), takes second place based on its Citescore, as an indicator of the high relevance of the work published in this source.

3.1.3. Top-cited articles

The number of citations of each article indicates its impact and potential contribution to the topic. Table 2 presents articles with the highest number of citations and a brief description of their work. Given the large number of documents, only those with more than 100 citations are listed (16 articles). Altogether, the top-cited papers deal with the relationship between different urban characteristics and the spread of the virus and have a strong focus on the impacts on the transportation sector. Out of the 16 listed articles, 12 of them were published in 2020, the first year of the pandemic outbreak. Most of these articles have been

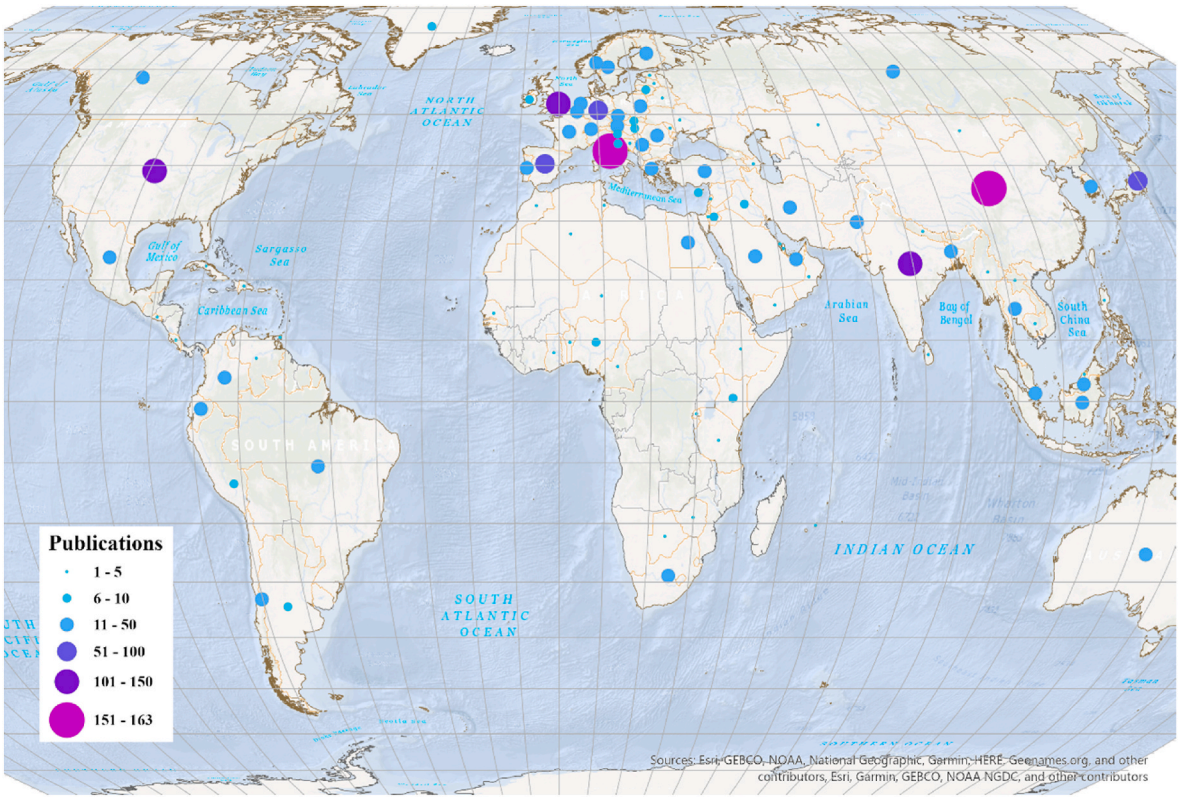


Fig. 4. Geographical distribution of the publications.

Table 1
Sources with most publications on related research.

Source	Documents	Citescore 2021	SJR 2021	Source type	Publisher
Sustainability	212	5	0.664	Journal	MDPI
Iop Conference Series: Earth and Environmental Science	66	0.6	0.202	Conference Proceedings	IOP Publishing
Sustainable Cities and Society	44	14.4	2.015	Journal	Elsevier
Lecture Notes in Networks and Systems	29	0.7	0.151	Book series	Springer Nature
Cities	28	9.4	1.656	Journal	Elsevier
Land	19	3.2	0.685	Journal	MDPI
Lecture Notes in Civil Engineering	19	0.5	0.133	Book series	Springer Nature
Science Of the Total Environment	19	14.1	1.806	Journal	Elsevier
E3s Web of Conferences	18	0.8	0.237	Conference Proceedings	EDP Sciences
Transport Policy	16	9	1.732	Journal	Elsevier

taken as the starting point for further and deeper analysis of the effects of the COVID-19 pandemic on the urban sustainability paradigm.

3.1.4. Bibliometric networks and cluster analysis

Using VOSviewer, a keyword co-occurrence network and documents coupling network were created. This approach helps illustrate the topics that were most addressed in literature during the pandemic period and highlights conceptual connections in the literature. In a co-occurrence network, nodes represent keywords, and the links represent co-occurrence relationships. In a bibliographic coupling network the nodes feature documents that reference the same set of cited documents and the links represent the relationship between them.

3.1.4.1. Co-occurrence analysis. Fig. 5 illustrates the network constructed using the 60 most relevant keywords among the reviewed articles. In the network, the size of the node represents a subject corresponding to its frequency and the thickness of the links indicates the strength of the relationship between the two concepts. Similarly, in the co-occurrence map, the spatial centrality of a keyword within the network represents its degree of centrality. In this context, an analysis of degree centrality can provide valuable insights into the most significant keywords in the literature. Central keywords are likely to be the most important and influential concepts in the literature, and can thus be used to detect hot topics and trends in the subject. In Fig. 5, the concepts were sorted into three thematic clusters, which were created around one or two highly connected concepts. To simplify the network visualization, the keywords 'COVID-19′ and 'Pandemic' were excluded from the visualization. Although these words are the two most frequent words within the reviewed literature, they do not add value to the analysis of trends in the literature. Removing them from the visualization does not affect the analysis and improves the interpretability of the network.

The network in Fig. 5 presents three thematic clusters related to the pandemic's effects on urban sustainability. These can be identified by colors: magenta, green, and blue. These clusters represent the complex nature of the challenges facing urban areas in the wake of the pandemic and provide a valuable framework for exploring the various factors that contribute to urban sustainability in future scenarios.

i. Cluster 1 – magenta. The magenta cluster highlights four primary keywords: 'sustainability', 'smart city', 'resilience', 'sustainable tourism', and 'sustainable development'. These concepts are central to

Table 2
List of top-cited articles.

Authors	Year	Title	Citations	Description	Source	Reference
Sharifi, A. & Khavarian-Garmsir, A.R.	2020	"The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management"	442	Systematic literature review describing the impact of the pandemic during the first months of the outbreak. They highlight the effects and lessons classified on relevant topics. As the publication was in the first year of the pandemic, the authors draw attention to a set of possible research topics for future work and critical topics	Science of the Total Environment	Sharifi and Khavarian-Garmsir (2020)
Coccia, M.	2020	"Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID"	369	Analysis of factors concerning the spread of COVID-19 in the 55 Italian provincial capital cities, based on the data of the early months of the pandemic. The study includes the evaluation of the impact of air pollution, meteorological conditions, and population on the virus propagation. The paper proposes potential strategies to mitigate the intense propagation of viral diseases.	Science of the Total Environment	Coccia (2020)
Hamidi, S., Sabouri, S., Ewing, R.	2020	"Does Density Aggravate the COVID-19 Pandemic?: Early Findings and Lessons for Planners"	363	Epidemiological analysis of the link between urban density and the spread of the virus in 913 counties in the United States. It also confronts the infection and mortality rates and their relation to the adherence to social distance guidelines and the quality of the health systems. It concluded that connectivity could have a greater influence on contagion rates than the density itself. The transmission of the virus is more influenced by the interconnectedness of a central city with its neighboring geographic units in a metropolitan area rather than the city's population density. The strong economic, social, and commuting ties between these areas heighten their susceptibility to pandemics. They are more prone to interactions among tourists and business travelers, both internally and externally, which elevates the potential for cross-border infections.	Journal of the American Planning Association	Hamidi et al. (2020)
Tirachini, A., Cats, O.	2020	"COVID-19 and public transportation: Current assessment, prospects, and research needs"	329	Review of the conditions of public transport systems during the first months of the pandemic, based on the early measurements taken by governments and agencies around the world. It addresses research needs and agenda for public health implications and alternatives to reduce crowding in public transportation, as well as the need to restore the capacity of these systems to operate in a post-pandemic scenario.	Journal of Public Transportation	Tirachini and Cats (2020)
Megahed, N.A., Ghoneim, E.M.	2020	"Antivirus-built environment: Lessons learned from Covid-19 pandemic"	306	Proposal of a paradigm for a post-pandemic urbanism paradigm, and the conditions that would be required to design a healthy and sustainable built environment based on the observed lessons from COVID-19. The authors propose a set of research areas for post-pandemic architecture and urbanism, categorized by urbanism, public spaces, housing, office space, and building construction and technology.	Sustainable Cities and Society	Megahed and Ghoneim (2020)
Shamshiripour, A. et al.	2020	"How is COVID-19 reshaping activity-travel behavior? Evidence from a comprehensive survey in Chicago"	232	Analysis of how the pandemic may have influenced the changes in the mobility patterns and travel behavior of people in the Chicago metropolitan area. It is based on a stated preference-revealed preference survey applied to individuals to state their habits before and during the pandemic, and their perspective of	Transportation Research Interdisciplinary Perspectives	Shamshiripour et al. (2020)

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Table 2 (*continued*)

Authors	Year	Title	Citations	Description	Source	Reference
				the post-pandemic future. The evaluation includes the conditions of their living conditions and the ease of performing work activities from home to avoid commutes, as well as the future of resilient public transport systems.		
Moreno, C. et al.	2021	"Introducing the "15-min city": Sustainability, resilience and place identity in future post-pandemic cities"	231	Definition of the concept of a "15-min city" as a paradigm for urban development and planning towards sustainability, resilience, and inclusive cities in the post-pandemic. The concept is framed on the articulation of urban proximities, density, digitalization, and diversity to provide people with quality of life and accessibility into their neighborhoods. The center point of this concept the proximity-based planning, where the neighborhoods are conceived or reconceived to optimize density and provide access to essential services within 15 min of walking or cycling distance.	Smart Cities	Moreno et al. (2021)
Choi, T.-M.	2020	"Innovative "Bring-Service-Near-Your-Home" operations under Corona-Virus (COVID-19/SARS-CoV-2) outbreak: Can logistics become the Messiah?"	210	The study explores the option of the shift of traditionally static service operations into mobile service operations for critical services by proposing a set of analytical models to explore it from the sectors of logistics and technology. This takes special relevance in a context like the pandemic where many business operations that required users to commute in crowded environments were disrupted by the pandemic. The evaluation of the feasibility of this model presents a framework for resilience and flexibility in different services.	Transportation Research Part E: Logistics and Transportation Review	Choi (2020)
Rume, T. & Islam, S.M.D.-U.	2020	"Environmental effects of COVID-19 pandemic and potential strategies of sustainability"	209	Literature review on the possible environmental factors of the pandemic, based on the publications during the early stages of the pandemic. Thus, it focuses mainly on environmental sustainability. The positive impacts have been mostly related to the lockdown and travel restrictions all over the world, on the other hand, the negative impacts were mostly related to the use of personal protection equipment and the excessive burden to the critical infrastructure like the hospitals, and the health system.	Heliyon	Rume and Islam (2020)
Pirouz, B. et al.	2020	"Investigating a serious challenge in the sustainable development process: Analysis of confirmed cases of COVID-19 (new type of Coronavirus) through a binary classification using artificial intelligence and regression analysis"	161	Development of a Neural Networks-based AI model to predict the number of COVID-19 cases. The model uses data from the first semester of the pandemic in the context of Chinese cities. The regression model depicts, for the training conditions, that the relative humidity affected positively the confirmed cases, and the maximum daily temperature affected negatively. As well as shown the positive effect of the early lockdowns to reduce the number of positive cases.	Sustainability	Pirouz et al. (2020)
Tirkolaee, E.B., Abbasian, P. & Weber, G.-W.	2021	"Sustainable fuzzy multi-trip location-routing problem for medical waste management during the COVID-19 outbreak"	137	The paper introduces the development and validation of a model to formulate a sustainable multi-trip routing definition for the carry-out of medical waste to comply with the required time-frames to reduce the risk of the different actors in the handling chain. A fuzzy approach was used to deal with the high uncertainty of the programming. To validate the proposition, it was used in the management of the city of Sari, Iran.	Science of the Total Environment	Tirkolaee et al. (2020)

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Table 2 (*continued*)

Authors	Year	Title	Citations	Description	Source	Reference
Campisi, T. et al.	2020	"The impact of covid-19 pandemic on the resilience of sustainable mobility in Sicily"	132	Study of the implications of the pandemic on transport behavior and point of view of the sustainable mobility solutions in Sicily, Italy. The analysis relies on a survey with 431 participants. The study includes the evaluation of the use of public transport during the lockdown periods and the likelihood of integrating sustainable modes into their daily life.	Sustainability	Campisi et al. (2020)
Abu-Rayash, A., Dincer, I.	2020	"Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities"	121	Examines how the COVID-19 pandemic affected the transportation industry and, how it has influenced energy conservation and the emission of greenhouse gases in different cities worldwide. It presents a proposal for an intelligent transportation system, defined by four key factors: transport efficiency, technology integration, traffic congestion levels, and accessibility.	Energy Research and Social Science	Abu-Rayash and Dincer (2020)
O'Hara, S. & Toussaint, E.C.	2021	"Food access in crisis: Food security and COVID-19"	118	Explores food insecurity history and urban agriculture's potential in the context of Washington, D.C. It highlights how innovative food production can address local food security and green infrastructure needs but also underscores ongoing socio-political barriers. How the COVID-19 pandemic magnified these issues, emphasizing the importance of community-based strategies for empowerment over traditional market-focused solutions.	Ecological Economics	O'Hara and Toussaint (2021)
Przybylowski, A., Stelmak, S. & Suchanek, M.	2021	"Mobility behavior in view of the impact of the COVID-19 pandemic-public transport users in Gdansk case study"	108	Evaluates how COVID-19 affected the travel behavior and safety perceptions of public transport users in Gdańsk, Poland. Based on a survey, it depicted that the pandemic substantially altered mobility, leading 90% of respondents to decrease their use of public transport. About 75% intend to resume its use post-pandemic, while others have lost confidence in its safety. These findings underscore the significance of improving safety perceptions to secure the future of public transport and promote sustainable transportation choices effectively.	Sustainability	Przybylowski et al. (2021)
Hakovirta, M. & Denuwara, N.	2020	"How COVID-19 redefines the concept of sustainability"	105	Early study highlighting some of the effects that the pandemic brought into society and how these serve as drivers for re-evaluating the priorities and approaches of sustainability. Based on these conditions, it proposes to add Human Health as a fourth pillar of sustainability.	Sustainability	Hakovirta and Denuwara (2020)

the field of urban sustainability and are closely interrelated as they all relate to the development and management of cities in a way that promotes long-term environmental, economic, and social sustainability.

The cluster also includes other keywords with a lower frequency, such as 'circular economy', 'housing', 'built environment', 'social distancing', 'urban agriculture', 'ecosystem services', 'carbon emissions', 'digitalization', 'GIS', and 'internet of things (IoT)'. These keywords are related to the central concepts of the cluster and highlight the various subthemes that contribute to the overall theme of urban sustainability. For instance, the concept of a 'circular economy' has gained increasing attention in recent years, as it represents a shift away from the traditional linear economic model towards a sustainable, closed-loop system. The pandemic had major impacts on the global supply chain and resource availability, further accelerating interest in the circular economy (Alva Ferrari et al., 2023). Similarly, 'housing' is an essential concept in urban sustainability, as it is critical to providing safe and affordable conditions for urban residents while minimizing the environmental impact of the urban environment in the whole life cycle (Encinas et al., 2021; Benfer et al., 2021). Inappropriate housing conditions could make it difficult to control the spread of pandemics as shown in different parts of the world (Ahmad et al., 2020; Peters and Halleran, 2021).

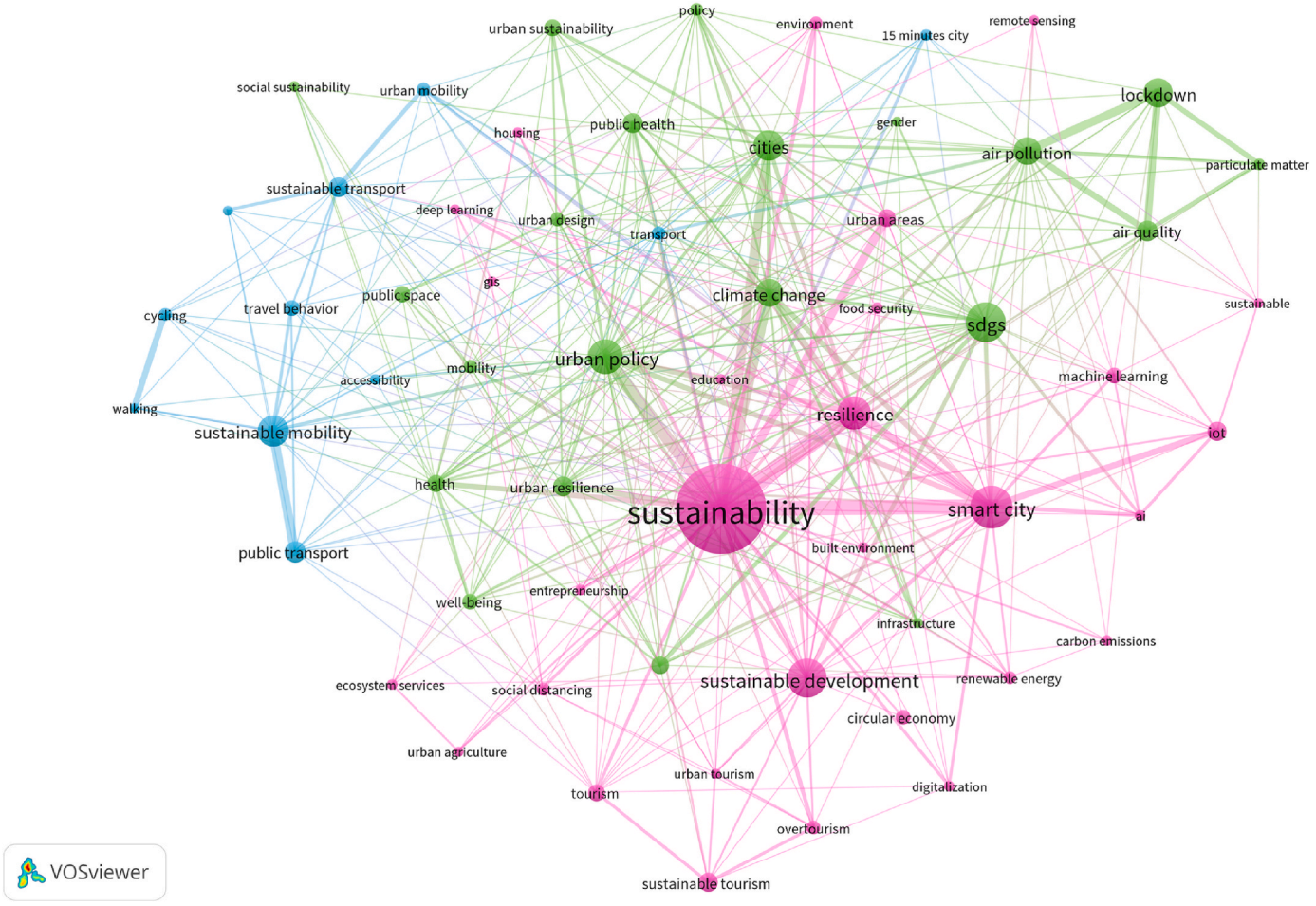


Fig. 5. Term co-occurrence map excluding the terms Covid-19 and Pandemic.

The concepts of 'social distancing' and 'tourism' highlight the consequences of the pandemic, as they reflect the need to balance public health concerns with economic development and social well-being. The pandemic has highlighted the importance of restructuring urban tourism policies to minimize their environmental impacts while offering opportunities for local economic growth (Casado-Aranda et al., 2021). 'Urban agriculture' and 'ecosystem services' illustrate the importance of green infrastructure and its benefits in terms of food security (O'Hara and Toussaint, 2021), biodiversity (Isabella et al., 2022; Sikorska et al., 2023), and climate resilience (Sikorska et al., 2023). These issues have also received considerable attention as the pandemic disrupted supply chains in many parts of the world. Finally, 'digitalization', 'GIS', and 'the Internet of Things' reflect the increasing role of technology in urban sustainability, as cities seek to use data-driven approaches to manage resources more efficiently and effectively within smart city solutions (KELLY and MOURITZ, 2020; Costa and Peixoto, 2020). Generally, the pandemic has accelerated the transition toward smart cities. However, there are concerns regarding the implications of such a transition for urban sustainability.

ii. Cluster 2 – green. The green cluster is centered on the issues of 'urban policy', 'sustainable development goals (SDGs)', and 'air quality. This cluster contains keywords related to policies, plans, and strategies aimed at achieving sustainable urban development as well as the goals set by the UN's SDGs. The other set of relevant keywords in this cluster included 'air pollution', 'lockdown', 'climate change', 'public space', and 'public health', which are issues that have become increasingly important in the context of the pandemic. Finally, the third level of relevant keywords includes 'health', 'well-being', 'particulate matter', 'urban sustainability', 'social sustainability', and 'urban design', concepts that are critical to achieving sustainable and healthy urban environments.

The presence of 'urban policy' and 'SDGs' in this cluster is linked to the importance of policy design and planning in achieving sustainable urban development. These concepts are often interconnected and require a multilevel governance approach that involves public institutions, civil society, and private actors (van Zanten and van Tulder, 2021). Multi-level governance also involves accounting for interlinkages in the regional context and urban-rural linkages that are critical for sustaining urban functions, particularly during times of crisis (Sharifi, 2022; Krellenberg and Koch, 2021; Mitchell et al., 2021).

The second-level keywords in this cluster reflect the challenges that cities face in achieving sustainable development, particularly during the pandemic. 'Air pollution', for example, has been critically analyzed in different contexts due to the limited mobility during lockdowns and the limitations to some industries (Fu et al., 2020; Zoran et al., 2023). The large body of evidence indicates that revolutionizing the mobility sector

is critical for achieving sustainable urban trajectories (Kakderi et al., 2021). Likewise, 'public space' has become a critical issue as people seek outdoor areas for exercise and social interaction while maintaining physical distancing. In response to such needs, various initiatives worldwide have focused on reclaiming urban spaces to promote more opportunities for socialization and active transportation. The pandemic and its impacts highlight the need for urban policies that are responsive to changing circumstances and prioritize the health and well-being of citizens, such as proximity-based city models, like the "15-min city" (Moreno et al., 2021; Allam et al., 2022a), that have acquired popularity in different cities around the world in the current post-pandemic scenario (Moreno et al., 2021).

Lastly, the third-level keywords in this cluster reflected the importance of adopting a holistic and integrated approach to urban sustainability. Concepts such as health, well-being, and social sustainability are important issues to consider in urban policy and planning, because of their impact on people's quality of life (Kakderi et al., 2021; DeWit et al., 2020). Similarly, urban design and sustainable practices such as reducing carbon emissions and promoting circular economy principles must be addressed in the planning of livable and resilient cities (Sharifi, 2022; AbouKorin et al., 2021). Overall, the green cluster highlights the critical role of policy and planning in achieving sustainable urban development, the challenges faced by cities in the context of the pandemic, and the importance of adopting a holistic and integrated approach to urban sustainability.

iii. Cluster 3 – blue. The blue cluster is focused on the topic of sustainable mobility. This cluster addresses one of the critical challenges in urban sustainability and transportation. The main concepts that define this cluster are 'sustainable mobility', 'public transport', 'travel behavior', 'accessibility', '15 min city', 'cycling', and 'walking'. These keywords are closely related and form a network of concepts that are crucial for the development of sustainable mobility systems. Transportation is a key aspect of urban sustainability, as it affects not only the environment but also the social and economic dimensions of urban life. The main keyword of the cluster, "sustainable mobility", highlights the importance of reducing the environmental impact of transportation in urban areas, such as reducing carbon emissions and air pollution.

'Public transport' is a critical component of sustainable mobility. Although it was blamed for the spread of the pandemic, it is essential for addressing the travel demands of urban residents in a sustainable way (Tirachini and Cats, 2020). Public transport systems have the potential to reduce the number of individual cars and traffic congestion, air pollution, and carbon emissions. 'Travel behavior' is also an essential concept in this cluster, as it relates to people's preferences regarding how they travel in urban areas, and it is important in modal selection (Shamshiripour et al., 2020). Thus, it is also important to build a system that is environmentally friendly, inclusive, and economically viable (Tirachini and Cats, 2020; Axhausen, 2020). 'Accessibility', on the other hand, refers to the ease of reaching a destination regardless of the mode of transport used. In this regard, the concept of a "15-min city" is also relevant, as it presents a vision of cities based on proximity and highlights the importance of having essential services, such as schools, shops, and healthcare facilities, within a 15-min walk or bike ride (Allam et al., 2022b). Finally, cycling and walking are two essential keywords in this cluster as they represent sustainable and healthy modal alternatives. These concepts have a positive impact on the social and economic dimensions of urban life, such as improving public health and reducing transportation costs.

The pandemic has offered unprecedented opportunities to promote active and public transportation (Kim and Lee, 2023). Some modes of transportation such as cycling and walking have gained traction as evidenced by the multiple initiatives aimed at reshaping urban spaces to accommodate them (Valenzuela-Levi et al., 2021a). New technologies such as e-bikes could further contribute to these trends (Teixeira et al., 2022). However, concerns over the safety of public transportation systems such as trains and buses may result in new interest in private cars, with major implications for sustainability (Tirachini and Cats, 2020; Axhausen, 2020). It is, therefore, important to take action to address such concerns. Overall, the concepts in this cluster highlight the importance of sustainable mobility in the context of urban sustainability and the main concepts that define the development of a sustainable transport system, as it affects not only the environment but also the social and economic aspects of urban life.

3.1.4.2. Bibliographic coupling. Fig. 6 illustrates the network of coupled documents from the bibliographic database. It depicts three thematic clusters that group a set of documents of relevance for each topic. These clusters can be identified by colors: magenta, green, and blue. These clusters represent the connections between the literature on the impacts of the COVID-19 pandemic on the paradigm of urban sustainability.

i. Cluster 1 – magenta. This cluster is at the core of the network and includes the nodes that connect the themes to the clusters located on the corners of the network. This cluster highlights the documents by Shokouhyar, S. et al. (Shokouhyar et al., 2021) and Elavarasan, R. M. et al. (Elavarasan et al., 2021). The first document depicts an exploration of challenges and opportunities to the sustainability of shared mobility solutions that have been raised with the pandemic (Shokouhyar et al., 2021). This document is also the only connection between the magenta cluster with the green cluster, as it has been coupled with the articles of Jiang et al. (2021) and Sharifi, A. & Khavarian-Ghasmir, A. (2020). This article also has one of the three links that connect the magenta cluster with the blue cluster, by being coupled with the study of Orro, A. et al. (Orro et al., 2020). These documents are characterized by dealing with the impacts of the pandemic on public transport systems or mobility behaviors, except for one document that presents a comprehensive analysis of impacts and lessons for urban planning and design (Sharifi and Khavarian-Garmsir, 2020). The remaining documents of this cluster are focused on the diverse implications of the strategies to prevent the spread of the pandemic on the multiple drivers of urban resilience. For instance, an evaluation of factors that determine resilience against epidemic outbreaks in Chinese cities (Chen et al., 2021); and the evaluation of the role of different technologies in the cities during the outbreak, and an outlook of how they could be used as a resilience driver in technology-dominated futuristic societies (Elavarasan et al., 2021). These conditions are also related to the concepts highlighted in the magenta cluster of the keywords network described above.

ii. Cluster 2 – green. This cluster, located in the left corner of the network, is defined by nine nodes, from which just two are linked to the network (Sharifi and Khavarian-Garmsir, 2020; Jiang et al., 2021), connected to one document of the magenta cluster (Elavarasan et al., 2021). This cluster is defined by a comprehensive review depicting lessons and impacts for urban planning and design (Sharifi and Khavarian-Garmsir, 2020), a spatial-temporal evaluation of risk exposure to the pandemic and urban sustainability strategies (Jiang et al., 2021) and an assessment of the impacts of the pandemic on the increase in solid waste disposal (Urban and Nakada, 2021). Overall, this cluster encompasses documents approaching sustainability from diverse points of view. It includes a general assessment of the environmental effects of the pandemic and proposes a set of strategies toward sustainability (Rume and Islam, 2020), as well as other studies dealing with the increase of solid waste due to the pandemic (Urban and Nakada, 2021; De-la-Torre et al., 2021). Likewise, the coupled documents also include

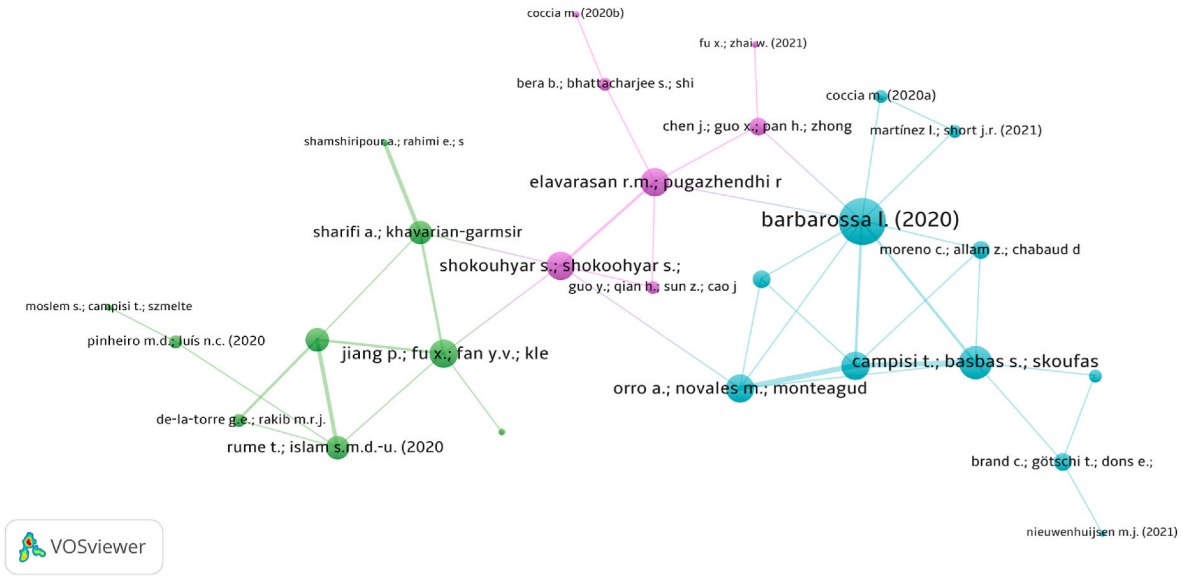


Fig. 6. Bibliographic coupling network.

an evaluation of proposals on how the pandemic could leverage into a more sustainable scenario from the perspective of the built environment (Pinheiro and Luís, 2020), as well as the nexus between the pandemic deaths, air pollution, and economic growth. In general, the coupled documents in this cluster deal with sustainability from diverse points of view and could as well be linked to the topics that have been also encompassed by the green cluster of the network of keywords presented in Fig. 5.

iii. Cluster 3 - blue. This cluster, located in the far right corner of the network, is connected by two nodes and three links to the magenta cluster. The document coupled with the study by Shokouhyar, S. et al. (Shokouhyar et al., 2021) (magenta cluster) assesses the impact of the lockdown on the bus transit services and how it could perform in the post-pandemic (Orro et al., 2020) Likewise, the study by Barbarossa, L. (Barbarossa, 2020) reflects on the challenges and opportunities to create more sustainable urban environments by re-defining the mobility paradigm towards a decarbonized system that focuses on active mobility. This study is linked to the other two documents in the magenta cluster (Elavarasan et al., 2021; Chen et al., 2021), and is also the node with the highest degree in the cluster, by being linked to nine documents. This cluster is focused mostly on transport and mobility and has the potential to develop new urban models oriented into active mobility and healthier urban environments (Nieuwenhuijsen, 2021), like the 15-min city (Moreno et al., 2021). The study of mobility behavior (Przybylowski et al., 2021) and how to provide the appropriate conditions for promoting the modal shift into active modes (Bergantino et al., 2021) have been addressed in most of the documents in the cluster. Lastly, the thematic areas addressed in this cluster could also be linked to the topics highlighted in the blue cluster of the co-occurrence network of keywords described in the section above.

3.2. Analysis of key topics

The following analysis sought to provide a more in-depth knowledge of the issues raised in the previous overview. This is accomplished by conducting a content analysis to identify relevant subjects, issues, and promising research trends in urban sustainability. Changes like the shift towards remote work and online learning have resulted in a significant reduction in transportation and commuting (Guzman et al., 2021), leading to decreased air pollution and greenhouse gas emissions in many cities (Fu et al., 2020; Wang and Li, 2021), with positive effects on the environment and public health. Additionally, the pandemic has emphasized the need for resilient and sustainable cities that can better handle emergencies and crises and transform their conditions for future disruptions (Sharifi, 2022; Pelling et al., 2021; UNESCO, 2020). Cities that invest in sustainable infrastructure, such as natural spaces, public areas, and renewable energy, have been better prepared and equipped to deal with the pandemic and its associated economic downturn (Isabella et al., 2022; Venter et al., 2020; Noszczyk et al., 2022). However, this outbreak has also presented challenges to the sustainable cities' paradigm, as budget cuts and reduced funding for sustainability initiatives have slowed progress in some areas (Tonne, 2021; Nundy et al., 2021). Furthermore, inequalities in urban areas have been highlighted by the pandemic, as low-income communities have been disproportionately impacted by the virus and its associated economic impacts (Benita et al., 2022; Baker et al., 2020).

These effects have been studied extensively since 2020 concerning different specific topics and reviews like this one. This analysis is divided into five main categories related to urban sustainability: Resilient urban planning, Sustainable mobility, Healthy urban environments, Social equity, and Circular economy. Fig. 7 illustrates the summary of the content analysis performed for the reviewed literature. It illustrates the state of the art by sorting the analysis into 33 key topics, and the frequency in which each of them was addressed in the reviewed literature. The plot also illustrates how often each topic was addressed in each of the five main thematic categories. A deeper analysis of these topics is presented in the subsequent subsections, sorted on each of the main thematic categories.

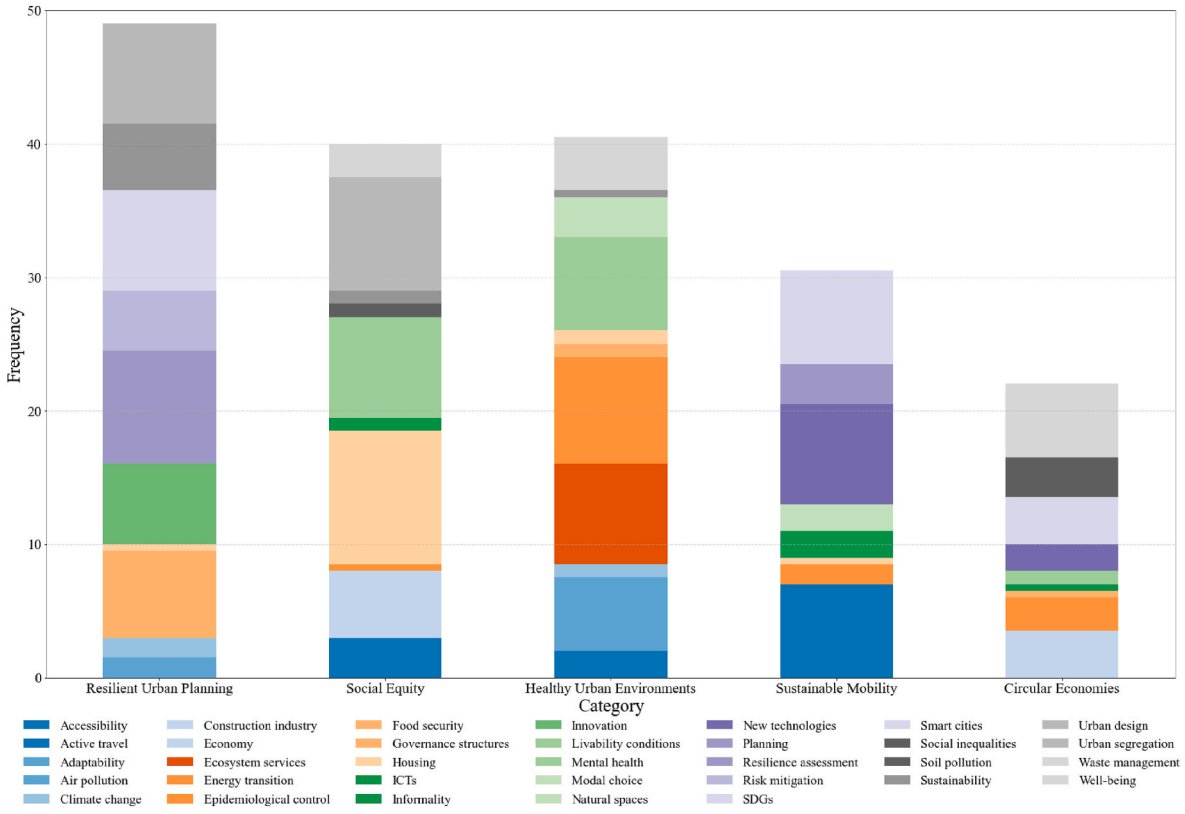


Fig. 7. Summary of the key topics in literature review.

3.2.1. *Resilient urban planning*

Resilient urban planning is crucial in the management and response to pandemic outbreaks, particularly in the wake of the COVID-19 pandemic (AbouKorin et al., 2021; Keenan, 2020; Hananel et al., 2022). Transformative resilience in urban areas has been highlighted as a backbone for planning sustainable cities (DeWit et al., 2020; Campolongo et al., 2020). Studies have shown that factors related to air quality (Bherwani et al., 2021; Jakovljević et al., 2021), waste management (Ouigmane et al., 2021; Onoda, 2020), public transport systems (Kakderi et al., 2021; Braut et al., 2022), sanitation infrastructure (Auerbach and Thachil, 2021; Shermin and Rahaman, 2021), and public spaces (Honey-Rosés et al., 2020; D'alessandro et al., 2020) could influence viral transmission. These dimensions have emerged among many factors that emphasize the need for improvement through planning mechanisms (AbouKorin et al., 2021; Afrin et al., 2021). For instance, scholars have investigated the impact of environmental factors, such as temperature and humidity, on the spread of COVID-19 (Barouki et al., 2021; Nazir et al., 2021), which is essential for emergency response planning (Campolongo et al., 2020; Wilkinson et al., 2020) and building long-term urban governance strategies to enhance urban resilience (Afrin et al., 2021; Elander et al., 2022). Tackling environmental challenges also offers co-benefits in terms of resilience to other stressors such as extreme heat and flooding. Coordination among different sectors and stakeholders is also vital in integrated urban governance models (Sharifi and Khavarian-Garmsir, 2020), which can incorporate data-driven analyses to support policy development and decision-making processes (Kakderi et al., 2021; Keenan, 2020).

Resilient urban planning must also consider the role of the housing sector, which has become critical in cities during the pandemic as people were forced to stay at home, and many had to work and study from home during long periods of lockdown. This is a critical aspect while planning for urban resilience as it plays a vital role in ensuring that people have access to safe and secure living environments (Encinas et al., 2021; Benfer et al., 2021). To address the challenges posed by the pandemic, resilient urban planning approaches have emphasized the need to rethink the role of housing in cities (Amirzadeh et al., 2023). Scholars have highlighted the importance of analyzing habitational units to assess livability conditions during quarantine (Benfer et al., 2021; D'alessandro et al., 2020; Cheshmehzangi, 2021). They studied the conditions of the housing sector according to what the built environment offered to people during the outbreak, revealing the deprived living conditions of the most vulnerable and the urban poor that made it difficult to contain the pandemic (Sahasranaman and Jensen, 2021; Ahmad et al., 2020). The discussion around the housing sector has evolved from the sole role of habitat to a multi-use spectrum of additional functions such as workplace, leisure, and even sports facilities during quarantine (Sarmento et al., 2021; Hubbard et al., 2021).

In addition to addressing the immediate challenges of the pandemic, resilient urban planning approaches have focused on the long-term sustainability of housing (Dastgerdi et al., 2021; Valenzuela-Levi et al., 2021b). For example, some cities have implemented integrative frameworks that provide data-driven analyses to support policy development and decision-making in an adaptable evidence-based paradigm (DeWit et al., 2020; Valenzuela-Levi et al., 2021b). These frameworks consider factors such as the quality of the built environment (Amerio et al., 2020), access to basic infrastructure systems (Valenzuela-Levi et al., 2021b), and exposure to threats and economic difficulties in vulnerable communities (Auerbach and Thachil, 2021). By adopting a holistic approach to housing, resilient urban planning can help create sustainable and resilient communities that are better prepared to cope with future crises (Kaklauskas et al., 2021; Valenzuela-Levi et al., 2021b).

Resilient urban planning must also address structural inequalities and vulnerabilities in communities to facilitate equitable access to resources and ensure that the response to crises does not exacerbate these issues (Amirzadeh et al., 2023; Takefuji, 2023). Implementing smart tools for urban applications powered by big data and ICTs can increase the efficiency of urban systems, enabling their adaptability to

evidence-based paradigms in the face of future crises. Overall, long-term planning and the application of lessons learned from past crises are crucial for enhancing urban resilience and emergency preparedness.

3.2.2. Social equity

In light of the pandemic's far-reaching socioeconomic impacts, including pushing millions of people into extreme poverty and damaging the global economy, the issue of social equity has become a critical concern (Ranjbari et al., 2021b; Haase, 2020). The pandemic exacerbated preexisting social inequalities and vulnerabilities within cities. Disruptions in economic activities, job losses, and increased poverty rates have affected individuals and communities, pushing them further into hardship and hindering their progress toward sustainable urban development. It has revealed the unequal distribution of resources and services, with marginalized populations bearing a disproportionate burden of the crisis, particularly those living in slums, being disproportionately impacted (Patel and Shah, 2020). The need to ensure access to affordable housing, quality healthcare, food provision, education, and social support systems has become even more critical in the post-pandemic scenario (Tokazhanov et al., 2020; Prieto et al., 2021). These communities faced challenges, such as high density, inadequate access to basic infrastructure, and precarious livelihoods, making it difficult to implement the most common mitigation measures, such as social distancing and quarantine (Tandel et al., 2021). These disparities highlight the urgent need to address social inequities and enhance the sustainability of urban environments. This calls for inclusive urban planning that prioritizes the provision of affordable housing, access to quality healthcare, and essential services for all residents, regardless of their socioeconomic status. Transformative policies should be implemented to improve the living conditions of the urban poor and ensure their safety, health, and well-being.

The social dynamics forced to manage the pandemic have triggered significant disruptions in economic activities, resulting in widespread job losses and an increase in poverty rates. These socioeconomic conditions have deep implications in urban settlements, worsening already existing inequalities and blocking progress regarding sustainable urban development (Shulla et al., 2021). For instance, in cities with economies heavily reliant on tourism, the closure of hotels, restaurants, and entertainment venues has led to a sharp decline in employment opportunities, leaving many individuals struggling to make ends meet (Casado-Aranda et al., 2021). Similarly, in informal settlements, where a large portion of the population relies on daily wage labor, lockdown measures, and economic downturns have caused widespread job losses and heightened poverty levels (Baker et al., 2020). The impacts of job loss and increased poverty extend beyond the economic realm and have far-reaching consequences for social cohesion and well-being. In vulnerable neighborhoods, the pandemic has further marginalized already vulnerable communities, fostering social equality and exacerbating health disparities (Tampe, 2020). Limited access to quality healthcare, inadequate housing conditions, and a higher prevalence of underlying health conditions have contributed to higher infection rates and poorer health outcomes among socioeconomically disadvantaged groups (Auerbach and Thachil, 2021; Pongutta et al., 2021).

Likewise, with the early lifting of restrictions for essential workers, low-income individuals were more exposed to virus infection due to daily mobility patterns and longer commutes between their residences and workplaces. They face barriers to using sustainable modes of transport, such as cycling or walking. It has been evidenced that these social groups suffer from a lack of appropriate infrastructure, like bike lanes or pedestrian-friendly streets. Also, the long distance between their residence and their workplace makes it harder to reach them using active alternatives (Guzman et al., 2021); other solutions like electrically-assisted bicycles which are more suitable for longer commutes are unaffordable technologies for these communities. They also tend to suffer from limited access to public transportation, with fewer options serving their areas, or low frequencies in a system operating over capacity, forcing them to get exposed to overcrowded environments or informal solutions (Campisi et al., 2020; Guzman et al., 2021), either way, they get under a higher risk of virus transmission (Guzman et al., 2021).

Moreover, when it was possible to shift to work-from-home dynamics, these communities were less likely to adapt because they lacked the necessary technology (Francis and Weller, 2022). Likewise, the closure of schools and the shift to remote learning have disproportionately affected students from low-income families, who may lack access to the necessary technology and face difficulties adapting to online education (Francis and Weller, 2022). These conditions not only threaten the immediate well-being of affected households but also set long-term challenges for their capacity to access basic services and improve their living conditions (Istrate and Chen, 2022). The literature review also revealed serious concerns about privacy protection, governmental transparency, and personal liberties in implementing smart solutions for the prevention and management of the virus (Shorfuzzaman et al., 2021; Sonn and Lee, 2020).

Furthermore, housing plays a pivotal role in shaping socioeconomic equity and acts as a determinant of access to other vital resources. Access to affordable housing has emerged as a major concern, as the economic fallout from the pandemic has left many individuals and families struggling to afford safe and adequate housing (Duca et al., 2021; Del Giudice et al., 2020). For instance, in cities where housing costs are already high, the pandemic has exacerbated the housing crisis, leading to increased rates of homelessness and housing insecurity (Ralli et al., 2021; Nichols and Mays, 2021). These conditions shape the critical quantitative deficit of the housing sector; however, low-income families also face the burden of a qualitative deficit (Peters and Halleran, 2021; Jaimes Torres et al., 2021a), as they often live in substandard housing conditions, lack access to critical services, and experience problematic environments in their neighborhoods (Truong and Asare, 2021).

Similarly, the pandemic has exposed the critical conditions faced by the urban poor in densely populated areas, particularly in informal settlements of developing countries. The availability of public spaces, limited access to essential services, and inadequate infrastructure have reinforced their vulnerability to the virus and have exacerbated existing social inequalities (Baker et al., 2020). Beyond housing units, the post-pandemic scenario has underscored the importance of ensuring access to essential provisions, reliable food supply, education, culture, and health facilities. In this context, urban compactness and the concept of proximity are particularly relevant for addressing pre-existing socioeconomic inequalities and their mitigation in the future (Marin-Cots and Palomares-Pastor, 2020). In many cities, marginalized communities often face challenges in accessing vital services because of spatial disparities and limited mobility options. With neighborhoods that prioritize proximity and the equitable distribution of amenities, cities can create more inclusive and socially just environments (Allam et al., 2022a). In the post-pandemic scenario, the emerging concept of a 15-min city as a planning policy (Moreno et al., 2021) takes extra value as a solution to these issues. This concept emphasizes the importance of proximity in creating sustainable and inclusive urban environments. This suggests that residents should have access to key services and amenities within a 15-min walking or cycling radius from their homes (Moreno et al., 2021). Ensuring that healthcare facilities, grocery stores, schools, and community services are located close to residential areas, cities can reduce inequalities, improve the well-being of their inhabitants, reduce dependence on long commutes, enhance social cohesion, and improve environmental sustainability (Allam et al., 2022c). For instance, in Paris, the concept of the 15-min city has been adopted as a planning strategy, with the government promoting the development of self-sufficient neighborhoods where residents can meet their daily needs within a short distance. By integrating housing, workspaces, recreational areas, and public services, Paris aims to create cohesive and livable neighborhoods that reduce reliance on long-distance commuting and foster a sense of local identity and inclusion (Allam et al., 2022a).

Addressing the systemic challenges of boosting social cohesion requires a comprehensive approach beyond the mere provision of quantitative approaches. A holistic perspective considers the interconnections among housing quality, health, infrastructure, urban design, employment, and social support systems. Similarly, it is necessary to promote community engagement and participation in urban development and housing policies. Involving marginalized communities in decision-making processes and recognizing their unique needs and perspectives can lead to more equitable outcomes. Collaborative policies among governments, housing organizations, and community stakeholders are essential for addressing inequalities and fostering sustainable urban environments. For instance, the C40 network is a coalition of major cities committed to addressing climate change and promoting sustainability. The network acknowledges that climate action should not exacerbate existing social inequities but enhance the quality of life for all citizens. Among these actions to jointly tackle climate change and inequality are New York's Cool Neighborhoods plan for facing the extreme heat in the historically marginalized neighborhoods; or the climate action plan for environmental justices of Barcelona, which has a strategic focus on justice and citizen coproduction for prioritizing socioeconomic inequalities as well as the climate challenges faced by the city (C40 Cities Climate Leadership Group, 2019).

3.2.3. Healthy urban environments

The built environment is crucial for promoting the well-being of individuals and communities, especially during pandemics (Watson et al., 2020). Extended quarantine periods during the first year of the COVID-19 outbreak demonstrated the urge for cities to provide conditions for people's health and safety (Pierantoni et al., 2020; Escorcia Hernández et al., 2023). Achieving the sustainability agenda requires that the different components of urban systems be aligned to provide these conditions to the inhabitants (Krellenberg and Koch, 2021). Among these, the literature highlights the mitigation and adaptation to climate change and the different sources of threat to people's lives, such as environmental pollution and natural hazards (Watson et al., 2020). Likewise, the discussion that human and environmental well-being are interconnected is increasingly acknowledged, leading to a growing emphasis on ecological factors as determinants of health (Backholer et al., 2021; Filho et al., 2020). Although lockdowns have implied some benefits of reducing environmental pollution (Wang and Li, 2021), improving water quality (Saadat et al., 2020; Barcelo, 2020), and the re-naturalization of urban environments (Isabella et al., 2022; Sikorska et al., 2023)concerns regarding other hazardous conditions such as drug pollution and improper waste disposal have been discussed (Barcelo, 2020; Menéndez and Higueras García, 2020). To create healthy urban environments, considerations should aim not only to care for people's physical health but also for their mental health (Peters and Halleran, 2021; Kim and Cho, 2020). To do so, beyond the requirements regarding the housing units (Peters and Halleran, 2021; Zarrabi et al., 2021; Jaimes Torres et al., 2021b), it is required that cities provide an environment with access to the required services (Marin-Cots and Palomares-Pastor, 2020), public space (Low and Smart, 2020), and natural spaces (Venter et al., 2020).

It is crucial to recognize that the challenges faced by urban areas extend beyond immediate health crises. The COVID-19 pandemic has served as a reminder that urgent action is needed to ensure the long-term viability and livability of cities in the face of a changing climate (Pelling et al., 2021). As cities continue to experience the impacts of climate change, such as extreme weather events (Hambleton et al., 2020), rising temperatures (Wang and He, 2023), and sea-level rise (Baker et al., 2020), the health and well-being of urban populations are becoming increasingly at risk (Watson et al., 2020; Sohn and Kotval-Karamchandani, 2023). By integrating climate change mitigation and adaptation strategies into urban planning and development, cities can create environments that are safe, healthy, sustainable, and resilient in the face of future challenges. Similarly, the critical issue of environmental pollution in urban areas has received great attention, emphasizing the urgent need for comprehensive action (Nazir et al., 2021). Even before the pandemic, the issue of urban centers often suffering from poor air quality due to different sources was at the center of the discussion as a critical factor for public health (East et al., 2021; Frank and Engelke, 2005). During the outbreak, however, a unique situation was evidenced, where extended lockdowns and restrictions on economic activities resulted in a noticeable reduction in air pollution levels in different urban areas worldwide (Fu et al., 2020). With industrial factories temporarily halted and personal transportation severely limited, cities experienced a decline in pollutant emissions (Zoran et al., 2023; Bherwani et al., 2021), leading to temporary improvements in air quality in some regions (Fu et al., 2020). This temporary respite from air pollution served as a reminder of the potential for positive change in urban environments.

Similarly, ensuring access to clean and safe water is another crucial aspect of a healthy and sustainable environment. Polluted water sources pose significant health risks, particularly in densely populated urban areas (Saadat et al., 2020; Rupani et al., 2020). The pandemic has highlighted the importance of maintaining reliable water supply systems, implementing effective water treatment processes, and ensuring the safe disposal of wastewater (Rupani et al., 2020; Gormley et al., 2020). Additionally, proper sewage management is essential to prevent water pollution, protect ecosystems, and safeguard public health (Shermin and Rahaman, 2021; Gormley et al., 2020; Mihai, 2020). Urban centers must invest in appropriate infrastructure and sustainable practices to efficiently manage sewage, reduce the risk of contamination, and promote healthier living environments. This crisis has also drawn attention to the issue of waste management (Munguía-López et al., 2022; Hantoko et al., 2021). For instance, the increased use of personal protective equipment and medical waste generation, critical during an extended health emergency, represent big threats and challenges in handling and disposing of waste sustainably (Mahmoudnia et al., 2022; Sharma et al., 2021). It is imperative to develop effective waste management strategies that prioritize the proper disposal and recycling of medical waste, including masks, gloves, and other protective gear (Munguía-López et al., 2022). This requires innovation and a smart approach to future increasing challenges (Onoda, 2020), as well as collective efforts between local authorities, healthcare institutions, and the public to ensure responsible handling of waste and management of different pollutants. By addressing these issues, urban centers can not only mitigate the immediate risks associated with environmental pollution but also build resilient and sustainable communities that prioritize the health and well-being of their residents.

Furthermore, the housing sector plays a critical role in shaping people's physical and mental well-being (Peters and Halleran, 2021; Zhu and Holden, 2023). Housing units are the initial-scale units that influence urban sustainability, and their significance has been amplified during the pandemic and will continue to hold relevance in a post-pandemic scenario. For instance, in the U.S., it was found that places with a higher percentage of households with poor housing conditions had a higher incidence and mortality associated with COVID-19 (Ahmad et al., 2020). It is crucial to critically examine the existing housing conditions and their implications. Although residential units are meant to provide safe and comfortable living spaces, many individuals face challenges such as overcrowding, inadequate ventilation, and substandard living conditions (Cheshmehzangi, 2021; Navas-Martín et al., 2022). These issues disproportionately affect marginalized and vulnerable communities, deepening existing disparities (Marí-Dell'Olmo et al., 2017). The pandemic has further highlighted inequalities in access to quality housing (Peters and Halleran, 2021), as those with limited resources have been disproportionately impacted by the lack of space and essential amenities required for health and well-being (Benfer et al., 2021; Baker et al., 2020). Beyond physical health considerations, the design and quality of residential units also significantly impact mental well-being (Amerio et al., 2020).

Pandemic-induced lockdowns have made it evident that living spaces must accommodate multiple functions, including work, exercise, and relaxation (Sarmento et al., 2021; Hubbard et al., 2021). However, many housing units are ill-equipped to meet these evolving needs, leading to increased stress, isolation, and a reduced quality of life (Peters and Halleran, 2021; Sarmento et al., 2021).

In the transition to a post-pandemic era, it is crucial to critically examine housing policies and urban planning approaches. The residential sector plays a key role in the sustainability of the cities, and housing policies must should go beyond merely ensuring affordable and accessible housing (Chan and Adabre, 2019). Even if these are critical issues to address, the pandemic has revealed that it is also required to ensure the provision of high-quality residential units and their articulation with the built environment to promote both physical and mental well-being (D'alessandro et al., 2020; Zarrabi et al., 2021). To do so, it is necessary to target systemic issues, such as inadequate housing regulations, gentrification, insufficient investment in affordable housing initiatives, poor livability housing conditions, inequities in the quality of residential units, and the integration with the built environment. A further comprehensive approach is needed encompassing affordable housing initiatives (Lăzărescu et al., 2020), sustainable design principles (Peters and Halleran, 2021; Cuerdo-Vilches et al., 2021), and inclusive planning approaches (Dastgerdi et al., 2021). One example is the initiative of the city of Paris to include the communities in a plan to fight energy poverty in the city, framed within the policy framework of their Climate action plan (C40 Cities Climate Leadership Group, 2019). Another noteworthy example is the action plan of Sydney to build trust with the community through a community engagement strategy that involves the community members in designing the projects (C40 Cities Climate Leadership Group, 2019). Moreover, the post-pandemic housing landscape presents an opportunity to reimagine cities and prioritize the creation of resilient and inclusive communities. This includes investing in social housing, implementing universal design principles for housing units and the built environment to accommodate diverse needs, and integrating accessible green spaces into cities.

Besides, the link between healthy urban environments and access to quality public spaces and natural areas has gained significance (Venter et al., 2020; Istrate and Chen, 2022). The pandemic has accentuated the importance of these spaces in promoting physical and mental well-being (Sikorska et al., 2023; Noszczyk et al., 2022), fostering social connections, and enhancing the overall quality of life (Isabella et al., 2022; Poortinga et al., 2021). Access to public spaces was critical for the reactivation of social interaction and mitigation of the virus spread in the early ease of restrictions (Isabella et al., 2022; Gubić and Wolff, 2022); however, it has been determined that the urban poor had the least access to this service in that period (Honey-Rosés et al., 2020). As cities adapt and recover, prioritizing the development and maintenance of accessible and inclusive public spaces is essential for creating healthier and more resilient urban communities. Inadequate access to green spaces and recreational areas further compounded these challenges, limiting opportunities for physical activity and natural engagement, which are vital for mental health (Abass, 2021; Wang et al., 2021).

Public spaces serve as vital gathering areas, offering opportunities for physical activity, recreation, and social interactions. In the post-pandemic era, investing in quality public spaces and natural areas is a central component of urban planning and development strategies. Apart from the potential ecosystem benefits of the re-naturalization of the cities (Backholer et al., 2021; Berdejo-Espinola et al., 2021), by providing accessible and well-designed public spaces, cities can promote healthier lifestyles, foster social cohesion, enhance the overall well-being of their residents, and improve the balance with the natural ecosystems within the urban environments (Abass, 2021; Ahmadpoor and Shahab, 2021). It has been discussed that the violent expansion of urban sprawl without considering the natural ecosystem, apart from increasing climate vulnerability, has led to an increase in human exposure to zoonotic agents, therefore, increasing vulnerability to zoonotic diseases through virologic mutations (UN-HABITAT, 2022). Thus, the development of ecological networks within the cities based on blue and green infrastructure, to foster landscape connectivity (Xiu et al., 2017), could order the interaction between humans and wildlife and reduce the risk of zoonotic diseases. A higher degree of connectivity is achieved through structural composition and the spatial configuration of the natural elements within cities and their surroundings (rivers, ponds, green areas, urban forests) (Sikorska et al., 2023; Xiu et al., 2017). As cities rebuild and reimagine their future, they have the opportunity to create vibrant and sustainable environments that prioritize the health and vitality of their residents and articulate the human co-existence with natural ecosystems, through the provision of quality public spaces and natural areas.

3.2.4. *Sustainable mobility*

Academic literature has emphasized the importance of urban mobility due to its vital role in city life, particularly amidst the COVID-19 pandemic. Studies have shown that transportation systems play a significant role in the spread of viral diseases (Cartenì et al., 2020; Manout and Ciari, 2021), emphasizing the importance of developing strategies to develop safer and more resilient transportation systems (Tirachini and Cats, 2020; Kakderi et al., 2021). During lockdowns, the suspension of nonessential travel and transport resulted in a significant reduction in emissions, highlighting the need for sustainable transportation systems (Mitchell et al., 2021; Nundy et al., 2021). One significant outcome of the pandemic was the decrease in atmospheric pollution in cities owing to the shutdown of several transport services (Fu et al., 2020; Jakovljević et al., 2021). For example, New York City saw a 50% reduction in air pollution levels during lockdown (Fu et al., 2020). This demonstrates the potential impact of reduced transportation emissions on improving air quality and reducing carbon emissions, underlining the importance of sustainable transportation alternatives. Strategies to reduce reliance on fossil fuels, like the promotion of active transportation (Allam et al., 2022a), and policies that encourage the use of electric or low-emission vehicles (Kakderi et al., 2021) are essential in this context. Future transportation policies should aim to promote the technological improvement of zero-emissions vehicles (e.g., electric, hydrogen) as well as the inclusion of active modes into an integrated transport system, like the articulation of smart bike-sharing programs into the public transport system.

The reduction in congestion due to mobility restrictions for non-essential trips was taken as an opportunity to increase cities' resilience, reduce the burden on public transport systems, and promote the modal shift towards active modes such as walking and cycling (Guzman et al., 2021; Arellana et al., 2020). However, disincentivizing public transportation owing to virus transmission risks and the tendency to choose private vehicles as the preferred mode of transportation has been identified as risk factors for the long-term sustainability of urban mobility (Amirzadeh et al., 2023; Axhausen, 2020). Thus, the promotion of public transport systems resilient to infectious diseases needs to be addressed as a challenge for sustainable transportation (Allam et al., 2022b). Eventually, the pandemic led to the adaptation of transportation systems to mitigate the spread of the virus, such as promoting alternative modes of transportation to reduce reliance on public transit, as has been seen in many cities where the number of kilometers of cycling infrastructure has increased since 2020 (Kim and Lee, 2023; Seifert et al., 2023), and the development of safe protocols for the operation of transportation infrastructure to support emergency response. Furthermore, repurposing innovative technologies such as IoT, big data analytics, AI, and automatized systems has allowed the evaluation of response measures (Costa and Peixoto, 2020; Yang and Chong, 2021). The application of these technologies can be extended to facilitate smart transport systems and support transportation planning (Kakderi et al., 2021). Likewise, details are needed on other approaches to foster the resilience of the mobility systems in an optimal operation to incentivize people to use them. This requires the action of different

consistent strategies for demand management, like the spreading of peak hours into different time frames as a strategy to reduce the overcrowding in the system (stations, stops, vehicles), and thus reduce the risk of contagious viral diseases (Lucchesi et al., 2022). Also, providing an appropriate level of service for the operation is key, by either increasing the frequency of the vehicles or their capacity (Campisi et al., 2020). The application of technologies for smart management and monitoring may serve as support to optimize the transport system within an operative capacity that provides safe biological conditions. Monitoring the system operation with real-time data, for instance, could leverage the planning and definition of the transportation offer, as it becomes one requirement to provide the appropriate conditions for a safe operation (Lucchesi et al., 2022).

Another transversal impact of the pandemic was the mobility patterns of the most vulnerable people in the cities during the crisis (De Vos, 2020). Different studies have shown that low-income people, typically inhabitants of marginalized areas, were more exposed to the virus infection owing to the daily mobility patterns they were subjected to (Guzman et al., 2021; Valenzuela-Levi et al., 2021b). It has been found that low-income people were less likely to perform remote work during the lockdown; thus, they were exposed to longer commutes between their places of residence and their workplaces (Cartenì et al., 2020; Manout and Ciari, 2021). These long commutes also imply a barrier for these people to make trips by sustainable and contagion-resilient modes of transport, such as cycling or walking (Guzman et al., 2021; de Valderrama et al., 2020). The combination of these factors meant that these individuals had higher exposure to virus transmission during quarantine periods. In addition to commutes for work purposes, it also highlighted the lack of accessibility to essential services such as healthcare and basic needs for vulnerable communities in urban slums and low-income neighborhoods (Kang et al., 2020). Therefore, it is necessary to integrate these topics into the transport planning process to reduce the sources of inequity and multidimensional segregation of the most vulnerable communities.

Overall, transportation systems are critical for urban sustainability, and the pandemic has emphasized the need for sustainable transportation systems to reduce emissions, promote healthier modes of transport, and provide access to essential services for vulnerable communities. Future research should focus on identifying ways to incentivize long-term sustainable transportation and promote multimodality, including the use of shared mobility, electric vehicles, and zero-carbon transportation infrastructure. For instance, the framework of Avoid-Shift-Improve (AVI) (UN-HABITAT, 2022) summarizes these practical lessons for future sustainable urban mobility. It is based on three kinds of interventions: Avoid interventions that aim to disincentivize polluting private vehicles and unnecessary trips. This relies on planning instruments like a balanced land-use distribution in compact urban units, or the implementation of regulations like low-emissions zones, vehicle-free areas, no-parking areas, or infrastructure allocation. Shift interventions aim to encourage active travel, shared mobility solutions, and public transport systems. This requires the development of economic instruments such as taxes for the use and purchase of fossil fuel vehicles, and congestion charges to disincentivize private vehicle use; as well as the provision of an efficient system to increase people's willingness to use public transport. Also, information instruments are required to increase public awareness of the existing services of the system, and the involvement of the community in the transport planning process. Finally, the Improve interventions aim to facilitate technological and institutional improvements of the existing system. This also seeks to promote efficiency through vehicle technology for fuel improvement, cleaner technologies, and cleaner production, for both public and individual motor vehicles (De Vos, 2020).

3.2.5. Circular economy

The COVID-19 pandemic has highlighted the importance of transitioning to a circular economy that focuses on reducing waste and promoting sustainable production and consumption (Ibn-Mohammed et al., 2021). This vision emphasizes resource efficiency, waste reduction, and the reuse and recycling of materials, which has gained significant attention in recent years as a means to achieve sustainable development goals in urban areas (Sonnier and Grit, 2022).

The disruptions caused by the pandemic have prompted discussions on rethinking traditional linear models of production and consumption and transitioning towards more circular and self-sufficient systems. In addition, it has exposed vulnerabilities in global supply chains, highlighting the need for greater resource resilience and production localization (Alva Ferrari et al., 2023). In this regard, for instance, food security in some cities has been compromised due to disruptions in some supply chains. It has led to the renewal of the discussion on urban self-sufficiency through the practice of urban agriculture to partially supply the demand and increase the food security of the cities (UN-HABITAT, 2022; Sukhwani et al., 2020). Likewise, the role of the rural-urban relationship takes place in the discussion of increasing urban food security, through the regional collaboration of different governments within multi-level governance frameworks (Sukhwani et al., 2020).

Waste management is a subcategory of the circular economy, and studies have emphasized its role during the pandemic. During the outbreak, disposing of medical waste has become a significant challenge and many concerns have been raised regarding this matter. The disposal of hazardous materials has been a critical dimension of the pandemic (Hantoko et al., 2021). For instance, the proper disposal of personal protective equipment is essential because it has been identified as an increased source of environmental pollution (Behera, 2021). Likewise, the collective protective measures also increased the use of single-use plastics and represented a big challenge for appropriate disposal, collection, and recycling to reduce their hazardous potential (Rai et al., 2023). In addition, the pandemic-induced shutdown of carbon-intensive industries implies a temporary decrease in greenhouse gas emissions, indicating the relevance of finding more sustainable approaches for the industry to achieve better practices toward a sustainable economy (Lenzen et al., 2020; Nicola et al., 2020). The limitations on mobility and disruptions in manufacturing and trade have led to a renewed focus on recycling, reusing, and repurposing materials to minimize waste generation and optimize resource utilization. For instance, the closure of certain industries during the lockdown has also led to a surplus of materials and resources, creating opportunities for their redirection into circular initiatives (Prata et al., 2020; Felix et al., 2022).

Furthermore, the pandemic has prompted a shift in consumer behavior and preferences, with a growing emphasis on sustainability and conscious consumption (Echegaray, 2021). This change in mindset provides an opportunity to promote circular economy practices such as repair, sharing, and reuse markets. The rise of online platforms and digital technologies has facilitated the exchange and reuse of goods, enabled more efficient resource allocation, and reduced the need for new production. Likewise, technologies such as immersive realities and digital twins have the potential to redefine several industries in the optimization and transition of their production and management (Allam and Jones, 2021). This opportunity to use digital tools to spread these practices, however, faces the challenge of a digital gap, as many smart solutions are massive. Thus, the scalability of these circular approaches in non-digital societies implies the challenge of supporting digital transition in the least-developed economies (KELLY and MOURITZ, 2020; Allam and Jones, 2021).

Moreover, in future urban development scenarios, the construction industry will play an important role in urban circular economies. As cities strive towards sustainability and resource efficiency, the construction sector holds immense potential for driving circularity (Coskun et al., 2022). The traditional linear production paradigm in construction, based on the take-make-dispose model, challenges the principles of circular economies, which aim to reduce waste, promote reuse and recycling, and minimize resource consumption (Coskun et al., 2022).

Embracing circularity in construction involves adopting innovative approaches such as designing for deconstruction, using recycled materials, and implementing strategies for material recovery and reuse. These approaches require huge innovation and change in production chains throughout the life cycle of the construction sector. Additionally, this industry can contribute to circular economies by embracing sustainable building practices, incorporating renewable energy systems, and integrating nature-based solutions into the built environment. Transitioning to a circular construction model in a post-pandemic scenario allows cities to not only minimize environmental impacts but also create job opportunities and economic growth toward a sustainable built environment. However, challenges to shift to a circular model remain, because the linear model has been dominant for a long time and most industries are reluctant to fight that inertia with the required efforts to transition into a circular model. Derived from this factor, other circumstances such as overcoming financial barriers may interfere with the transition due to the required initial high investments to mutate production practices, as well as the economic competitiveness of the sustainable practices against typical linear models of production and consumption (Heshmati and Rashidghalam, 2021). Conventional practices hold lower costs, compared to emerging circular approaches, which would affect the willingness to adopt the costs of transforming existing practices. Promoting public awareness among stakeholders, and educating consumers about the need to transition into a circular model, could be effective ways to streamline the process. Addressing these challenges requires collaboration among policymakers, industry professionals, researchers, and other relevant actors and stakeholders to develop and implement strategies that foster circularity, including the construction industry and its supply chain.

Overall, the implementation of circular economy practices in cities faces several challenges. These include the need for supportive policies and regulations, collaboration among stakeholders, and the development of innovative business models (Heshmati and Rashidghalam, 2021; Marchesi and Tweed, 2021). These needs could be articulated in different applications such as the development of collaborative industrial parks, which foster collaboration among businesses to optimize the use of resources, reduce and manage waste, and share infrastructure within strict ecological standards (Ribeiro et al., 2018; Rweyendela and Kombe, 2022); and the development of collaborative urban farming initiatives, not only to provide food and improve food safety but to reduce waste and foster community engagement and prosumers view. This could be extended into the development of prosumers in the energy sector with the development of energy communities and technical nexus (Heshmati and Rashidghalam, 2021). The COVID-19 pandemic has highlighted the importance of addressing these barriers and accelerating the adoption of circular economic strategies to build more resilient and sustainable urban systems.

4. Future research challenges

Moving forward, the review highlights several key research topics that need further investigation in the paradigm of urban sustainability for the post-pandemic scenario. This section discusses some research perspectives identified throughout the literature review. First, it seems crucial to develop a deeper understanding of the long-term impact of the pandemic on the built environment and public health, addressing the particular needs of each context, the extent of the territory, the demographic conditions, and the heterogeneity of the environments worldwide. This requires a comprehensive evaluation of changes in individual and collective behavior after the pandemic. Also, establishing a robust framework for transformative cities that can effectively withstand future disruptions, like the effects of climate change, or outbreaks like the covid pandemic, is imperative. Assessing the enduring effects of the pandemic on urban environments is vital for informed decision-making and policymaking, and for this, it will be necessary to disclose the conditions of each context in which a phenomenon will be evaluated.

Furthermore, there is a need to comprehend the future implications of policies implemented during the pandemic on community well-being and socioeconomic inequities. This understanding will be instrumental in devising strategies and policies that can mitigate disparities and foster sustainable urban development. Consequently, future research should prioritize the exploration of these areas to fill the existing knowledge gaps. Likewise, it is essential to investigate innovative planning strategies to reduce vulnerability and promote resilience among disadvantaged communities. This entails evaluating and proposing strategies that address social and economic inequalities, ensuring equitable access to essential services, affordable housing, and community resources. An illustrative example is the "15-min city" concept, which emphasizes proximity and aims to minimize the need for long commutes while promoting active transportation and enhancing residents' quality of life. While this vision of proximity-based cities holds significant potential to face several issues, including the adaptation to climate change, it also poses considerable challenges. These challenges, although, will be different for each case depending on the vulnerability conditions of the case of study (geomorphology, availability of resources, level of exposure, population). The implementation of such concepts raises multiple complex questions and considerations, requiring further research to unravel their full long-term implications.

Likewise, developing further research on how to permeate the housing sector with the multidimensional analysis of sustainability is vital for the advancement of the SDG agenda. The review shows that the housing sector plays a pivotal role in achieving sustainable urban development by addressing various dimensions such as social equity, affordable housing, and urban sustainability. One key area of focus is the broad promotion of affordable or social housing policies, which are crucial for ensuring adequate housing for all and reducing housing disparities. Research should deepen to identify effective strategies and mechanisms to facilitate the provision of affordable housing, including innovative financing models, public-private partnerships, and inclusive planning approaches.

Moreover, integrating urban sustainability assessment within a multiscale framework seems essential. This asks for evaluating the environmental, social, and economic impacts in different scales relevant to the city throughout its lifecycle. Research should explore how sustainability assessment tools and methodologies can be effectively integrated into decision-making processes, enabling policymakers, planners, and developers to make informed choices that align with sustainable development goals. Technology can catalyze supporting this evaluation and promoting sustainable practices. For instance, the utilization of digital twins, which are virtual replicas of physical spaces, can facilitate data-driven decision-making, optimize resource allocation, and enhance the efficiency of projects. Integrating spatial and public data, along with participatory mechanisms, can further enhance the understanding of community needs and preferences, fostering more inclusive and sustainable solutions. However, it is crucial to address the digital gap and the potential for intensifying social inequities, given that the availability of technology and the degree of technological development might differ from one city or country to another. Strategies to ensure equitable access to technology and digital literacy must be a priority to avoid deepening existing disparities and to safeguard that the benefits of technological innovations reach all segments of society.

On the other hand, further research on the role of the construction industry for the urban sustainability paradigm is crucial for advancing circular economies, and the decarbonization of the urban environments. The construction sector holds immense potential to drive sustainability, and exploring emerging topics such as Environmental, Social, and Governance (ESG) principles can shape a comprehensive framework for sustainability throughout the industry's lifecycle. Research can delve into understanding how the construction industry can adopt ESG practices to minimize environmental impacts, promote social equity, and improve institutional governance. This includes the need for research in the implementation of sustainable construction materials and

techniques, assessing the social implications of construction projects on local communities, and developing governance mechanisms that ensure smart decision-making. Furthermore, future research on how to integrate the concept of urban sustainability assessment can provide a holistic approach to evaluate the environmental, social, and economic aspects of development projects within the broader urban context. Future research can explore methodologies for assessing and benchmarking sustainability performance, developing indicators to measure circularity and resource efficiency, and identifying best practices for integrating sustainable principles throughout the urban development value chain.

5. Major findings

After presenting the results of the systematic review, in the following section the major findings are summarized to give new insights for future research needs and extend existing research.

5.1. Resilient urban planning

- Explore the long-term impact of the pandemic on the built environment and public health for informed decision-making and policymaking.
- Development of robust frameworks for transformative cities to withstand future shocks and the effects of climate change.
- Explore strategies to enhance the resilience of critical infrastructure systems in urban areas towards a future scenario of high uncertainty.

5.2. Social equity

- Examine the long-term impacts of the pandemic on social inequalities in urban areas and propose strategies to improve them.
- Deepen the analysis of the role of community engagement and innovative participatory mechanisms for urban development processes to ensure equitable outcomes.
- Explore innovative housing policies and financing models to promote effective affordable housing and reduce housing disparities.
- Examine potential mid- and long-term negative impacts, like the creation of urban gentrification, displacement, and social inequity, of current urban policies like 15-min cities, and propose strategies to mitigate negative impacts.
- Investigate the social and economic impacts of urban regeneration projects on local communities and develop inclusive mechanisms to promote their participation in the definition of such projects.
- Investigate the effects of the digital gap as a barrier to adopting smart technologies and urban digitalization and address the need for digital inclusion for vulnerable communities.

5.3. Healthy urban environments

- Develop new strategies to promote the re-naturalization of urban spaces as an integrated framework to improve ecosystem services and physical and mental well-being.
- Explore actions and policies for the long-term improvement of air quality, and decrease of pollution levels in urban areas, considering the lessons learned from the pandemic period.
- Develop approaches for integrated assessment of the relationship between urban form, access to nature, and public health outcomes.
- Examine the social determinants of health in mesoscale urban environments and develop interventions to promote health equity.
- Develop new mechanisms for maximizing the potential benefits of nature-based solutions.

5.4. Sustainable mobility

- Evaluate the long-term effects of the pandemic on mobility systems and investigate solutions for long-term recovery, with a focus on encouraging people to use public transportation.
- Examine mechanisms to integrate active transportation modes, such as walking and cycling, as main dimensions of urban mobility systems.
- Investigate quantitatively the penetration potential of innovative technologies, such as electric vehicles and shared mobility technologies, into existing public transport systems, along with their potential to enhance urban sustainability.
- Explore new mechanisms to promote the integration of transportation planning with urban planning, like the scalability of proximity-based development strategies, to create efficient and sustainable mobility systems.

5.5. Circular economies

- Explore strategies for promoting circular economy principles in the construction industry and reducing waste generation, by adopting the principles of ESG.
- Investigate the potential of sustainable materials and construction techniques to enhance resource efficiency in urban development.
- Assess the economic viability and social implications of large-scale circular economy practices in urban areas.
- Examine the role of digital technologies and data-driven approaches, like digital twins, in enabling circular economy solutions for smart societies.
- Investigate the integration of circular economy principles in urban planning and policy-making processes, through the development of multi-level governance structures.

By addressing these future research perspectives, scholars, policymakers, and urban planners can work towards developing sustainable and resilient cities in the current post-pandemic. These research directions are expected to contribute to the creation of evidence-based strategies, policies, and interventions that foster inclusive growth, reduce inequalities, and enhance the overall well-being of urban communities.

6. Conclusions

6.1. Final remarks

This study aims to elucidate the current state of academic research on the effects of the COVID-19 pandemic on the urban sustainability paradigm. The pandemic has had far-reaching impacts across society, and as a result, it has been approached from various academic disciplines. Given the multidisciplinary nature of urban issues, summarizing the body of knowledge poses a challenge. To address this, we conducted a systematic literature review, employing visualization and content analysis techniques to examine the literature on different topics.

By adopting a comprehensive review, it was possible to include a wide range of literature sources that address the same topic. Through visualization, a geographic disparity in knowledge production was observed, with limited academic work produced in developing countries, which at the same time have been disproportionately impacted by the pandemic. In the literature, resilience emerged as a cross-cutting concept closely related to urban sustainability, although a consistent definition of resilience in this context was lacking. This raises concerns about the explicit conceptualization of resilience in the literature produced during the pandemic years, particularly regarding transformative resilience as a framework to reconsider perspectives such as coping with shocks or returning to a previous state. It is proposed that future research should explore the vision of urban resilience in the post-

pandemic, considering its various dimensions within the context of urban sustainability.

Moreover, while resilience is crucial for the sustainability of cities in the post-pandemic period, there is still a need to integrate these topics into the mitigation and adaptation to climate change in future research. This analysis identified five transversal key topics impacted by the pandemic within the urban sustainability framework: resilient urban planning, sustainable mobility, healthy urban environments, social equity, and circular economies. Across the topics, it was retrieved that the implications disproportionately affect vulnerable populations, including developing countries, minorities, and marginalized communities, indicating the need to focus on the inclusion of these communities in the current post-pandemic context. Even if there is a need to foster the sustainability transition worldwide, it is important to acknowledge that the current sustainability conditions are not the same in the developing world. There is a huge challenge in promoting the transition in the developing world to balance the conditions and leave no one behind.

Furthermore, the housing sector emerged across all the topics discussed in the analysis. The reviewed literature exposed its significant role as a critical component of the urban system, and its impact on urban sustainability and urban decarbonization. Poor housing conditions were associated with intensified negative health impacts during the pandemic, both physically and mentally. The built environment, as an extension of housing conditions, was identified as a driver of these impacts. Access to services, public green areas, and adequate infrastructure were identified as dimensions with significant deficits during lockdown periods. Therefore, it was disclaimed the need for comprehensive research on sustainability assessment, with a focus on vulnerable communities, employing a multiscale approach that encompasses the links between housing and the built environment.

6.2. Limitations

The study has certain limitations that should be acknowledged. The analysis focused on examining the impacts of the COVID-19 pandemic on urban sustainability, and during the content analysis, it was summarized into five categories. Although efforts were made to include a wide range of relevant literature, it is possible that some relevant studies or perspectives were left out. The study mainly relied on peer-reviewed academic literature, which may introduce biases and exclude valuable visions from other sources of literature, including reports, policy analyses, and grey literature. These additional sources could provide practical insights and community-level responses that were not fully incorporated in this review. Furthermore, the study was conducted up to February 2023, and more studies have been published since then. As presented in Fig. 4, contextual variations across regions, cities, and communities are relevant in the study of this field. The context of the topics discussed should be considered when interpreting and generalizing the findings, as the impacts of the pandemic were influenced by diverse place-based factors such as socioeconomic conditions, healthcare systems, governance structures, and cultural dynamics.

6.3. Implications

Despite stated limitations, this study contributes to the existing knowledge and aims to stimulate further research and actions toward resilient, sustainable, safe, and inclusive cities in the post-pandemic era, as it illustrates a summary of the available knowledge regarding sustainable cities and its systemic dimension by visualizing the connections among the studies developed on this topic. In this way, this work presents to the interested actors a compilation of knowledge about the impacts that the pandemic brought to the urban life under different conditions, and socioeconomic contexts. This exercise allows to raise awareness about the diverse issues that have been faced, and potential barriers in the progress for sustainable development. Likewise, the statement of future challenges and research needs serves as roadmap for the actors (researchers, policy makers, urban planners) to guide efforts in the near future and leverage the development of the urban sustainability agenda.

These efforts could be materialized in different ways based on the roles of the actors. Public servants could support this with the assignment of budget destinated to fund new research, fund programs to address and break social gaps, for the promotion of businesses focused in tackling these challenges, and other financial mechanisms supporting the sustainable transition. As well, from the public sector it is needed to boost innovation in the governance mechanisms that rule the development process. In a scenario of high uncertainty and constant change it is required to have an strong governance structure with enough capacity to act and integrate actors towards one objective, but also with enough flexibility to take action and respond to different circumstances. Similarly, from the private sector it is necessary to promote and strengthen innovation, and new business models aligned with the sustainability agenda and the evolving needs of the society. Furthermore, the involvement of the citizens in the development process seems crucial for the efficiency of these efforts. Although it is necessary to develop new participatory mechanisms, it is also needed to raise awareness the citizens about these issues, and the importance of taking an active role and getting involved in the development process of the cities.

Funding

This research was funded through a Borsa di Studio for Doctorate students granted by the Politecnico di Torino and Compagnia di San Paolo.

CRediT authorship contribution statement

Jhon Ricardo Escorcia Hernández: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Visualization. **Sara Torabi Moghadam:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Ayyoob Sharifi:** Conceptualization, Writing – review & editing, Supervision. **Patrizia Lombardi:** Writing – review & editing, Supervision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used GPT-3 and Paperpal, AI-assisted tools to make style corrections and improve the readability of the document. After using these tools, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

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

Data availability

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

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