The role of urban resilience in research and its contribution to sustainability

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ARTICLE INFO

ABSTRACT

Urban resilience is an emergent concept that is receiving an increasing attention. Its definition is linked with the ability of an urban system to resist, maintain continuity and recover through all stresses while adapting and transforming towards sustainability. The aim of this study is two-fold. First, we analyse the research output on urban resilience using bibliometric techniques and Web of Science (WoS) in order to define the scope and identify topics in the urban resilience literature. CiteSpace software is used to establish the intellectual framework. Second, their contribution to sustainability dimensions and Sustainable Development Goals (SDGs) based on the research output is explored.

For that purpose, we examined 1014 publications during the period 1998–2020. The findings reveal urban resilience literature has grown since the 2009.A specialization in recent years from more theoretical research to a more practical is identified. In terms of contribution towards sustainability, the findings show the number of publications that directly address sustainability is scarce and more balanced to environmental and social perspectives. These findings can provide a better understanding of the patterns and trends in the field and provides first evidence of the contribution of academic research on urban resilience to sustainability.

1. Introduction

The concept of resilience has gained increasing interest in policy and urban planning in the last decades (Moser et al., 2019). Considering that 56.2% of the people in the world live in urban areas (United Nations, 2018), and the multiple hazards related to climate and other global environmental changes they have to face up, urban resilience has become a priority for cities' governments.

The scientific literature about urban resilience has also grown up rapidly (Nunes et al., 2019). The origin of urban resilience theory can be found in Holling's seminal paper (1973) on the resilience of ecological systems (Meerow et al., 2016). He defined resilience as 'A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables' (Holling, 1973, p.14). Since then, resilience has been defined in many different ways (Meerow et al., 2016; Schiappacasse &

Müller, 2018) and used in a wide variety of research areas, such as environmental sciences, ecology, engineering and psychology (Xue et al., 2018). Three main interpretations dominate the literature: engineering, ecological and socio-ecological (Davoudi et al., 2012; Folke, 2006). Engineering resilience refers to the capacity of a system to return to equilibrium after disturbance (Pimm, 1991). Ecological resilience is the capacity to absorb disturbance and maintain main functions and structures while undergoing change (Folke, 2006). Socio-ecological resilience is the ability of complex socio-ecological systems to change, adapt, and transform in response to stresses and strains (Folke et al., 2010). In this paper we adopt Meerow et al.'s (2016, p.39) definition of urban resilience: 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'. This definition

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includes and relates the three main interpretations of resilience so is wide enough to comprise all the literature about urban resilience.

The concept of sustainability, although some authors places its origins in the 1970s or even before (Mebratu, 1998; Mitlin, 1992), became popular among academics, practitioners and politicians after the report of the World Commission on Environment and Development *Our Common Future*. In this report sustainable development is defined as "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs…" (WCED, 1987, p. 8). Despite its success, the concept of sustainable development has received considerable criticisms for been a human centred approach (Shahadu, 2016) frequently linked to the hegemonic economist vision of economic growth (Naredo, 2004; Ruggerio, 2021) and for its ambiguity and diversity of interpretations (Mebratu, 1998; Naredo, 2004).

The terms sustainable development and sustainability are commonly used as synonyms (Olawumi & Chan, 2018; Ruggerio, 2021; Shahadu, 2016); however, some authors suggest that they are different (Olawumi & Chan, 2018) and prefer to use the term sustainability to separate the concept from the notion of economic growth (Naredo, 2004). Nevertheless, there is not a consensus about the definition of sustainability and interpretations go from the 'weak' sustainability to the 'strong' sustainability (Naredo, 2004; Ruggerio, 2021). The first one is based on economic principles and is similar to the concept of sustainable development, whereas the latter is based on ecological principles. The main concern of the strong sustainability is the health of ecosystems that sustain life (human and non-human) (Naredo, 2004).

Despite the lack of consensus about the concept of sustainability Ruggerio (2021, p. 9) suggests that any sustainability definition should include three criteria: "a) account for the complexity of socio-ecological systems by encompassing economic, ecological, social and political factors; b) account for intergenerational and intragenerational equity; and c) address the hierarchical organization of nature, that is, acknowledge the feedback between the socio-ecological systems and their surroundings". He also states that socio-ecological systems are in constant change, so they can follow a path towards sustainability or unsustainability but they cannot be categorized as sustainable. This statement contradicts the traditional conceptualization of sustainability as a durable and stable state that, once achieved, could persist for generations (Ahern, 2011; Meerow et al., 2016).

In this paper we used the term sustainability, instead of sustainable development, applied to cities. In this regard, and according to Ruggerio's (2021) criteria, urban sustainability is an ongoing process 'to better attend to human well-being, more effectively to encourage and to benefit from ecological processes and integrity, and better to promote (intergenerational and intragenerational) social equity' (Pickett et al., 2013, p. S13). A city cannot be sustainable in the sense of being self-sufficient, but can become more sustainable acknowledging its interdependence of the socio-ecological systems beyond urban borders (Pickett et al., 2013).

Whereas academic interest in urban resilience has grown, urban sustainability research has declined (Zhang & Li, 2018). Resilience is replacing sustainability in many discourses; however, they are conceptually different (Redman, 2014). For example, sustainability is commonly implemented through increasing efficiency, which could result in reducing redundancy, one key characteristic of systems' resilience (Elmqvist et al., 2019; Meerow et al., 2016; Redman, 2014). Whereas in the sustainability literature there is a strong emphasis on balancing environmental, social and economic aspects, it does not usually occur in resilience research (Meerow & Newell, 2015) and practice (Chelleri et al., 2015). Moreover, whereas sustainability is inherently normative and positive, is not the case for the resilience concept. Highly resilient cities may be locked into an undesirable state (Elmqvist et al., 2013). Resilience, when treated in isolation, may lead to unsustainable developmental pathways (Elmqvist et al., 2019; Zhang & Li, 2018).

For other authors, resilience is a subfield of research within sustainability science (Shahadu, 2016) or are seen as complementary

approaches that should be jointly considered in political agendas (Chelleri et al., 2015; Elmqvist et al., 2019; Zhang & Li, 2018). Elmqvist et al. (2019, p.270) propose to 'describe urban systems as having multiple possible development pathways or trajectories' to sustainability. Resilience would be 'the capacity to adhere to, or simply strengthen, a specific pathway', that is, the 'capacity to deal with uncertainties, continue to develop while maintaining functions and stay on the same trajectory'. A framework that integrates resilience and sustainability requires recognizing cross-scale implications or trade-offs among spatial and temporal scales (i.e. avoiding that increasing resilience in one spatial or temporal scale erodes resilience in other scales) (Chelleri et al., 2015), through questions related to resilience why? For whom? Of what? To what? When? and Where? (Meerow and Newell, 2019).

The Agenda 2030 for Sustainable Development (United Nations, 2015) and its 17 Sustainable Development Goals (SDGs), adopted by all United Nations Members, is a plan of action for sustainability that is being implemented at national (Sachs et al., 2021) and local scales (Cavalli et al., 2020; ICS and SDSN, 2021; REDS, 2020) in many countries in the world. Resilience is explicitly mentioned in six of the objectives, being SDG 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" the one that specifically refers to urban sustainability and resilience. Resilience is, therefore, acknowledged as a necessary condition in the path towards sustainability (Acuti et al., 2020).

Previous bibliometric studies have analyzed the topic of urban resilience. Table 1 summarizes the main studies, the search strategies, the databases used and the number of results obtained. Meerow et al. (2016) were the first ones to carry out a bibliometric analysis in urban resilience. They focused on urban resilience definitions, but also, they identified the most influential studies and analyse the theoretical origins and development of the research area. Pu and Qiu (2016) carried out a more extensive review to trace research basements and trajectories, emerging trends and new developments on urban resilience. Nunes et al.'s (2019) bibliometric analysis had a wider coverage. Instead of using the expressions 'urban resilience', 'resilient city' or 'resilient cities', as the previous studies do, they chose to search the single words 'urban', 'resilience', 'cities' and 'resilient' with a result of more than 4000 publications. Their objectives were to analyse how urban resilience evolved in urban development, planning and management, in what way the different research areas contributed to the development of urban resilience and how urban resilience evolved conceptually. The most recent bibliometric study on urban resilience is Yang et al.'s (2021) paper about the resilient city. They carried out a temporal and spatial analysis of the most recent urban resilience literature (2010–2019). However, none of those studies values the contribution of the urban resilience literature towards the traditional dimensions of sustainability (economic, environmental and social) (Elkington, 1998; Lozano, 2008)

Table 1

Summary of the bibliometric studies in urban resilience, search strategies, databases and number of results.

Authors and publication year	Search strategy used	No. results and database
Meerow, S., Newell, J. P. & Stults, M. (2016)	"urban resilience" and "resilient cities"	172 (Web of Science and Scopus); period (1973–2013)
Pu, B., &Qiu, Y. (2016).	"urban resilience" or "resilient city" or "resilient cities"	1296 (Web of Science); period (1986-August 2015)
Nunes D. M., Tomé, A. &Pinheiro M. D. (2019).	"urban", "resilience", "cities" and "resilient" in Topic (title, abstract or keywords)	4180 (Web of Science); period (1984-February 2018)
Yang, Q., Yang, D., Li, P., Liang, S. &Zhang Z. (2021)	"resilience and urban", "resilience and city", "resilient and urban", "resilient and city" in Keywords	1249 (Web of Science); period (2010–2019)

and SDGs, a gap this study will fill in.

This study aims to analyse the research output on urban resilience and their contribution to sustainability dimensions and SDGs. This bibliometric analysis was guided by two research questions:

– RQ1- Which research areas and which research topics comprise the research core in urban resilience? Which topics and publications have attracted attention and for how long are labelled as 'landmark papers and key topics'? This question seeks to understand when the concept appears firstly published on academic research and the areas (based on the Web of Science categories) in which this topic has been published at journal level. In addition, the main research topics studied in the scientific literature at the publication level are analyzed, as well as landmark papers and key topics.
– RQ2- What is the contribution of this output towards the dimensions of sustainability and SDGs? In this regard, no other previous study has analyzed this alignment towards the goals and their contribution to the main pillars of sustainability.

In this paper we added new keywords to the search strategy than previous studies to also capture publications that focus on neighbourhood resilience, considering that neighborhoods are specific parts of the urban environment, and resilience thinking associated with cities. This research also complements other bibliometric reviews because it analyses how the literature on urban resilience contributes to sustainability and SDGs.

The rest of the paper is organised into three different sections. In the 'Materials and methods' section, we describe the data sources and explain the analytical methods and technical procedures, as well as the indicators used. The findings are presented in the 'Results and discussion' section. Finally, the paper ends with the 'Conclusions' of the results, with suggestions for further research.

2. Materials and methods

2.1. Data collection and search strategy

We conducted a bibliometric analysis to analyse the research output of urban resilience. Data was downloaded on 29 September 2020 from Clarivate Analytics' Web of Science (WoS) Core Collection (SCI, SSCI, A&HCI) and Proceedings databases. We used the following combination of key words in the 'Topic' area (abstract, title, and keywords): TS = ("urban* resilien*" OR "city resilien*" OR "resilien* city" OR "cities resilien*" OR "resilien* cities" OR "neighbourhood* resilience") OR ("resilience thinking" AND (cities OR city)). In this paper, we combined different search strategies from previous works (see Meerow et al., 2016; Pu & Qiu, 2016). The search strategy used is broad enough to capture all the publications on this topic. The term 'community resilience' was omitted because it provides false positives (publications unrelated to urban resilience) and, conceptually, it is not associated exclusively within the cities (e.g. in rural districts or coastal community resilience in rivers). All types of publications published were included and no temporal limitations were defined in the search strategy in WoS.

2.2. Bibliometric indicators

The final dataset was analyzed using the following indicators:

1) Research patterns
   – **Yearly trend** in scientific output in urban resilience.
   – **Output by countries**: absolute values and 'Activity Index' (AI) (Schubert & Braun, 1986). The Activity Index is used to analyse the degree of relative specialization of the countries in urban resilience topic. The indicator represents the percentage of contribution of each country to the total WoS production compared to the percentage of contribution in the analyzed topic.

– **Concentration of the articles in a few journals**. As some bibliometric laws indicate (e.g. Bradford's (1934) law), many articles in a subject field are published by a few sources (e.g. journals), concentrating the output in core journals. This concentration of articles is related to the emergence of a discipline. To detect this concentration, we used a tertile calculation (i.e. two points that divide an ordered distribution into three parts) with all the journals ranked by frequency. By using this classification, two three-year subperiods from 2015, coinciding with the launch of the SDGs, were considered. The first one includes publications from 2015 until 2017, and the second from 2018 to 2020.

2) Identifying research areas and topics
   – **Co-occurrence of WoS categories.** All books and journals included in the main collection of this database are assigned to at least one of five large categories (Arts and Humanities; Life Sciences and Biomedicine; Physical Sciences; Social Sciences; Technology) which in turn are divided into multiple research areas. This allows identifying thematic clusters (e.g. relations between areas) within the scientific landscape. We used VOSviewer tool to identify the number of publications in each cluster and the inter-journal relationships. Each node represents a WoS category and their size is associated to the number of publications, whereas the edges are the co-occurrences between two terms (the more appear together, the higher strength value) and colours indicate a greater affinity of topics. In addition, the normalization method used was the Ling/Long modularity (more details in Chen, 2016).
   – References and keywords **co-citation cluster analysis** was used to detect research topics of urban resilience literature using CiteSpace software. To detect the different topics (and by extension the different nodes that compose each cluster), the criterion was the g-index (Egghe, 2006) threshold value in the yearly records, based on the distribution of citations received by each publication. In addition, a correction factor of 5 to calculate the reference co-citation value, which allows to select the largest number of highly cited publications for the analysis. The different nodes are co-cited publications and the edges represent the co-citation links. The labels of each cluster were determined using the log-likelihood ratio (LLR) by considering the abstracts information. The clustering quality is measured in terms of the modularity value (i.e. the higher that value, the more distinctly defined is the cluster). The citation burst on each node is a concept associated with a change of a variable's value (e.g. citation intensity) in a relatively short time and indicates the change in usage frequency. That is, it values the degree of citation intensity (in order to determine a hot topic) for a given reference or keyword.

3) Identifying landmark papers and key topics (i.e. publications and keywords with a sudden increase in the number of citations) on the field.
   – **Keywords bursts citation.** We used Kleinberg's (2003) algorithm to analyse the usage frequency of keywords (i.e. burst strength) in order to determine the hotness of a topic.

4) Sustainability contribution.
   – **Sustainability dimensions interrelations.** In order to determine the contribution towards sustainability, the title, abstract, and keywords from the publications of this study were manually checked and classified into the dimensions of sustainability. Although some authors make other classifications (e.g. the three mentioned and the political-institutional) (Ruggerio, 2021) we chose the most extended one (Elkington, 1998; Lozano, 2008). First, those publications that included the keywords 'sustainability' or 'sustainable' were selected. Second, these publications were classified in social, economic and environmental sustainability. As an example, if a publication includes 'social vulnerability' as a keyword it is considered 'social sustainability' whereas 'regional climate model' is for the environmental. This allows having the same publication classified in more than one category.

– **Contribution to Sustainable Development Goals (SDGs)**. For this analysis, the tool OSDG (https://osdg.ai/), which classifies text and publications in the different goals, was used. This tool builds an integrated ontology from the feature sets identified in previous research (open-source ontologies) and matches the ontology items (see Bautista-Puig, 2020) to the topics using machine learning models and Microsoft Academic Graph (more details in Pukelis et al., 2020).SDGs assigned to publications could be multiple and the relevance of an SDG is interpreted as being strong or moderate. In addition, it only works with publications with a DOI number. In our study, 921 publications have a DOI number (90.82%).

3. Results and discussion

This section presents a descriptive analysis of the research output as well as a discussion of the results on urban resilience divided into: research patterns (yearly trend, output by countries, concentration of the articles in a few journals), identification of research areas, topics, landmark papers and key topics and sustainability contribution.

3.1. Research patterns

3.1.1. Yearly trend

A total of 1014 records were retrieved during the period 1998 to September 2020: 689 (67.94%) scientific articles, 220 (21.69%) proceeding papers, and 142 (14%) other typologies (i.e. reviews, book chapters). Resilience has evolved significantly as a research topic since its initial appearance in the literature in 1973 (Xu & Marinova, 2013; Xue et al., 2018). However, in our dataset, the first document identified in the scientific literature in which 'urban resilience' was mentioned was in the special issue entitled 'Butte: resilient city with an unforgettable past' (Murphy, 1998). The evolution of records by year of publication is graphed in Fig. 1. Output on this topic rose from 1 publication in 1998 to 180 in 2020 and 74.85% of the publications were published in the last 5 years of the time period considered. The cumulative average growth rate

shows an increasing tendency during the period (35.73% of all typologies of publications from 2003 to 2020).

Our results show that the concepts of resilient cities and urban resilience have mainly appeared in the literature during the present century, with a rapid growth since 2010. This tendency is also reflected in previous studies (Nunes et al., 2019; Pu & Qiu, 2016; Yang et al., 2021). In 2018, 2019 and 2020 there is a similar number of publications. It seems that rather than being a stabilization of urban resilience literature (Yang et al., 2021), it is a stagnation between 2018 and 2019. We only analyzed publications published until September 2020 so probably the number of publications is higher during this year than in 2019 mainly due to the delay in WoS indexation.

3.1.2. Output by countries

Fig. 2 shows the geographical distribution of urban resilience publications. The most productive countries on this topic were the United States (213 publications, 21%), followed by the United Kingdom (136 publications, 13.41%), China (88 publications, 8.68%), Australia (76 publications, 7.50%) and Germany (59 publications, 5.8%). Despite the potential influence of language and indexation biases in the Web of Science (Newell & Cousins, 2015), the output by countries underlines a clear interest in the topic by the research communities of those countries. Pu and Qiu (2016) and Yang et al. (2021) also pointed the US and UK as the countries that made the major contribution to the topic of urban resilience, while China, Australia and Germany appear in the list of the top 10 countries but in a different order. Although this is not surprising (bigger countries produce more publications) this concurs with previous studies that stated sustainability-oriented research is mostly produced by authors from developed countries (e.g. Olawumi & Chan, 2018). Although developed countries have a larger production in urban resilience (Pu & Qiu, 2016), the lack of a clearly defined concentration of the output in geographical terms stresses the transnational relevance of the topic. However, all these papers have mainly analyzed publications found in Web of Science and Scopus written in English, so a bibliometric analysis using other databases and including publications in other languages could produce different results (Amano et al., 2016).
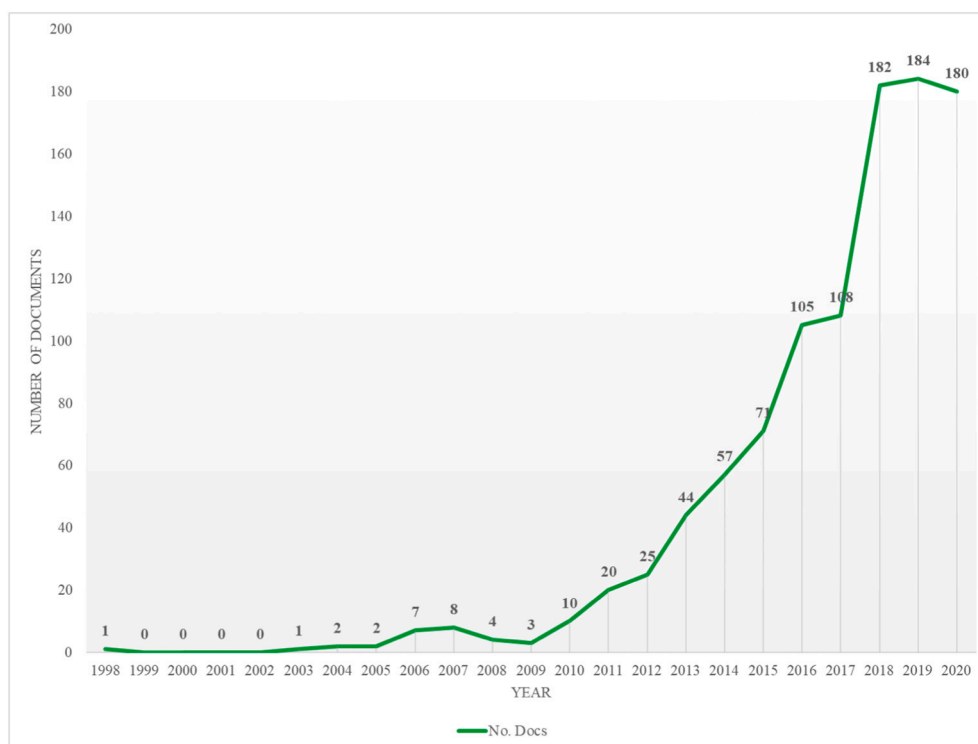

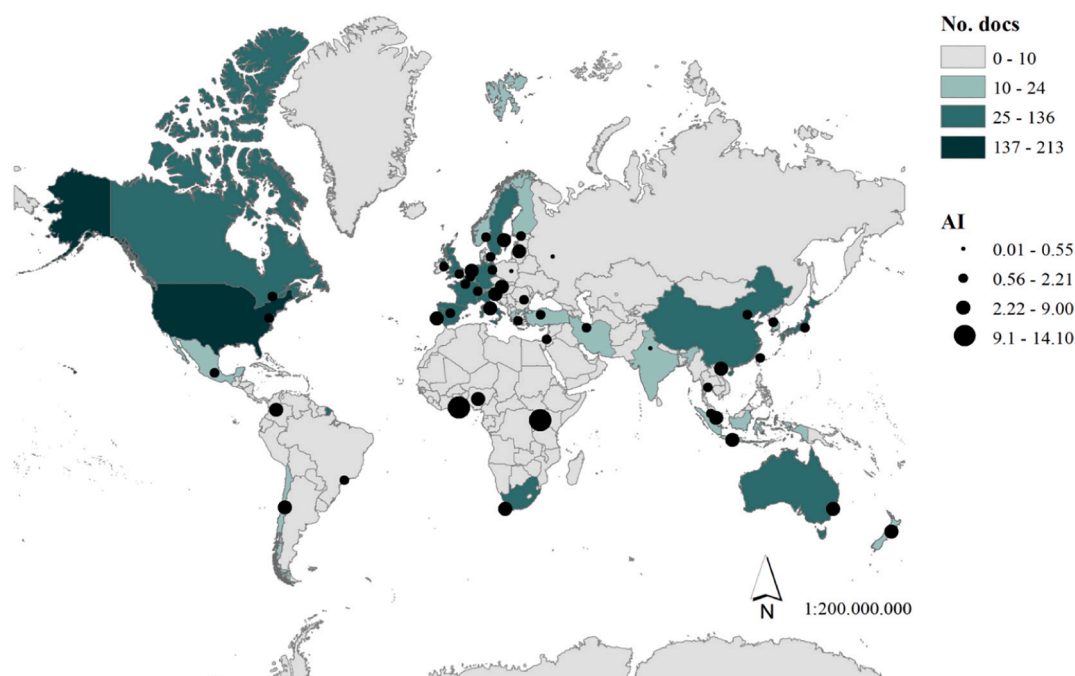**Fig. 1.** Yearly evolution of the publications in urban resilience.

Fig. 2. Geographic distribution of scientific publications and AI (countries with 10 > publications).

Regarding the specialization on this topic production of a specific country with respect to other countries or to the whole world (measured by the AI), Indonesia is leading the specialization in the whole period (20 publications and AI of 8.69), Slovenia ($n = 11$, AI = 5.53), South Africa ($n = 28$, AI = 4.79) and Portugal ($n = 33$, AI = 4.6) stand out in specialization. Only countries with at least 10 publications were considered. This might be plausible related to some actions, e.g. World Bank initiated the building urban resilience in East Asia program in 2012 (Gunawan et al., 2015).

3.1.3. Creation of a new research field

Table 2 shows the distribution of articles on urban resilience by journal, divided by tertiles according the decreasingly ordered list of articles per journal. Tertile 1 accumulates the first 33% of articles. In period 1that percentage of articles is concentrated in 13 journals, the core of most productive journals on urban resilience. These 13 journals represent the 8.07% of the total number of journals in the period (161). For the same tertile, in the second period, the number of journals that concentrate the first 33% of urban resilience articles is 8, only the 3.35% of the total number of journals for that period, which is also greater than in the first period (239). This high degree of concentration indicates the emergence of urban resilience as a field of study, concurring with Bradford law (1934). This observation shows a concentration process: certain journals become specialized in the topic whereas others become less active in the field. Some journals significantly increase their contribution to the field of urban resilience. At the same time, in the

third tertile, the opposite takes place: the number of journals is greater, implying that new publications begin publishing on the topic of urban resilience. Specialized journals consolidate their position as reference publications attracting papers on the topic and, at the same time, resilience begins to be studied from other fields.

Table 3 shows the number of articles and accumulated % (of the total number of articles in each period). Four journals are common as the most productive journals in both periods: *Sustainability*, *Cities*, *International Journal of Disaster Risk Reduction* and *Urban Studies*. These can be considered both pioneers and specialized journals in the field and reinforces the output that urban resilience is a field studied from a wide variety of research areas.

3.2. Identifying research areas and topics

3.2.1. Identifying research areas

The research areas can be visualized in Fig. 3. Each journal is associated to a research area related to the journals in the WoS database. The analysis identified 47 categories (nodes) with 217 links (edges) and 6 clusters were created (Table 4). The size of each circle is proportional to the number of publications assigned to each category. The highest-ranking categories were: 'Environmental Sciences' (occurrence of 296), 'Environmental Studies' (287), 'Urban Studies' (214) which are the major research areas contributing to the development of urban resilience (Pu & Qiu, 2016; Yang et al., 2021), while a large set of inter-related areas are also present as contributors, such as geography, water resources and regional & urban planning.

The largest cluster is #1 "Engineering and technology" followed by the cluster #2 "Environmental and urban studies". The fact that the largest cluster (i.e. the one with the highest number of nodes) comprises the engineering and technological research areas, reinforces the idea that they had also importantly contributed to the development of the resilience concept in general (Xue et al., 2018) and urban resilience in particular (Nunes et al., 2019; Yang et al., 2021), especially in the assessment of urban resilience (Suárez et al., 2020). However, if we consider the number of links per paper the largest cluster is #5 "Environmental and sustainability sciences" (#link strength$_{avg}$ = 279.75), denoting a stronger connection between the articles on these categories.
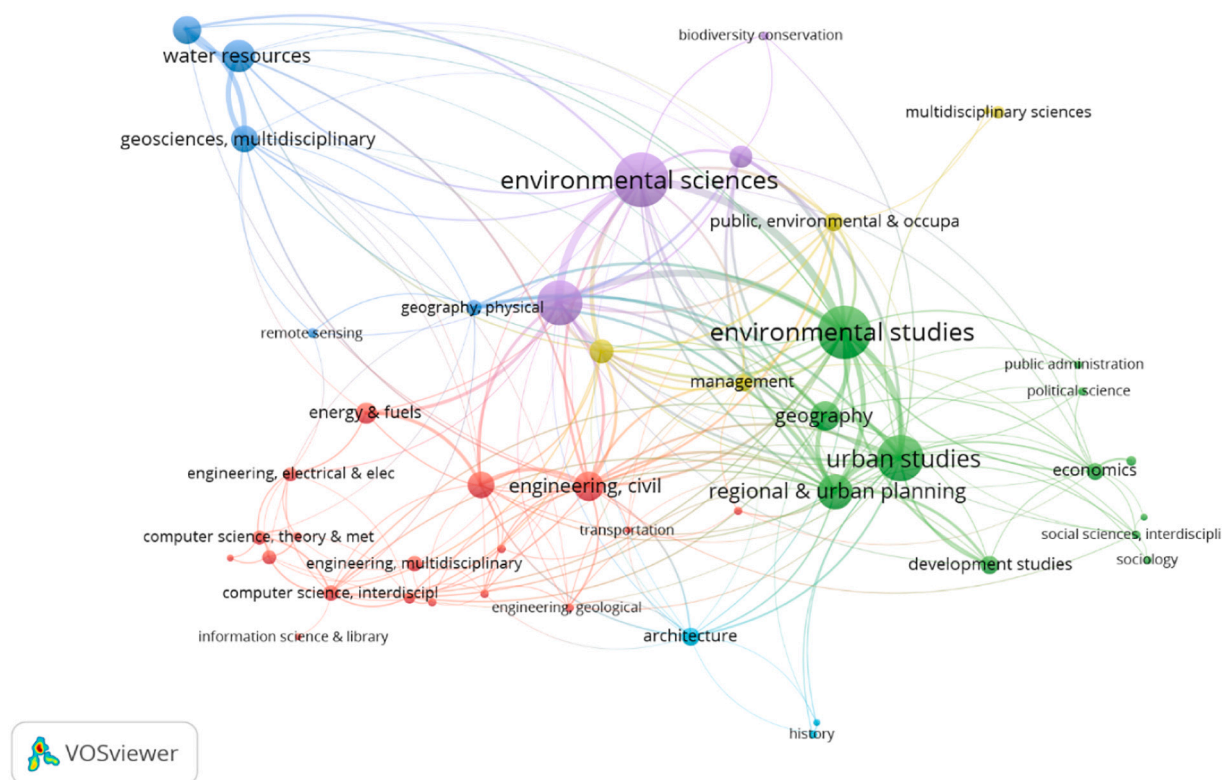
Table 2
Concentration of articles on urban resilience by number of journals in the two periods analyzed. Distribution by tertiles.

	Period 1 (2015–2017)		Period 2 (2018–2020)	
	Number of journals	Percentage of journals	Number of journals	Percentage of journals
Tertile 1	13	8.07	8	3.35
Tertile 2	51	31.67	54	22.59
Tertile 3	97	60.25	177	74.06
Total number of journals	161	N/A	239	N/A

Table 3

Journals accumulating up to 33% of the articles in the field of urban resilience in periods 1 and 2 (common journals in bold).

Period 1 (2015–2017)			Period 2 (2018–2020)		
Journal	Grand Total	Accum. %	Journal	Grand Total	Accum. %
Sustainability	20	7.04	**Sustainability**	66	12.08
Scientia Iranica	13	11.61	**Cities**	26	16.84
Cities	8	14.43	**International Journal of Disaster Risk Reduction**	18	20.14
Environment And Urbanization	6	16.54	Environmental Science &Policy	17	23.26
Landscape And Urban Planning	6	18.66	Sustainable Cities And Society	15	26
Natural Hazards	6	20.77	7th International Conference on Building Resilience: Using Scientific Knowledge To Inform Policy And Practice In Disaster Risk Reduction	12	28.20
Building Research And Information	5	22.53	**Urban Studies**	11	30.21
European Planning Studies	5	24.29	Journal of CleanerProduction	9	31.86
International Journal of Disaster Risk Reduction	5	26.05			
Urban Studies	5	27.81			
Current Opinion in Environmental Sustainability	4	29.22			
Ecosystem Services	4	30.63			
Land Use Policy	4	32.04			

Fig. 3. Co-occurrence Web of Science (WoS) categories for urban resilience with a frequency of 5 (nodes = WoS categories; node size = proportional to publications on each node; edges = co-occurrence of subject categories).

3.2.2. Identifying research topics

Fig. 4 shows the co-occurrence of references and keywords from the publications analyzed in this study; moreover, other labelling results are presented (Table A.1, Appendix A). According to the criteria identified, 1010 references meet the g-index criterion (correction factor of 5) with a total of 236 nodes and 467 edges. The network has high modularity (0.7699). This value indicates that the different clusters are well-defined in terms of the co-citation clusters. The references and keywords with high burst values are shown as red circles, while the purple colour represent high betweenness values. The largest cluster (according to the co-occurrence values) is #0 "Enabling strategies". It includes terms related with climate change, adaptation or ethics, among others. It is followed by the cluster #1 'New model', #2 'Urban socio-ecological' and

#3 'Cities transition'. The #0 cluster, 'Enabling strategies' is the most recent (2016) followed by #7 'Enhancing resilience' (2015) and #5 'Cross-boundary learning' (2014). The oldest is #6 'Resilient city' from 2009. Regarding the silhouette value the clusters #6 and #3 have a value close to 1. It means that they are more distinctly defined (Table A.1).

Fig. 5 shows a timeline of the topics on urban resilience. The clusters are arranged on a horizontal timeline and ranked by frequency in descending order (Chen, 2016). The curves are citation links. Moreover, large nodes are of particular interest, because they are highly cited or have citation bursts or both. It can be observed that #6 and #1 clusters are pioneering specialities that last longer, and the rest of the clusters were formed later. The most recently evolving topic within urban

Table 4
Summary table with cluster information.

Cluster	Label	#nodes	#linkstrength$_{avg}$	Top-3 Most-frequent WC and frequency
#1	Engineering and technology	18	37.83	engineering, civil (87); construction & building technology (74); energy, fuels (48)
#2	Environmental and urban studies	12	142.83	environmental studies (287); urban studies (214); regional & urban planning (124)
#3	Earth sciences	5	107.40	water resources (102); meteorology & atmospheric sciences (81); geosciences, multidisciplinary (70)
#4	Environmental engineering and public health	5	77.20	engineering, environmental (59); public, environmental & occupational health (36); management (29)
#5	Environmental and sustainability sciences	4	279.75	environmental sciences (296); green & sustainable science & technology (205); ecology (54)
#6	Architecture and history	3	21.00	architecture (35); history (8); history of social sciences (5)

Note: Labels are assigned based on the categories within its cluster.

resilience, 'enabling strategies', points towards a practical turn in the orientation of the related research, evolving from more abstract terms to the development of implementation strategies. Climate change is one of the terms that compound this cluster suggesting that urban resilience to climate hazards is being paid more attention in academic research than other type of risks (Nüchter et al., 2021), even though cities have to deal with a wide range of hazards (Cambridge Centre for Risk Studies, 2015).

Some clusters are short-lived (e.g. #7). The evolution of the topics on urban resilience across time reflects a wide variety of short-lived terms, together with remarkable bursts in the emergence of specific topics. This is congruent with the analyses of citation bursts that show short time spans of two year together with a few longer periods up to 9 years.

3.3. Identification of landmark papers and key topics on the field

Table 5 shows the burst detection on the keywords from all the dataset. Thirteen different bursting keywords according to CiteSpace software were found. 'Urban planning' (7.48), 'hazard' (6.06), 'resilient city' (5.06), or 'biodiversity' (4.9) have the highest citation burst values. The keyword China (3.41) is also one of the most cited in recent years in the urban resilience literature, which suggests that there is a growing interest on the field in this country. However, if we check this information temporally, the earliest keywords and with longest time spans (in red) are 'resilient city', 'biodiversity', 'adaptation' and 'planning'. These keywords are being replaced by others such as 'urban planning', 'hazard', 'green roof', 'temperature' or 'disaster'. These results suggest a specialization on the field of urban resilience from a more theoretical perspective towards the development of resilience strategies to cope with specific threats. At the same time that the burst of the keyword 'adaptation' ends, the burst for 'complexity' begins. A possible explanation is a switch in resilience conceptualization from an ecological point of view, where adaptation is crucial, to a socio-ecological perspective that assumes that complex systems are in constant change
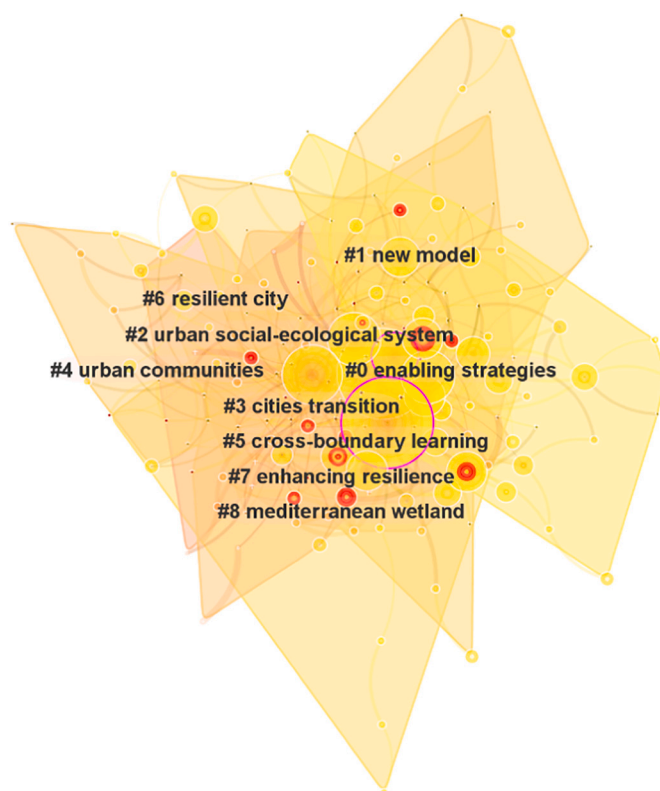

Fig. 4. G-index generated landscape of the co-cited references and keywords in urban resilience (1998–2020). Convex hulls represent different clusters, and the nodes are proportional to co-cited references and keywords. Colours of the clusters indicate the year (yellow are more recent and purple are older). Red circles indicate the bursts. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and transformability becomes a key strategy of the resilient city (Folke, 2006). Moreover, 'transformability' begins to appear in the title of some of the most recent cited references (Table A.2). Similar trends are also mentioned in the work of Yang et al. (2021).

This technique was also used for the references in the publications of the dataset. The 24 references with the highest burst are listed in Table A.2. The minimum duration of the burst is two years (Bozza et al., 2015; Colding, 2007; Folke et al., 2010; MacKinnon & Derickson, 2013; Pelling, 2010; Walker et al., 2006) and the maximum rise to nine (Newman et al., 2009; Vale & Campanella, 2005). According to these results, Vale and Campanella (2005) is the pioneering book and it focuses on how modern cities recover from a disaster. Just five years later, Newman et al. (2009) published a book in which they argue that intelligent planning and visionary leadership can help cities to overcome crisis. Both books have the highest number of citations (at this writing,[1] 937 and 909 respectively). However, Folke's (2006) paper has the highest burst strength (8.7), which presents the origins of the resilience perspective and an overview over time. This paper is widely cited (6785 citations). The second paper with the highest strength (7.28) is Cutter et al. (2008) who propose a new framework (i.e. the disaster resilience of place model) for measuring disaster resilience (3087 citations).

The most recent publications are more related to quantification (e.g. Bozza et al., 2015; Cimellaro et al., 2010), resilience thinking (e.g. Cutter et al., 2010; Folke et al., 2010) or new urban resilience approaches (e.g. collaborative learning for improving urban resilience, Toubin et al., 2015).

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[1] The number of citations of these publications was obtained from the Google Scholar database on 25 November 2020
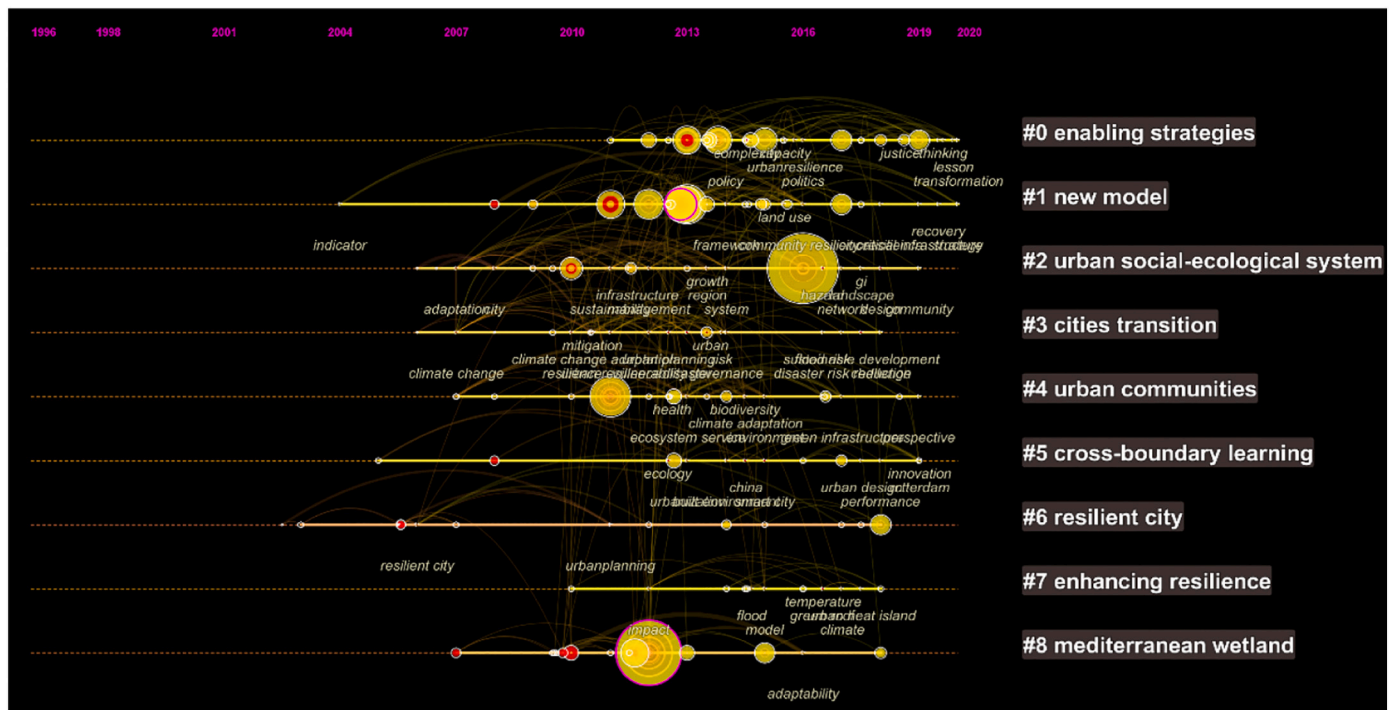
Fig. 5. Timeline of the research topics of urban resilience.

Table 5
Top 13 keywords with the strongest citation burst.

Keywords	Strength	Begin	End	1998 – 2020
urbanplanning	7.4804	2013	2016	
hazard	6.0644	2017	2018	
resilientcity	5.0635	2006	2014	
biodiversity	4.9079	2008	2016	
greenroof	3.8895	2017	2018	
temperature	3.8895	2017	2018	
participation	3.5824	2014	2016	
China	3.4197	2015	2018	
earthquake	3.3838	2014	2017	
adaptation	3.2803	2007	2012	
disaster	4.464	2013	2014	
planning	4.264	2011	2016	
complexity	4.108	2014	2017	

Note: the red colour indicates the time span.

3.4. Contribution towards sustainability and sustainable development goals (SDGs)

Only 391 papers contend the keywords 'sustainability' or 'sustainable'. These papers were classified according to the content (title, abstract and keywords) in the three dimensions of sustainability. Fig. 6 shows the interrelations between the sustainability dimensions and the number of publications in each one. Although resilience is being considered as a complementary approach to sustainability (Chelleri et al., 2015; Elmqvist et al., 2019) only the 38.56% of the analyzed urban resilience papers also directly address sustainability. The pillar most addressed is social sustainability (341 docs, 87.21%) followed by environmental sustainability (319, 81.59%), similar to Xu and Marinova (2013) findings and differing from sustainability science research that
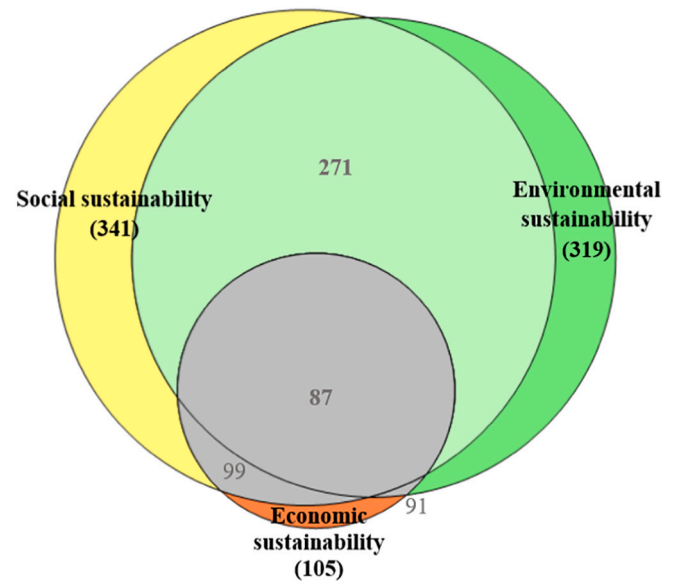

Fig. 6. Venn diagram of the interrelations between sustainability dimensions and number of publications that address each pillar.

leans more towards the environmental perspective (Bautista-Puig, 2020). Economic sustainability is the least addressed (105 papers, 26.85%).

Moreover, the contribution to SDGs is analyzed (Fig. 7). 709 papers (69.92% of the total sample, 76.98% of the papers with a DOI number) were classified into, at least, one SDG. For that purpose, the tool OSDG was used. Most papers with a DOI were classified into one SDG although they did not contain the keywords 'sustainability' or 'sustainable'. Despite the variability in the emergence of topics and their relevance in terms of citation bursts, the classification of articles in SDG underlines the weight of SDG 11 'Sustainable Cities and Communities' (664 publications). These results are not surprising since this SDG is focused on
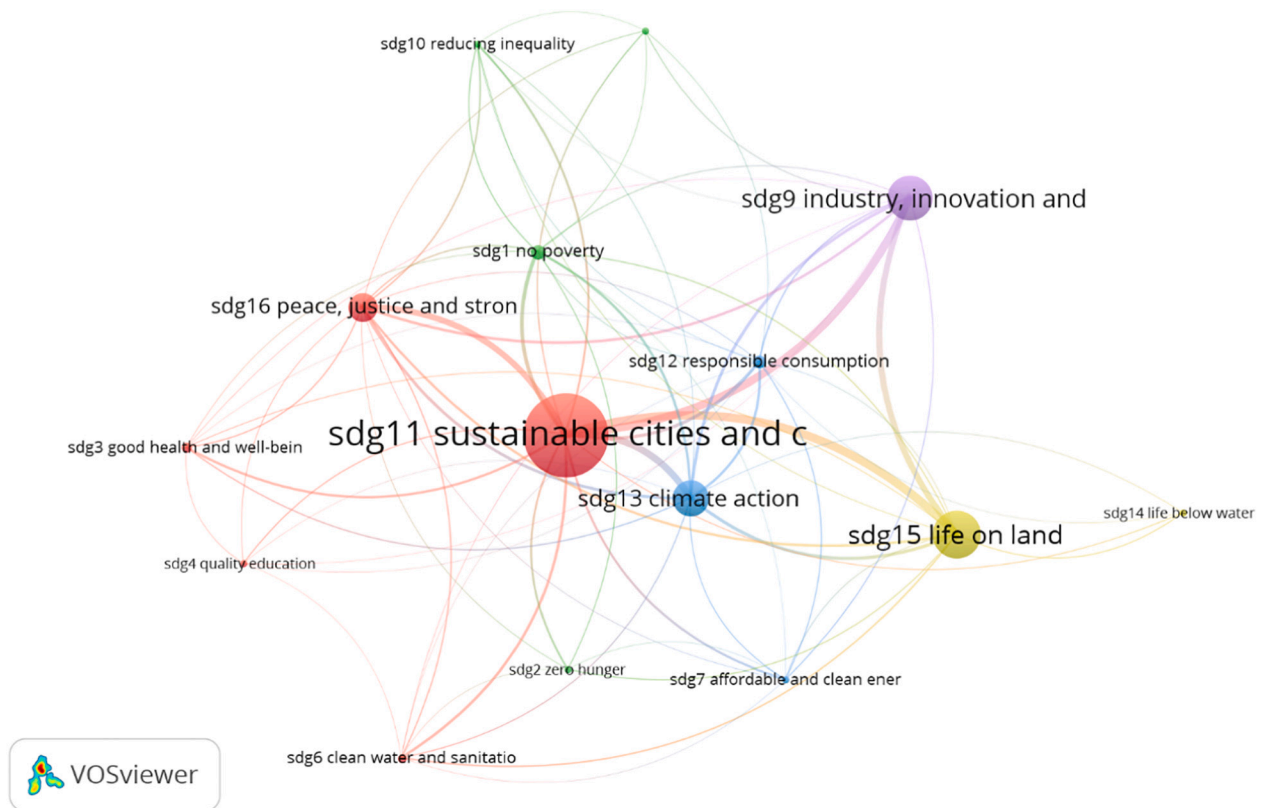
Fig. 7. Co-occurrence of Sustainable Development Goals (SDGs) based on urban resilience publications (with a co-occurrence>5).

the urban environment and one of its specific targets is to foster resilience to disasters. It is followed by SDG15 'Life on land' (303 docs.), SDG9 'Industry, innovation, and infrastructures' (282 docs.), SDG13 'Climate action'(208 docs.) and SDG16 'Peace, justice and strong institutions' (161 docs.).

There is a strong connection between SDG 11 and SDG 15 'Life on land' (strength of 296), which is also the second SDG with more occurrences. The conservation of biodiversity, a high cited keyword in urban resilience literature (Table 5) and a key to foster resilience (Elmqvist et al., 2019), is a main target of SDG 15. SDG 13 'Climate action' has also a high number of occurrences, since resilience to climate change has traditionally been a topic of the urban resilience literature (Meerow & Newell, 2015; Pu & Qiu, 2016; Yang et al., 2021). Some urban resilience papers also contribute to SDG16 'Peace, justice and strong institutions' which suggests that trade-offs and social justice are being addressing in some extent. Finally, these results reinforce the idea that economic sustainability is poorly addressed by the urban resilience literature, thus enabling to conclude that this aspect of urban resilience might present interesting opportunities for further, novel research. In addition, the links between SDG9 and SDG11 (link strength of 271) are also relevant which denotes a connection between these goals on urban resilience publications.

Some of the limitations of this study should be noted. First, the use of keywords for selecting the research output, might not necessarily capture the whole output of research. We restricted our search to papers that explicitly include the concepts of 'resilient cities', 'urban resilience', 'neighbourhood resilience' and similar expressions, excluding urban-centric resilience papers that do not include these terms (i.e. research about resilience in urban contexts without considering the resilience of the urban system as a whole). Nunes et al. (2019), who conducted a search using the single words 'urban', 'resilience', 'cities' and 'resilient', found that the technological sciences, together with the social and the medical and health sciences, have widely contributed to the study of resilience in urban contexts before the expansion of urban resilience

research in the environmental biosciences. This outcome differs from the results of this paper.

Another limitation was the use of WoS database, which may have limitations owing to the underrepresentation of non-English-language publications available. In addition, despite all types of publications from WoS were considered from the three databases from the Core Collection, some other typologies of interest (e.g. reports) were not captured. In this vein, there is considerable grey literature about urban resilience within the civil engineering and urban planning research areas that is no considered in this paper (e.g. the publications of The Global Facility for Disaster Reduction and Recovery (GFDRR) partnership).

4. Conclusions

Urban Resilience is a concept that has become an important goal for cities, especially in the face of climate change challenges. However, little is known if it is mature enough to be constituted as a discipline and what their interlinkage with sustainability and SDGs is. In this study, we conducted a bibliometric analysis to analyse the research output in academic research of urban resilience. The results provided insights into the patterns and research trends, landmark papers and key topics as well as their contribution tothe dimensions of sustainability and SDGs on this field.

The findings of this study show that although urban resilience has evolved significantly in terms of number of publications, the output concentration of articles in recent years and in a few journals denote that it is still emergingas a discipline. The different topics identified in this research illustrate a specialization in recent years from more theoretical research to a more practical (e.g. by giving resilience strategies).They also suggest that socio-ecological resilience is being more accepted by urban resilience researchers than the engineering and ecological interpretations.

The main novelty of this paper is the analysis of the contribution of

urban resilience literature to the environmental, social and economic dimensions of sustainability and the 17 SDGs. In terms of contribution towards sustainability, the findings show the number of publications that directly address sustainability is scarce and more balanced to environmental and social perspectives. The economic dimension is poorly addressed, an aspect of urban resilience that might present interesting opportunities for further research. Thus, urban resilience research should increasingly focus on exploring the relationship between resilience and sustainability. Concerning SDGs, although there are some publications that focus on SDG16, it would be desirable for resilience research to consider issues of socio-ecological justice and trade-offs between spatial-temporal scales.

Our results could be complemented by means of qualitative research methods (e.g. interviews) to uncover more specific motivations and drivers for researchers to publish on urban resilience in different contexts. Moreover, further research could be focused in some particular areas of urban resilience (e.g. energy) and elucidate the future trends of the urban resilience literature and how it addresses sustainability and SDGs.

CRediT authorship contribution statement

Núria Bautista-Puig: Conceptualization, Investigation, Formal analysis, Methodology, Visualization, Data curation, Writing – original draft. **Javier Benayas:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Jorge Mañana-Rodríguez:** Investigation, Methodology, Formal analysis, Writing – original draft. **Marta Suárez:** Conceptualization, Investigation, Formal analysis, Methodology, Data curation, Writing – original draft. **Elías Sanz-Casado:** Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Acknowledgements

Appendix A

Table A.1
Clusters of co-occurrences of references and keywords in urban resilience.

Cluster ID	Size	Silhouette	Year	Log likelihood ratio (LLR)	Label (Latent Semantic Indexing)
0	30	0.711	2016	enabling strategies (45.39, 1.0E-4); scoping review (45.39, 1.0E-4); governing resilience (40.33, 1.0E-4)	climate change; adaptation; ethics; agenda; justice; context; exploring equity; spatial planning
1	25	0.765	2014	new model (54.58, 1.0E-4); considering adaptability (54.58, 1.0E-4); low-carbon resilient city (46.15, 1.0E-4)	urban resilience; spatial-temporal evolution; evidence; influencing factors; plain urban agglomeration; guanzhong; cote d'azur region; provence
2	24	0.789	2012	urban social-ecological system (47.08, 1.0E-4); local practice (33.87, 1.0E-4); geodesign framework procedure (33.5, 1.0E-4)	urban resilience; spatial-temporal evolution; evidence; influencing factors; plain urban agglomeration; guanzhong; practice; landscape pattern
3	23	0.84	2012	cities transition (29.77, 1.0E-4); multi-vector approach (29.77, 1.0E-4); low-carbon emission development (29.77, 1.0E-4); institutional pathway (29.71, 1.0E-4)	resilience; koper; port cities; floods; practice; landscape pattern; sustainable development goals; resilient urban design
4	22	0.758	2013	urban communities (54.03, 1.0E-4); social need (53.14, 1.0E-4); setting priorities (53.14, 1.0E-4)	urban resilience; green infrastructure; embedding social inclusiveness; appropriateness; engineering assessment; assessment; city level; high-resolution data
5	15	0.784	2014	cross-boundary learning (58.63, 1.0E-4); diverging concept (58.63, 1.0E-4); planning nature-based solution (53.83, 1.0E-4)	urban resilience; transformations; rethinking knowledge systems; decolonial contributions; low-hanging fruit'; landscape-based assessment; global south; promise
6	15	0.826	2009	Resilient city (52.9, 1.0E-4); smart city (41.32, 1.0E-4); inclusive adaptation (38.99, 1.0E-4)	resilient city; seismic risk; spatial multicriteria approach; adaptive capacity; coastal cities; sustainable development goals; moscow; poor neighborhoods
7	14	0.731	2015	enhancing resilience (64.55, 1.0E-4); bridging resilience modelling (64.55, 1.0E-4); geovisualization technique (64.55, 1.0E-4)	climate change; city resilience implementation; aware cities; measuring resilience; floods; combining spatial-network analysis; operating urban resilience strategies; urban heat island
8	14	0.738	2011	mediterranean wetland (39.8, 1.0E-4); adaptive co-management (39.8, 1.0E-4); local planning practice (39.8, 1.0E-4)	urban resilience; enacting resilience; performative account; practice; global south; rebuilding; resilient urban design; urban sustainability challenges

Table A.2
Top 24 References with the Strongest Citation Bursts.

References	Year	Strength	Begin	End	1998 - 2020
Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global environmental change*, *16*(3), 253-267.	2006	8.7045	**2010**	2014	
Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global environmental change*, *18*(4), 598-606.	2008	7.2898	**2012**	2016	
Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and society*, *15*(4).	2010	7.1432	**2015**	2017	
Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and society*, *11*(1).	2006	6.7692	**2013**	2014	
Ernstson, H., Van der Leeuw, S. E., Redman, C. L., Meffert, D. J., Davis, G., Alfsen, C., & Elmqvist, T. (2010). Urban transitions: on urban resilience and human-dominated ecosystems. *Ambio*, *39*(8), 531-545.	2010	6.6929	**2013**	2018	
Newman, P., Beatley, T., & Boyer, H. (2009). *Resilient cities: responding to peak oil and climate change*. Island Press.	2009	6.3548	**2009**	2017	
Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American journal of community psychology*, *41*(1-2), 127-150.	2008	6.1092	**2013**	2016	
Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756-760.	2008	6.1092	**2013**	2016	
Vale, L. J., & Campanella, T. J. (2005). *The resilient city: How modern cities recover from disaster*. Oxford University Press.	2005	5.9112	**2005**	2013	
Brand, F. S., & Jax, K. (2007). Focusing the meaning (s) of resilience: resilience as a descriptive concept and a boundary object. *Ecology and society*, *12*(1).	2007	5.4711	**2012**	2015	
Wardekker, J. A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change*, *77*(6), 987-998.	2010	4.9625	**2013**	2016	
Simmie, J., & Martin, R. (2010). The economic resilience of regions: towards an evolutionary approach. *Cambridge journal of regions, economy and society*, *3*(1), 27-43.	2010	4.5371	**2013**	2018	
Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. J Homel Secur Emerg Manag 7 (1).	2010	4.1679	**2015**	2018	

Reference	Year	Strength	Begin	End	Burst
Pelling, M. (2010). *Adaptation to climate change: from resilience to transformation*. Routledge.	2011	4.0112	**2017**	2018	
Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and society*, *15*(4).	2010	3.8011	**2016**	2017	
Colding, J. (2007). 'Ecological land-use complementation' for building resilience in urban ecosystems. *Landscape and urban planning*, *81*(1-2), 46-55.	2007	3.6847	**2013**	2014	
Colding, J., & Barthel, S. (2013). The potential of 'Urban Green Commons' in the resilience building of cities. *Ecological economics*, *86*, 156-166.	2013	3.608	**2014**	2017	
MacKinnon, D., & Derickson, K. D. (2013). From resilience to resourcefulness: A critique of resilience policy and activism. *Progress in human geography*, *37*(2), 253-270.	2013	3.6005	**2016**	2017	
Nations, U. (2014). World urbanization prospects. United Nations: San Francisco, CA, USA.	2014	3.6004	**2016**	2018	
Coaffee, J., Wood, D. M., & Rogers, P. (2009). The everyday resilience of the city. *Basingstoke: Palgrave Macmillan. doi*, *10*, 9780230583337.	2008	3.5957	**2012**	2014	
Cimellaro, G. P., Reinhorn, A. M., & Bruneau, M. (2010). Framework for analytical quantification of disaster resilience. *Engineering structures*, *32*(11), 3639-3649.	2010	3.3882	**2014**	2018	
Bozza, A., Asprone, D., &Manfredi, G. (2015). Developing an integrated framework to quantify resilience of urban systems against disasters. *Natural Hazards*, *78*(3), 1729-1748.	2015	3.3342	**2017**	2018	
Toubin, M., Laganier, R., Diab, Y., & Serre, D. (2015). Improving the conditions for urban resilience through collaborative learning of Parisian urban services. *Journal of urban planning and development, 141*(4), 05014021.	2015	3.3235	**2018**	2020	
Ahern, J., Cilliers, S., & Niemelä, J. (2014). The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation. *Landscape and Urban Planning*, *125*, 254-259.	2014	3.1991	**2016**	2018	

Note: The medium blue indicates the period that the burst started and red is associated with the years with the strongest burst.

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