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Resilient City: Characterization, Challenges and Outlooks

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Abstract: The increasingly severe environmental pollution and the Earth's ecological crisis make the concept of resilient cities (RCs) a hot topic in urban research. We ran a bibliometric analysis to analyze the research progress, areas, hotspots, and strategies pertaining to RCs. The core collection came from the Web of Science (WoS) database as the data source to explore 4462 literature works on RCs. The results revealed that development time series analysis is divided into three stages. Changes in the number of publications are linked to natural disasters, the ecological environment, and science policy. The top five issuing journals accounted for 24.15% of the total sample. Country cooperation mainly is concentrated in countries with good economic development trends, such as the United States, China, and the United Kingdom. There were 63 core authors. The most published research institution was the Chinese Academy of Sciences. The RC research hotspots included the definition of resilience and evolution, the study of resilience as an analytical framework for urban issues, and resilience assessment indicators. This paper shows that RCs should strengthen multi-country cooperation and interdisciplinary integration and should focus on comprehensive research on basic theories, evaluation systems, and action mechanisms to reference future research on RCs further.

Keywords: resilient city; literature review; climate change; sustainable development; vulnerability; resilience assessment; CiteSpace; bibliometric analysis; progress and prospects; visualization

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1. Introduction

With the frequent occurrence of "Black Swan" incidents, such as climate change, earthquakes, and pandemics such as coronavirus disease 2019 (COVID-19), dramatic changes in the landscape have been caused by human activities, and the rapid loss of biodiversity, the urban environment on which humans rely for survival, is in grave danger [1,2]. Improving RCs, defined as cities' ability to respond rapidly, adapt swiftly, feedback dynamically, and maintain growth in the face of abrupt social crises, has emerged as an essential research topic in urban planning and geography [3,4]. The application of resilience theory to urban development and the institutional standardization of RCs will help solve the increasingly complex vulnerability and uncertainty risks that have occurred through urbanization and achieve sustainable urban development.

Under the global trend of promoting crisis prevention and the construction of ecology, multidisciplinary fields have explored the theory of RCs, the integration of regional economic resilience and evolutionary geography, the structure of a comprehensive and multi-level RC evaluation theory system, research of RCs under emerging risk perturbations, and the complex evolutionary mechanism of all-hazard RC systems [5–8]. In 2002, the International Council for Local Environmental Issues (ICLEI) first introduced the concept of "resilience" to the field of urban construction and disaster prevention and mitigation, and the research on RCs has gradually developed since then [9]. In 2017, the

United Nations established a strategic partnership on RCs with international organizations such as Directorate Generals-International Cooperation and Development (DG-DEVCO) and the World Bank Group [10,11]. In the same year, the City Resilience index was developed by the consultancy firm ARUP (bearing the name of Ove Arup), with support from the Rockefeller Foundation [12]. It is the first sophisticated tool for assessing RCs in the world [13], which can strengthen cities to build competitive and resilient development strategies for their future RCs and is an essential milestone in the history of RCs [14]. With continuous progress in urbanization, RCs have become an essential part of these countries' metropolitan development plans.

Scholars have conducted research on RCs in various aspects, such as theoretical evolution, practical experience, urban public spatial resilience, urban riverfront spatial resilience, and resilience assessment [15–17]. However, knowledge maps of the overall architecture and dynamic trends of RCs based on bibliometric presentation are insufficient. Only a few articles in the WoS database address the literature on RCs, and the latest year of analysis ended in 2019. There have been no new reviews with bibliometric analysis in this field in the past two years. Therefore, it is necessary to sort out the relevant literature works and determine the progress, fields, hotspots, strategies, and mainstream research framework in this area. This paper used CiteSpace bibliometric software to visualize and analyze the research literature on RCs from 2001 to 2021 in the WoS database from a multifaceted perspective. We discussed its characteristics and future development trends, and identified the latest research journals, countries, core authors, institutions, and hot spots, so as to provide reference and enlightenment for subsequent research and practice.

As a result, this paper constructed research methods and tools accordingly: Section 3 discusses the current state of research on RCs. Sections 4 and 5 discuss and summarize the shortcomings of current RC research and propose relevant analysis and future prospects.

2. Data Sources and Methodology

2.1. Data Sources

In 2000, the United Nations issued the Millennium Declaration for the new century, signaling a new phase in the field [18]. For this reason, the data source was selected from the Science Citation Index Expanded (SCI-E) of the Core Collection Database of WoS (http://apps.webofknowledge.com/ (accessed on 2 March 2022)) for the past 20 years, including both the classic and latest research material. Citation Index Expanded (SCI-E; SCI for short) is an internationally recognized authoritative database [19]. We limited the scope of research by filling in the search formula: TS = (Resilient City) OR TS = (Urban Resilience) OR TS = (City Resilience)) OR TS = (Elastic City) AND SU = (Urban), where TS is the Topic and Su is the Research Area. To ensure the accuracy of the research, non-academic papers were removed, including book reviews, conferences, and newspapers, with a total of 4462 academic journal papers published in the field of RC research from 2001 to 2021 being retrieved as the basis of the research analysis, retrieved on 1 March 2022.

2.2. Research Methods

Scientific knowledge graphs, a type of visual literature analysis gradually developed for big data visualization, are one of the critical methods for studying the development dynamics of various disciplines [20,21]. Combining multidisciplinary theories and co-occurrence analysis methods and using a modern theory of multidisciplinary integration contribute to helping researchers effectively sort through existing research trajectories [22–24]. The current knowledge graph analysis tools include HistCite, Bibexcel, SCI2, VOSviewer, and CiteSpace, a widely used scientific knowledge graph software based on the Java platform developed by Dr. Chaomei Chen Drexel University, USA [25]. In comparison to other visualization software, CiteSpace can perform self-occurrence, co-occurrence, and clustering analysis of science and technology data in a specific knowledge domain, visually capture hot topics, and show the sudden emergence of new research topics in

a specific period, as well as explore possible trends, knowledge relevance, and research frontiers [26–28].

This paper used CiteSpace 5.8R3 knowledge mapping software and bibliometrics to visually analyze the literature related to RCs. The research results mainly focus on 12 aspects: Publication volume, publication journals, publication regions, publication authors, research institutions, co-cited articles, research fields, keyword co-occurrence networks, keyword co-occurrence time partitioning, keyword clustering analysis, research clustering timeline, and research trends. It further composed and summarized the research results of RC development thus far, objectively revealed the dynamic development process and evolution trend of RCs, explored the frontiers and hotspots of RC theory and practice research, and provided a scientific reference for RC research.

Method: Using the WoS data analysis board, the time slice length was set to 1; the other operations alone were left alone; "Author," "Institution," "Country," "Keyword," "Reference," "Cited author," and "Cited journal" were selected as the network node type; and a co-occurrence analysis of RC research and the SCI core journal database from multiple perspectives was conducted, generating a visualized knowledge map. After checking whether the modularity (Q value) and silhouette (S value) obtained according to the network structure and clustering clarity in the information bar above the left were obvious and reasonable, the map was then studied. In general, the module value range is [0, 1], the module value $Q > 3$ clusters considerably, the average profile value $S > 0.5$ clusters fairly, and the average profile value $S > 0.7$ clusters precisely. The mapping information column clearly showed that the module value Q and mean profile value S values were within a suitable range; thus, their use as a basis for analysis was reliable [29].

3. Results

In recent years, due to the frequent occurrence of crisis events such as extreme climate disasters, major epidemics, and urban terrorist attacks, more and more countries have begun to pay attention to RC construction [30]. Around the world, other international metropolises, such as New York, London, Chicago, and Tokyo, have coincidentally formulated planning details related to RCs to respond promptly to unexpected crises [31–33]. The global outbreak of COVID-19 has been a wake-up call to the world. It is now more urgent than ever to build RCs that proactively respond to public health emergencies [34]. Countries are realizing the need to rethink the status quo and be proactive to increase the resilience of communities, societies, and economies to better prepare for future unexpected disasters [35–37].

3.1. General Overview of the Research Progress

3.1.1. Volume of Publications

The change in the chronological order of paper submissions is a significant indicator of the development of a research field, which, to some extent, reflects the activity of the research topic over a certain period. Research in this area shows an increasing trend year on year, with three stages from 2001 to 2021 (Figure 1). This shows that the study of RCs has attracted wide attention and has become a research hotspot.

1. Between 2001 and 2007, the frequency of natural disasters increased. Disaster prevention and mitigation progressively became the center of academic attention. The number of publications published during this period was fewer than 87, indicating a lack of research concentration.
2. The period between 2008 and 2017 represents the development phase, during which the theoretical foundation of the current research was primarily completed. The increase in the literature with the emergence of extreme events in different eras, as well as the launch of the United Nations International Strategy for Disaster Reduction (UNISDR) in 2012 to establish the Asian Cities Climate Change Response Network, demonstrates the awakening of resilience awareness and the improvement of resilience [38].

3. Between 2018 and 2021, as the effect of COVID-19 drew extensive attention from researchers worldwide and the number of publications increased significantly, culminating in 2021 with 1118 yearly articles. Meanwhile, several cities in affluent nations and regions have begun to address climate change by adopting sustainable city construction policies, protocols, or rules [39]. As a result, it is possible to deduce that variations in the number of messages delivered by cities are connected to natural catastrophes and environmental and scientific policies.

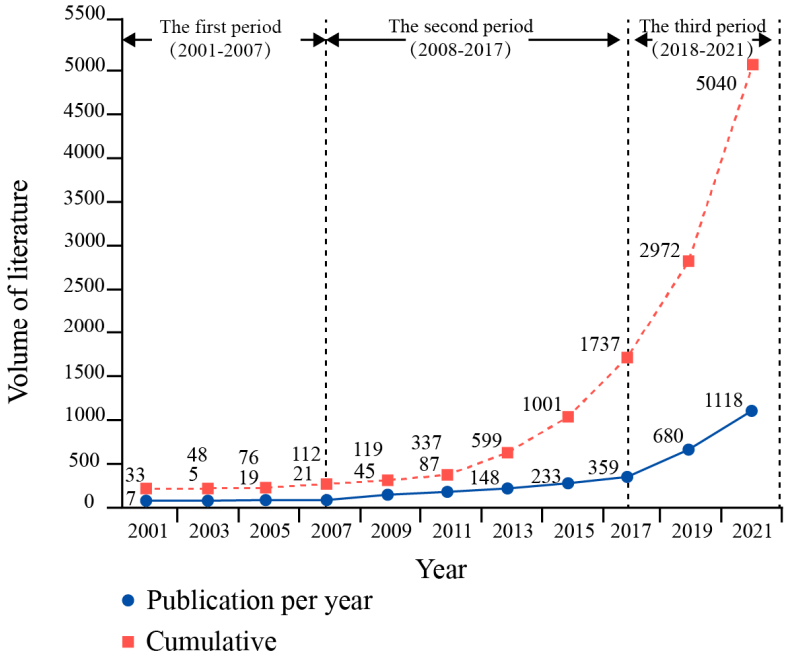

Figure 1. Number of research articles from 2001 to 2021.

3.1.2. Distribution of Published Journals

The distribution of issuing journals can more effectively represent the attention and influence of RC research in relevant publications and provide resources for scholars [40]. According to the published statistics from 2001 to 2021, 4462 SCI-E articles on RCs were found from 1029 publications (Table 1). The top five journals and publications comprised 538 articles in *Sustainability* and 205 articles in the *International Journal of Disaster Risk Reduction*. There were 117 articles in *Natural Hazards*, 111 articles in *Sustainable Cities and Society*, and 107 articles in *Water*. The top five journals accounted for 24.15% of the total sample, and the average impact factor was 4.2726. *Sustainable Cities and Society* had the highest impact factor, reaching 7.587. According to the top five journals that publish literature on RCs and their influence, the main research directions were building science, climate change, environmental science, landscape, urban planning, and sustainable development. This indicates that these topics are the main research directions in this field.

Table 1. Summary of the number of relevant literature works published in main journals.

S/N	Journals	Publisher	Quantity	Impact Factor	Country
1	*Sustainability*	MDPI	538	3.251	Switzerland
2	*International Journal of Disaster Risk Reduction*	ELSEVIER	205	4.320	Netherlands
3	*Natural Hazards*	SPRINGER	117	3.071	United States
4	*Sustainable Cities and Society*	ELSEVIER	111	7.587	Netherlands
5	*Water*	MDPI	107	3.103	Switzerland

Table 1. *Cont.*

S/N	Journals	Publisher	Quantity	Impact Factor	Country
6	*International Journal of Environmental Research and Public Health*	MDPI	103	3.390	Switzerland
7	*Science of The Total Environment*	ELSEVIER	86	7.963	Netherlands
8	*Landscape and Urban Planning*	ELSEVIER	78	6.142	Netherlands
9	*Urban Forestry & Urban Greening*	ELSEVIER GMBH	73	4.537	Germany
10	*Journal of Cleaner Production*	ELSEVIER SCI LTD	72	9.297	United States

3.1.3. Regional Cooperation Distribution of Publications

Analysis of the literature published in different regions reflects, to a certain extent, the importance and influence of the country in this field [41]. The node type was set to "Country," and the time slice was set to one year to generate the country collaboration co-occurrence map. The node value was 171, and the linkage was 698. The size of the node font represents the number of publications, the linkage indicates the cooperation between publications, and the thickness of the linkage indicates the strength of the collaboration, representing 171 countries that have conducted relevant research in this field and produced 698 collaborations. The top five in terms of the number of publications were 1361 in the U.S., 674 in China, 423 in the U.K., 322 in Australia, and 307 in Italy. The RC research areas from 2001 to 2021 were concentrated in the U.S., China, the U.K., Australia, and other nations with good economic development trends that collaborate more closely in RC research (Figure 2). Centrality identifies highly connected nodes in a network, with the bridge between two other unrelated nodes connected by a particular node. The thickness of the purple lines in Figure 2 represents the level of centrality, reflecting the academic influence. According to Figure 2, those with a strong influence were the U.S., U.K., Germany, France, etc. This shows that the U.S. is the absolute leader in RC research and is in a dominant position, providing technical support for RC research and providing a better research platform for future development.

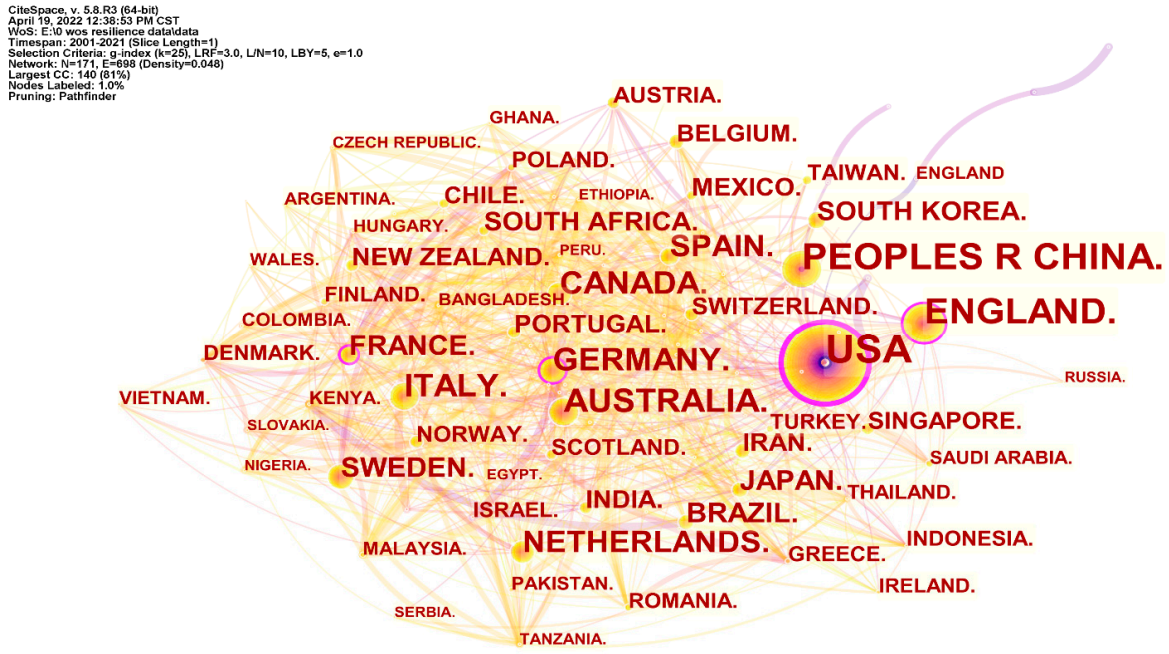

Figure 2. Collaborative co-occurrence map of RC regional cooperation distributions.

3.1.4. Author Collaboration Distribution

The author collaboration map reveals the publication status of scholars in the investigated research fields, identifies authors with high research ability and recognizes the more active and influential scholars through author collaboration [42]. The node type was set to "Author," and the time slice was set to one year (Figure 3). The graph has 3783 nodes and 9898 lines, indicating that 3783 authors have conducted relevant research in this area and 9898 collaborations have been formed, with more authors studying RCs and engaging in closer collaboration. Collaborations have become closer and more frequent. According to Price Law, $M \approx 0.749 * \sqrt{Nmax}$ (M = number of papers and N = number of papers with the highest number of authors), meaning that the core authors of the research field can be identified, and that authors can be recognized as the core authors of a research field when their number of papers reaches the M value. The number of articles published by authors in RC research is shown in Table 2. Four or more articles included core authors, laying the academic foundation. Price Law stipulates that the total number of core authors accounts for more than 50.00% of the total number of publications before a core group of authors can be formed. The total number of publications by 63 core authors was 459, accounting for 10.28% (less than 50.00%) of the total sample, indicating that the research scholars in RC research are scattered and have not yet formed a core group of authors.

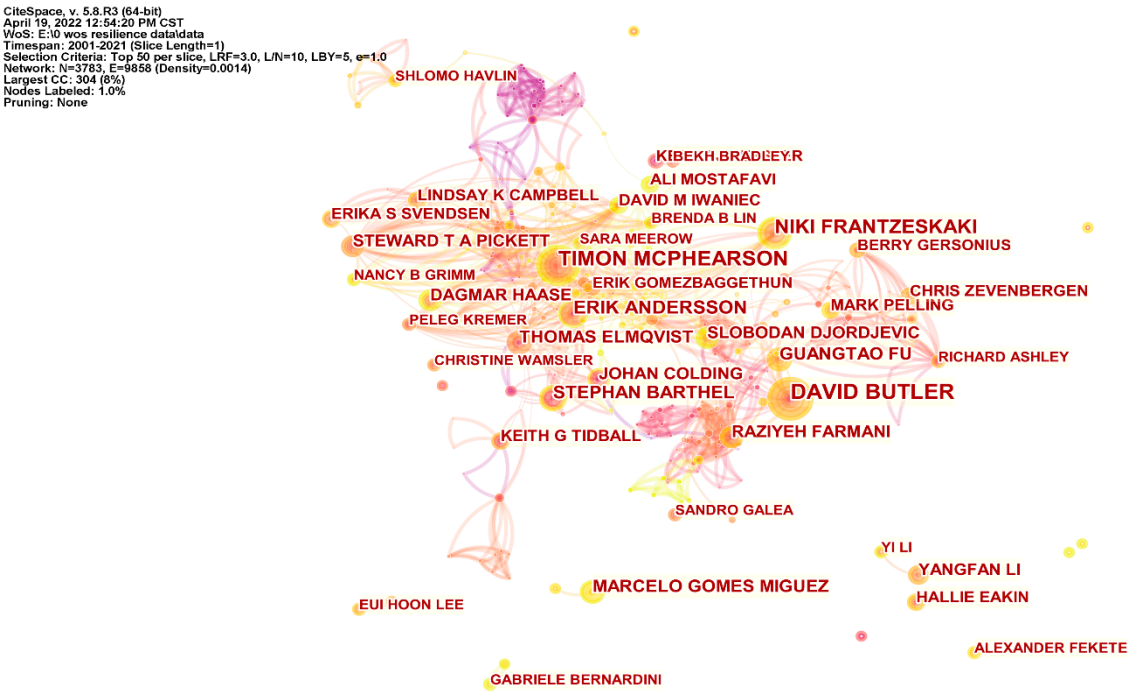

Figure 3. Collaborative co-occurrence map of RC authors.

It can be seen that the number of scholars with a high number of publications is more limited, with most authors having a low number of publications—only one or two. There were 13 authors with more than 10 publications. The author with the highest number of publications was David Butler, Professor at the Centre for Water Systems at the University of Exeter in the U.K., with 20, thereby ranking ranked first in publications. His research focuses on applied research, assessment frameworks, and management systems for urban water system planning from an RC perspective and has contributed significantly to building flood RCs.

Table 2. Statistics on the number of articles published by core authors of RC research.

S/N	Author	Quantity	S/N	Author	Quantity	S/N	Author	Quantity
1	David Butler	20	22	Erika S Svendsen	8	43	Kylie Ball	5
2	Timon Mcphearson	19	23	Berry Gersonius	7	44	Rita Salgado Brito	5
3	Niki Frantzeskaki	15	24	Erik Gomezbaggethun	7	45	Min Ouyang	5
4	Erik Andersson	13	25	Kerry J Ressler	7	46	Yan Wang	5
5	Stephan Barthel	12	26	Eui Hoon Lee	6	47	Mary L Cadenasso	5
6	Marcelo Gomes Miguez	11	27	Alexander Fekete	6	48	Anna Laura Pisello	5
7	Thomas Elmqvist	11	28	Gabriele Bernardini	6	49	S Thomas Ng	5
8	Guangtao Fu	11	29	Shlomo Havlin	6	50	Nadja Kabisch	5
9	Dagmar Haase	10	30	Bekh Bradley	6	51	Gian Paolo Cimellaro	5
10	Johan Colding	10	31	Christine Wamsler	6	52	Tianzhen Hong	5
11	Slobodan Djordjevic	10	32	Peleg Kremer	6	53	Bilal M Ayyub	5
12	Raziyeh Farmani	10	33	Nancy B Grimm	6	54	Rebekah R Brown	5
13	Steward TA Pickett	10	34	Sara Meerow	6	55	Barry Evans	5
14	Yangfan Li	9	35	Brenda B Lin	6	56	C Zevenbergen	5
15	Keith G Tidball	8	36	Richard Ashley	6	57	Stephan Pauleit	5
16	Chris Zevenbergen	8	37	Sandro Galea	6	58	Ayyoob Sharifi	5
17	David M Iwaniec	8	38	Yi Li	6	59	Luca Salvati	5
18	Mark Pelling	8	39	Aline Pires Verol	5	60	Hayley Leck	5
19	Lindsay K Campbell	8	40	Joong Hoon Kim	5	61	Henrik Ernstson	5
20	Hallie Eakin	8	41	Enrico Quagliarini	5	62	Eduardo Martinezgomariz	5
21	Ali Mostafavi	8	42	D Serre	5	63	Zhilong Chen	5

3.1.5. Distribution of Cooperation with Research Institutions

Combined with the analysis of national cooperation networks above, it was found that the number of national publications and the strength of academic influence depends mainly on the research capacity of key national research institutions. Through research institution cooperation mapping, it is possible to understand which institutions are currently focusing on and researching RC-related topics and effectively distinguish each institution's development achievements and research capabilities, thus facilitating cooperation between institutions [43]. There were 839 nodes and 2226 links in the mapping, indicating that 839 institutions have conducted research in this field and 2226 collaborations have been generated, which means more authors and closer collaboration in RC research (Figure 4). The Chinese Academy of Sciences (80) published the highest number of publications, followed by Arizona State University (76), which had the most prominent mediated centrality of 0.12 among research institutions, indicating its solid scientific influence in the field of RCs. Other institutions with centrality $\geq$0.1 include Stockholm University (56) and the University of Exeter (55). The research institutions with more than 40 publications between 2001 and 2021 are shown in the chart, of which 6/7 are higher education institutions, and 1/7 are research institutes or centers. This indicates that higher education institutions are the leading force in RC research and lead the major research trends in RC research.

The Chinese Academy of Sciences' focus on the field of RC research indicates that the domain is closely related to the development of China. The Chinese Academy of Sciences' research is the same as China's overall research, involving urban planning, infrastructure disaster prevention systems, and related policies. In contrast, the research is closely integrated with practice, often using China as a case study to conduct research activities. Non-university institutions' participation indicates that more researchers in the field are becoming concerned. Following the development of RC research, more non-university institutions or professional research institutions should be included to supplement university research and promote overall development research progress and more in-depth research content.

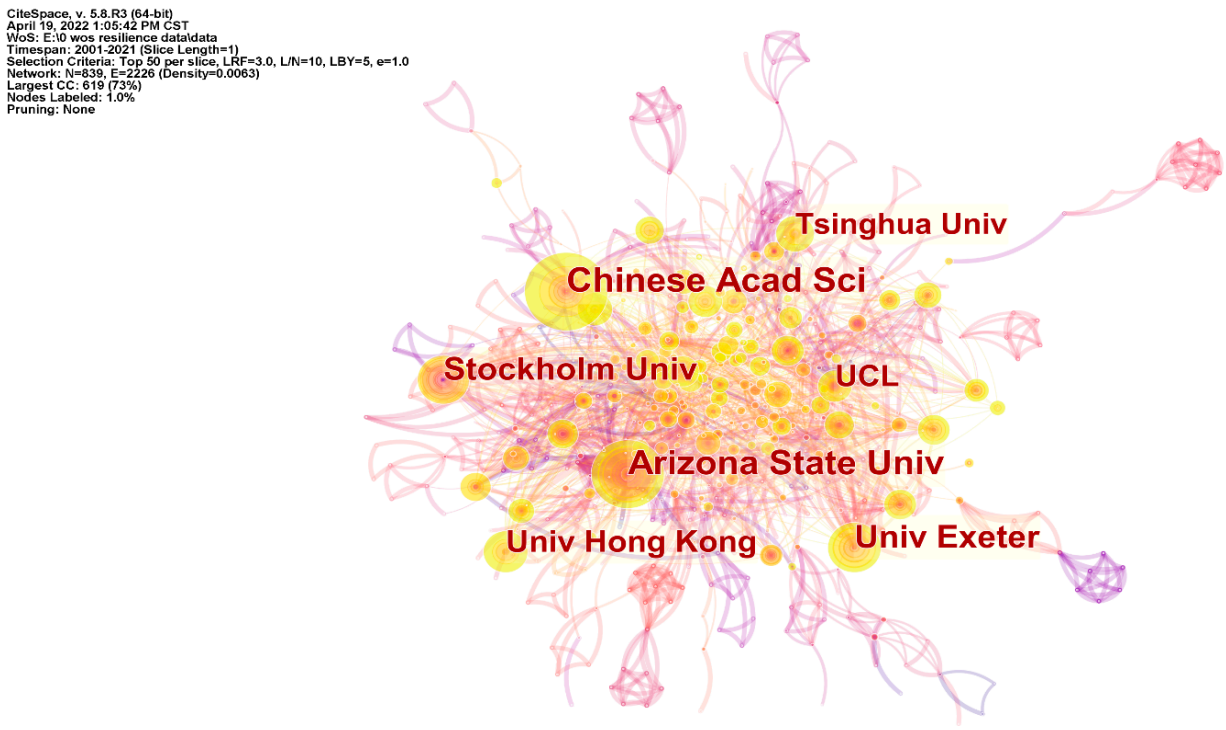

Figure 4. Collaborative co-existence map of RC research institutions.

3.2. Research Fields

3.2.1. Cited References

Co-cited literature is a highly recognized phenomenon in science, where two references are cited by the same literature, which is advanced and innovative in terms of research content or understanding of the problem [44]. The node type was set to "Reference" in the software to generate a cooperative map of co-cited literature. The top 20 papers focused on RCs after 2014, with 11 of the top 20 co-cited papers in 2015 and 2016 (Figure 5). This indicates that, since *World Urbanization Prospects 2014 and the Sendai Framework for Disaster Risk Reduction 2015–2030*, the research on RCs has gained importance at the international political level, prompting scholars during this period to focus on innovative research on the critical issues of resilience theory [45].

The literature was arranged in descending order of the number of citations, and eight papers with more than 40 citations were extracted from the period 2016–2019 (Table 3). Research on RCs is still in its early stages. The chart displays the literature cited more than 40 times under the topic of RC research, including the authors of the literature, the year of publication, and so on. In terms of publication time, the total number of cited papers was one in 2015, four in 2016, one in 2017, and two in 2019.

One of the most cited pieces of literature in RC research is the 2016 article by the American scholar S. Meerow (the most significant nodes in the figure represent the highest citation rates). Meerow attempts to view the resilience of a collection of target capabilities that cities strive for through appropriate planning, policies, and interventions. Resilience theory is not well integrated with the fundamental concepts of urban theory in the existing definition of RCs. Meerow suggested a new definition of RCs, namely, "RC is a socio-ecological and socio-technical network that connects an urban system and all of its components at multiple spatial and temporal scales. The ability to maintain or quickly recover required functions, adapt to change in the face of disruptions, and rapidly transform systems that impede current development" [46]. The future resilience theory will establish the groundwork for studying social-ecological systems. On the other hand, Hosseini and Cullter systematically examined the RC evaluation system.

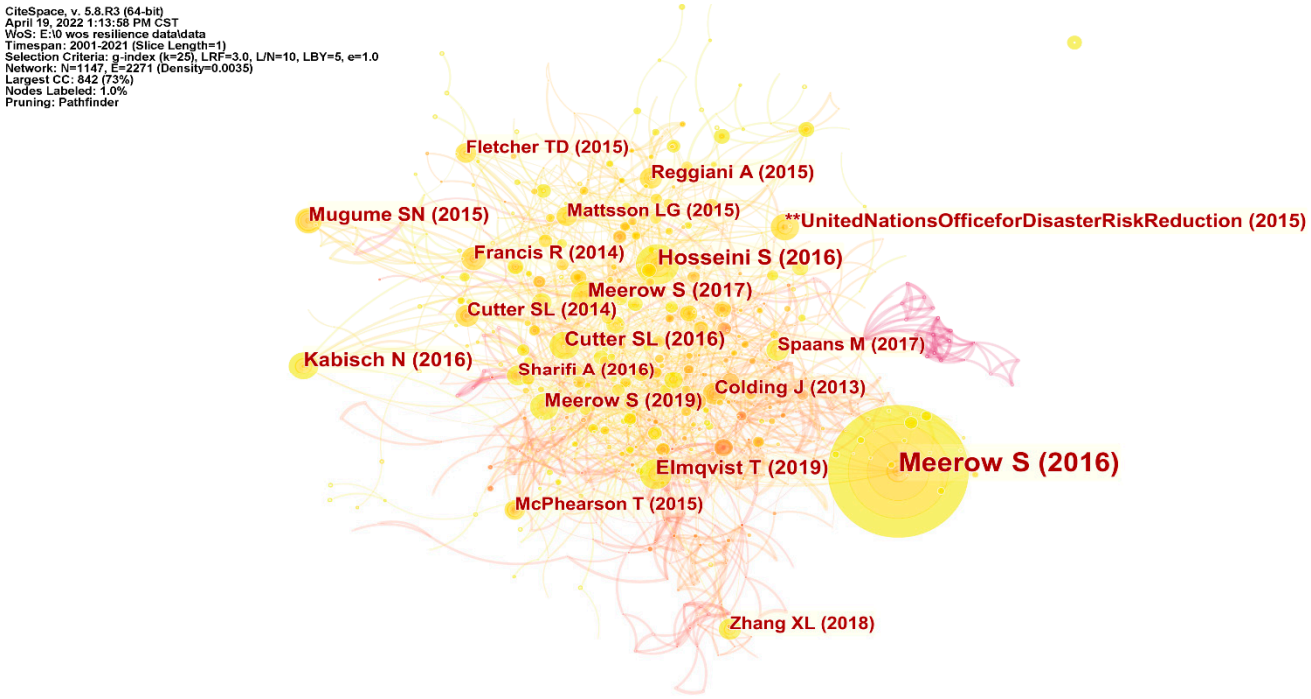

Figure 5. Collaborative co-occurrence map of highly cited articles in RC research.

Table 3. Highly cited references of RC research.

S/N	References	Time	Impact Factor	Frequency
1	Meerow, S., 2016, *Landscape Urban Plan*	2016	6.142	192
2	Hosseini, S., 2016, *Reliability Engineering and System Safety*	2016	6.188	62
3	Meerow, S., 2017, *Landscape Urban Plan*	2017	6.142	48
4	Cutter, S.L., 2016, *Natural Hazards*	2016	3.102	45
5	Elmqvist, T., 2019, *Nature Sustainability*	2019	19.346	45
6	Kabisch, N., 2016, *Ecology and Society*	2016	4.403	43
7	Meerow, S., 2019, *Urban Geography*	2016	4.732	41
8	United Nations Office for Disaster Risk Reduction, 2015, Sendai Framework for Disaster Risk Reduction	2015	/	40

3.2.2. Research Fields

Based on the above analysis of the co-cited literature, the key issues, and hotspots of general concern in RC research focus on three aspects: the definition of concepts, analytical approaches, and evaluation indicators. These fundamental issues and hotspots of widespread concern can intuitively reflect the main research content that constitutes the knowledge base in this field, namely, the following three aspects:

1. Definition and evolution of the concept of resilience.

In the 1970s, Canadian ecologist Crawford Stanley Holling introduced the term resilience from mechanics into the field of ecology [47]. Research on resilience has brought more and more attention to the concept of resilience. Afterward, resilience went from an ecological concept and infiltrated the theoretical research literature. Scholars in sociology and economics began to intervene, focusing on the transition of environmental resilience to the application of resilience concepts to social-ecological systems [48]. Subsequently, resilience gradually began to formally enter the field of urban planning. Many academics have begun to focus on RCs in relation to climate change and catastrophe risk, recognizing

the crucial role of urban design in promoting resilience [49]. In the end, the concept of resilience began to be applied to the specific design of urban form elements. Most of the representative researchers at this stage had professional design backgrounds, including urban design and landscape ecologies, such as Jack Ahern of the University of Massachusetts Amherst and Graeme Ka of Cook University.

Many scholars used resilience as a "metaphor" in the early research stage of the RC research literature. Metaphors are powerful tools for creating comprehensive new ideas, allowing us to use theories or methods from the field of resilience in an entirely different field and to link knowledge from the field of ecology to other fields to support and promote innovation in urban design methods. It is important to note, however, that the incorporation of resilience as a metaphor is at risk of increasing "resilience as a buzzword" and "resilience has no other use than the title" [50], such as staying at this level, thus hindering the usefulness of the concept of resilience. The reason is that the concept of resilience is in the process of a cognitive paradigm shift from engineering resilience to ecological resilience and then from ecological resilience to evolutionary resilience (Figure 6) [51,52]. Cognition has been in a state of continuous evolution.

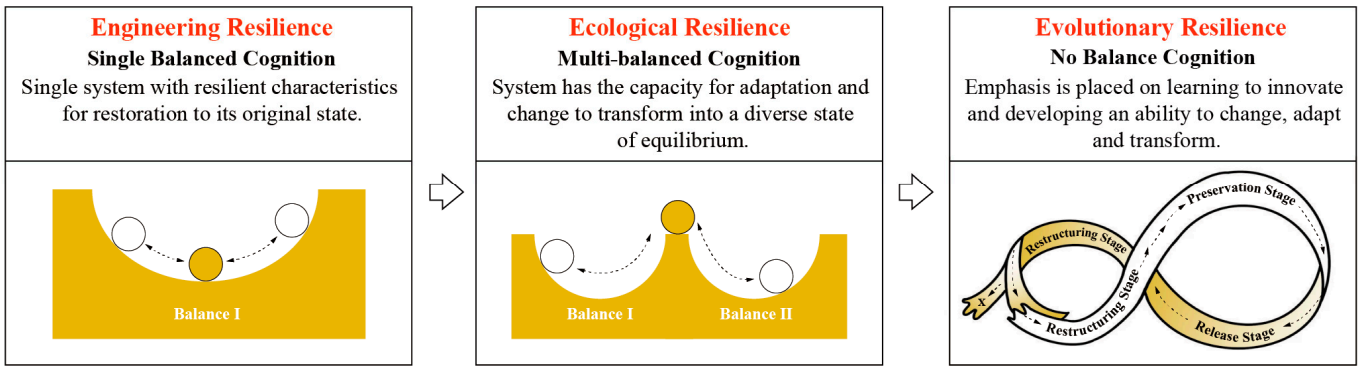

Figure 6. Engineering resilience–ecological resilience–evolutionary resilience evolutionary change.

However, owing to the forward-looking, transformational, and intrinsically ambiguous character of the resilience concept, methodological and technical innovation in urban spatial planning, design, and management led by the notion of resilience is a new area of resilience research [53]. Despite the growing number of studies in the urban sector that incorporate the notion of resilience in various ways, there is no agreement on whether resilience is a loose "motivational" metaphor or a rigorous analytical framework in urban design research and practice. As a result, unpacking the various ways in which the concept of resilience has been integrated into the field of urban design will aid in identifying the problems or barriers in each of these integration approaches and thus support the transformation and development trends of contemporary resilience-oriented urban design [54–56].

2. Research on resilience assessment indicators.

Regular assessment and physical examination of resilience as an essential indicator of sustainable urban development is crucial for dealing with risks such as climate change and achieving urban sustainability [57]. However, a uniform consensus on the best methods and tools for RC evaluation has not yet been reached. Scholars have tried to evaluate RCs using different evaluation methods and indicators based on specific research backgrounds, providing new perspectives and inspirations for further research. For example, in 2016, Hosseini categorized and reviewed the methods of quantifying system resilience [58]. In the same year, Cullter conducted research on resilience evaluation methods and tools and divided them into three types: Indicator method, scorecard method, and toolset method [59].

3.3. Research Hotspots and Research Strategies

3.3.1. Keyword Co-Occurrence Networks

Literature keywords are a reflection of the author's refinement and induction of an article's main content [60]. Word frequency analysis of keywords is often used in bibliometrics to reveal the distribution of research hotspots [61]. "Resilience" had the largest node and the highest word frequency, followed by "climate change." This indicates that faced with global warming, RCs offer a promising paradigm for urban development (Figure 7). Some cities have designed RC planning and construction programs in terms of different adaptation goals and focus areas based on climate risks. RC planning and construction schemes have been designed from different adaptation goals and key areas. Using CiteSpace to draw a co-occurrence map of RC research keywords, we were able to reflect the hotspots and evolution trends. Upon further observation, other high-frequency keywords based on their co-occurrence relationships presented the following three main research contents, according to which the main research contents were analyzed:

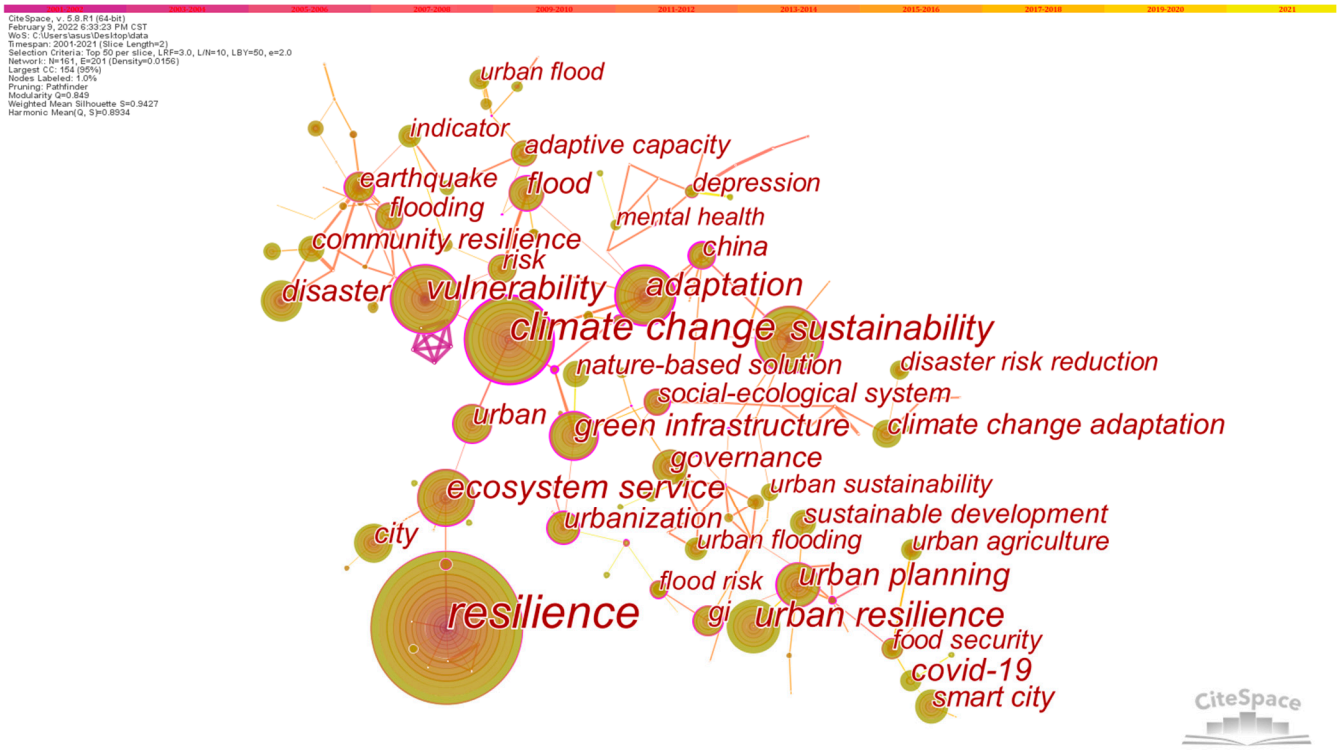

Figure 7. Collaborative co-occurrence map for RC keywords.

1. The Research Perspective of RCs Focalizes Disaster Prevention and Mitigation

The research perspective of RCs mainly focuses on disaster prevention and mitigation, involving post-disaster reconstruction, risk assessment, disaster prevention and mitigation, and risk management. The main contents involved climate change, vulnerability, and adaptability in terms of word frequency. The types of vulnerability that have been studied more frequently involved flooding, earthquakes, and disasters, indicating that natural disasters such as climate change and earthquakes are the primary sources of uncertainty, involving post-disaster reconstruction and risk. Therefore, we have to face new unknown risks (such as SARS and COVID-19) that cannot be predicted in advance [62,63] or fairly evaluate the hazard-induced effect. RCs require to establish disaster prevention and mitigation strategies to deal with "fuzzy" and "uncertain" characteristics.

2. The Primary Coverage of RCs Involves the Construction of a Community Resilience Assessment System

In the face of sudden disaster risks, systematic resilience evaluation theory systems have become an important measure to identify the vulnerable factors of the community system, reduce the risk of building resilient communities, and improve the level of community resilience [64]. "Disaster" and "indicator" are the research hotspots at this stage. In addition, "depression" and "mental health" also became explosive topics. According to the studies, increasing evidence showed that negative emotions such as anxiety and fear caused by disasters have led to adverse effects on individuals' mental and physical health. Moreover, public health crises have raised extensive concerns about the resilience of cities and their ability to prevent and control risks [65,66]. With the expansion of resilience in social ecology, the significant importance of social persons or groups in enhancing city and community resilience has likewise emerged [67].

3. The Construction of RCs Is Mainly in the Field of Urban Planning

Research has focused on adaptive strategy research to improve RCs by optimizing factor allocation and urban governance structure. This aspect is mainly based on sustainability, governance, and the social-ecological system, showing the related research on ecosystem resilience from a system perspective and the improvement of RCs and sustainability based on ecological services [68,69]. The research involves green infrastructure, disaster risk reduction strategy, and climate change adaptation.

3.3.2. Keyword Clustering Analysis

The size of the cluster block represents the number of members under the cluster. The labels for each cluster can include the title, keywords, and subject headings in the abstract of the citing document citing the citation for that cluster [70]. Cluster analysis can help to clarify research topics further [71]. The keyword clustering function of CiteSpace was used to generate a clustering network of keywords, as shown in Figure 8, to reflect the current research hotspots. Professor Chen pointed out that the higher the S value in the clustering results, the stronger the homogeneity. If S > 0.5, the clustering is considered reasonable. In this example, the S value was 0.55, which meets the clustering requirements.

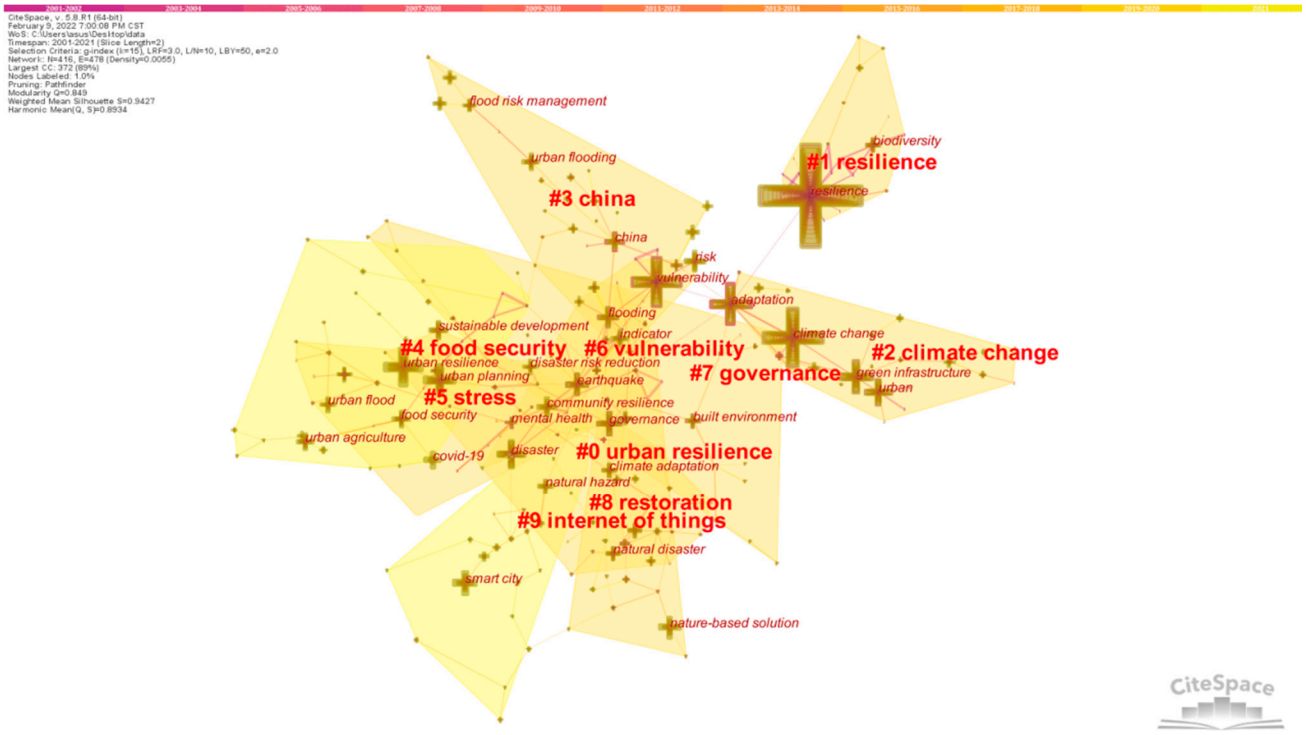

Figure 8. Cluster co-occurrence map for RC keywords.

Analyzing the CiteSpace cluster diagram showed 11 kinds of cluster relationships (Figure 8), while the number of keywords was inversely proportional. These 11 major research themes for RCs were urban resilience (#0), resilience (#1), climate change (#2), China (#3), food security (#4), stress (#5), vulnerability (#6), governance (#7), reconstruction (#8), and Internet of Things (#9). The research under the theme of RCs can be roughly divided into three categories, namely, theoretical discussion, strategy mechanism, and evaluation measurement research. Among them, clusters #0, #1, and #3 belong to the theoretical discussion category, while clusters #4, #5, #6, #7, #8, and #9 belong to policy mechanisms.

3.3.3. Keyword Co-Occurrence Time Partitioning

Based on the comprehensive analysis results, the evolution of RC research can be roughly divided into three stages (Figure 9):

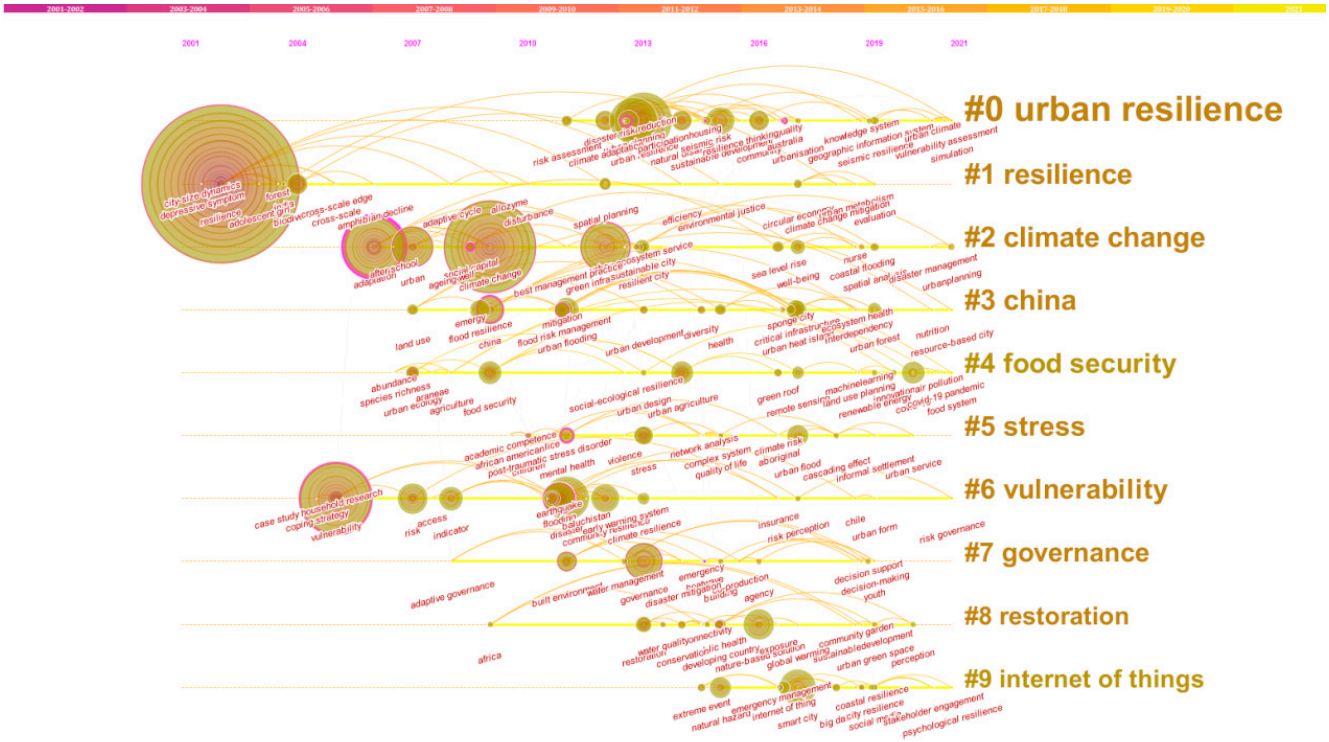

Figure 9. Temporal zoning map of RC keyword co-occurrence.

1. Ecological Resilience Changing to a Complex of Ecological and Social Resilience

Before 2006, resilience research concentrated on the ecological area, namely, examining climate change and ecological vulnerability [72]. Biodiversity was the main research hotspot. Meanwhile, besides focusing on the evolution and development of natural systems, concepts regarding human social systems such as adolescences and households began to appear, which indicates that the concept of ecosystem resilience was gradually applied to human social systems. After 2006, with the continuous expansion of the meaning of "resilience," people began to pay attention to the adaptability of urban systems to acute shocks and chronic pressures, and adoption became a research hotspot. Scholars have begun to investigate the relevance of resilience to social systems and the variables affecting the resilience of socio-ecological systems as the meaning of resilience expands [73]. Furthermore, scholars have identified the importance of social elements such as social capital, demographic features, volunteer activities, values, and beliefs in RCs. RCs have evolved into a complex system comprised of natural ecosystems, human and social systems, physical facility systems, and interactions as the term.

2. Physical Resilience Gives Way to a Mix of Physical and Psychological Resilience

Since 2020, humankind has suffered tremendous challenges and losses due to the new pandemic and the increasing frequency of natural disasters caused by climate change [74]. "Resilience" has been elevated to an unparalleled level. Simultaneously, academics have focused on specific groups' mental health or resilience (e.g., youth exposed to risk or stress) in various communities and other settings [75]. This exemplifies the use of the notion of resilience in psychology. According to research, relational networks comprised of families, community members, and organizations strengthen community attachment and establish powerful social support systems that contribute to community cohesion and resilience [76]. Emotional governance and inclusive institutional frameworks decrease the associated psychological risks originating from preventing and controlling public health crises comparable to those seen in megacities [77].

3. The emphasis of urban disaster prevention and management rapidly changing away from hardware building and toward the use of comprehensive scientific and technical instruments in disaster prevention and mitigation [78].

RCs can prepare for, respond to, and recover quickly from external shocks caused by nature and artificial disasters. Since 2016, due to the depth of construction and administration, RC research has been backed by new-generation information technology such as big data, artificial intelligence, cloud computing, 5G, and the Internet of Things (IoT) [79,80]. Monitoring and early warnings for various disasters, the analysis and management of urban risks, urban post-disaster recovery assessment, resource allocation, and other essential links in the construction of RCs all rely on advanced software and hardware facilities to be fully and effectively implemented [81]. From disaster emergency response to real-time multi-directional monitoring and scientific quantitative assessment, the use of data-driven and decision-making models to guide RC construction and the realization of closed-loop management of pre-disaster planning and construction, disaster emergency response, and post-disaster reconstruction and recovery have made urban disaster prevention and management more intelligent and emergency decision-making more scientific [82]. Currently, with the increasing use of big data, IoT, and other information technologies, the link between RCs and intelligent cities is becoming stronger, boosting urban optimization, and upgrading and strengthening urban safety. With the continuous development of RC and smart city concepts, contemporary cities should organically combine the smart city and RC construction and management platforms to build future cities that integrate "smartness" under daily operation and "resilience" under disaster scenarios.

3.3.4. Research Trends

A breakthrough of CiteSpace is to provide a burst word analysis method based on the word frequency growth algorithm (burst detection) [83]. The method detects specialized terms with high change frequency in a short period by counting citation keywords and presents a citation burst with temporal distribution and dynamic change characteristics, ranked according to size. Examining the historical co-occurrence frequency distribution of emergent words and summarizing their trends over time is suitable for analyzing emerging trends and sudden changes in the development of disciplines [84]. Thus, it can better reflect the research frontiers and development trends in RCs. Herein, the network node was set as "Keyword," and burst terms were selected as the word type to generate 100 burst words that appeared from 2001 to 2021 (Figure 10). "Strength" represents the emergent strength, "Begin" represents the emergent start year, and "End" represents the emergent end year.

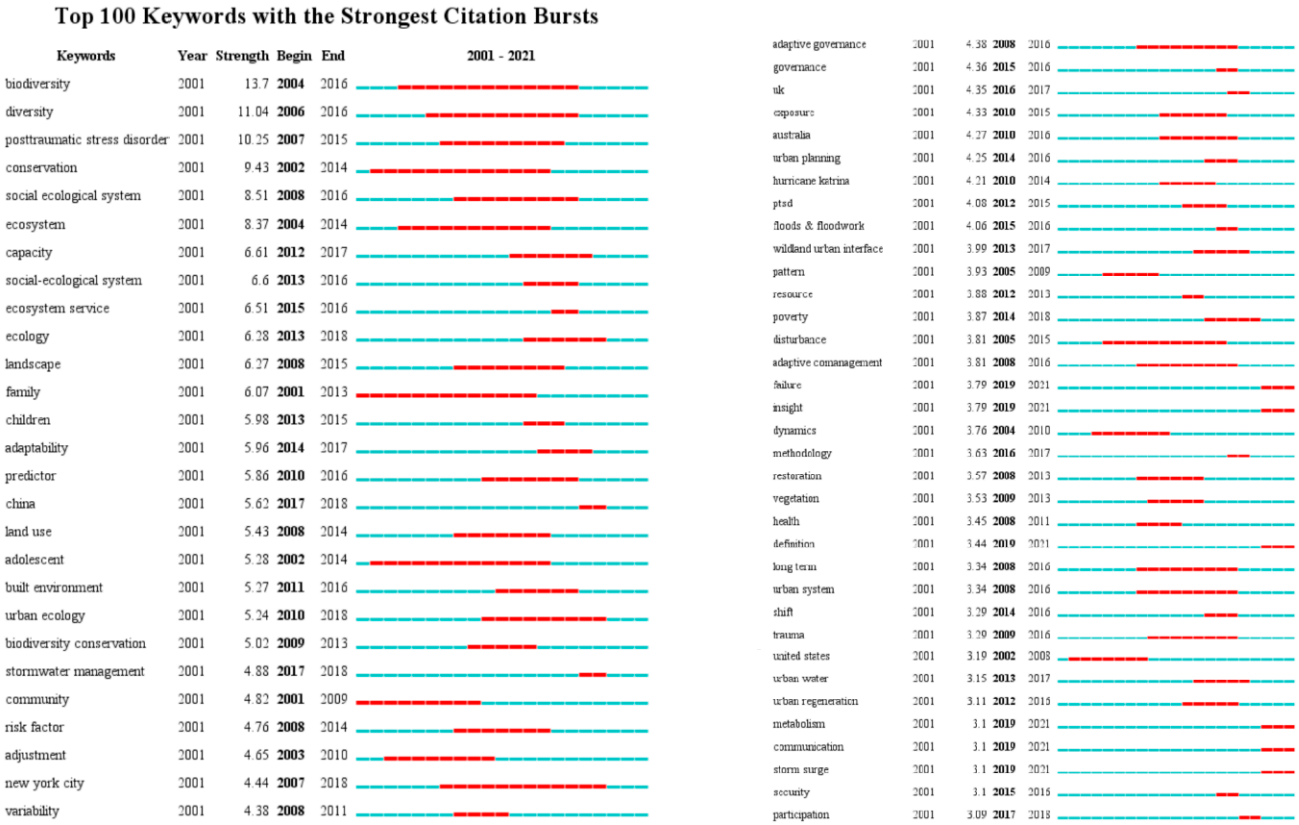

Figure 10. Top 100 keywords with the strongest citation bursts.

The comprehensive development trend of RC research has mainly gone through three stages:

1. From 2001 to 2014, the keyword with the highest emergent intensity in history was "diversity." The strength value reached 15.81, and its initial emergence occurred in 2006. A realistic background to explain this is that the frequent occurrence of natural disasters has led to biodiversity loss. Thus, the research trend primarily focused on biodiversity conservation, public safety, natural disaster risk, and sociodemographic fields.
2. From 2015 to 2018, with the promulgation of the national policy decree, the influence of RCs increased. Therefore, since 2015, the keywords of "governance" and "quality," "perception," and "quality" have become more frequent and have maintained a high degree of prominence. Additionally, the research trend began to turn to urban planning renewal, sustainable development, and other fields. With the in-depth research of theories, countries began to carry out long-term applied research through the promulgation of laws and policies, among which China became a newcomer to the field [85,86].
3. From 2019 to 2021, it is worth noting that many keywords maintained a high emergent intensity, such as "index," "benefit," "risk assessment," "mitigation," "mental health," and "dynamics." Research trends have focused on RC risk assessment, RC index, dynamic mechanism analysis, and ecosystem services. Such research has shown that urban ecological infrastructure is an important measure for dealing with global climate change and solving the problem. The integrated development of RCs and smart cities and the risk assessment of natural disasters based on resilience theory were the general trends in these two years [87,88].

4. Discussion

4.1. Review

Years of work have resulted in substantial advances in theory, methodology, and case studies in RC research. The scope broadens and narrows as it moves from the macro- to micro-level, from a single perspective to several views, from focusing on single large initiatives to national unfolding. We discovered that research on RCs has been separated into three sections (Figure 11).

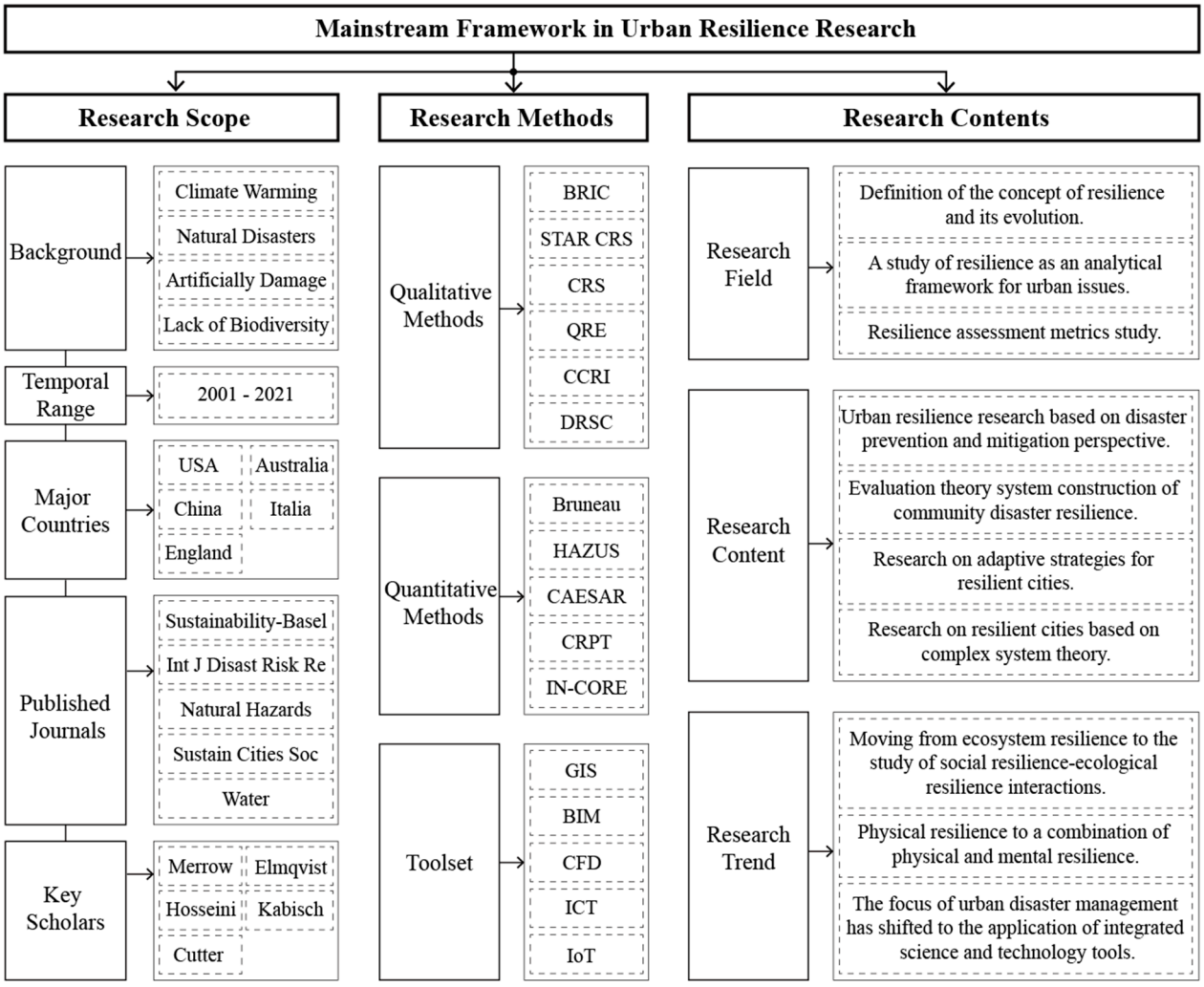

Figure 11. Mainstream framework in RC research.

First, in terms of the research scope, countries have increased their focus in response to global warming, frequent natural catastrophes, and a lack of biodiversity. The number of papers on RC research has dramatically grown. National cooperation is mostly centered around the U.S., China, the U.K., Australia, and other nations with strong economic development patterns, with whom cooperation is more closely coordinated. In contrast, other countries are widely dispersed and significantly fewer in number. Furthermore, the top five journals in terms of article count include *Sustainability*, *International Journal of Disaster Risk Reduction*, and *Natural Hazards*. Those scholars with the highest article co-citations are Meerow, Hosseini, Cutter, Elmqvist, and Kabisch. Notably, Meerow is a core author in the author co-citation network, and he suggested that RC research needs to be inclusive and flexible, which is a promising method for academic collaboration.

Second, both quantitative and qualitative research methods have been employed. Since 2016, empirical research based on quantitative analysis has begun to increase, mainly

related to assessment, with the assessment content involving community resilience and flood control resilience. Hosseini addressed resilience assessment by categorizing and reviewing methods that quantify system resilience [59]. Quantitative classifications can be defined in terms of definitions. For example, Cullter considered resilience an essential indicator of sustainable urban development for regular assessment and physical examination [58]. Meanwhile, qualitative research primarily consists of the definition and development of the concept of resilience, with a "qualitative" analysis of resilience. Using the methods of induction and deduction, analysis and synthesis, abstraction and generalization, the development of resilience and the integration of the urban field have progressed. As an ecological concept, resilience first appeared in the theoretical research literature, with prominent experts and scholars focusing on environmental resilience: the stability, resistance, and recovery time of ecosystems resisting external shocks. Subsequently, scholars in sociology and economics began to intervene to carry out applied research on the concept of resilience in social-ecological systems. Among them, as an essential complex social-ecological system, a series of studies focusing on its social resilience and ecological resilience have emerged, providing the possibility to integrate the social system elements and ecological system elements in a city and helping to understand the social system in said city. The interaction with the ecosystem fundamentally gave birth to the modern thinking of "urban resilience" [89]. Subsequently, the field of urban planning began to participate in research on the concept of resilience, which is starting to be applied to the specific design of urban form elements. Most representative researchers have professional design backgrounds, including urban design and landscape ecology. These include Jack Ahern of the University of Massachusetts Amherst, Graeme Cumming of James Cook University, and Ayyoob Sharifi of Hiroshima University.

Finally, in terms of research content, the research of RCs has established an "infrastructure–institution–economy–society" research framework. This framework involves the definition of the evolution mechanism, the planning response method, and evaluation metrics from three perspectives: Definition evolution, resilience construction strategy, and resilience assessment. Scholars are all dedicated to researching RCs from the standpoint of catastrophe prevention and mitigation and actively responding and recovering after disasters based on the complex evolutionary system. Simultaneously, the research has evolved from ecological resilience to coupled social-ecological resilience through timeframes. Furthermore, mental resilience and health issues have received attention. Emotional governance and inclusive systems clearly reduce the risk of derived social mindsets resulting from public health event prevention and control in similar megacities. With the rise of IoT and the development of smart cities, the focus of urban disaster prevention and management has shifted from hardware development to integrated scientific and technological tools in disaster prevention and mitigation. The organic combination of RCs and smart cities improves urban disaster prevention and management and emergency decision-making.

4.2. Prospects

The research on RCs mainly focuses on ecology, disaster science, sociology, urban planning, and other disciplines. This research has developed rapidly in recent years, and several rich research results have been achieved. However, it was found that the current literature has many shortcomings in terms of the theoretical framework, studies of an empirical nature, and differences in multiple disturbances. Due to the significant differences in the understanding and analytical perspectives of different disciplines on RCs, the theoretical framework of RCs has different focuses, and no accepted theoretical framework has yet been formed. Natural sciences such as disaster prevention and mitigation and ecology are concerned with reducing the impacts and losses caused by disaster risks. In contrast, research is concerned with the physical aspects of cities. Humanities such as urban planning, sociology, and geography advocate addressing urban risk through planning, management, and multi-party participation, focusing on the social dimension's impact on RCs. Because of the complexity of urban systems and the intersectionality of resilience concepts, most

current resilience assessment studies end abruptly when results are available, with no reliability tests being performed, resulting in significant differences in assessment indicators exist. These issues limit the extension and application of the theoretical framework of RCs. This theoretical framework establishes acceptability by distilling the characteristics and connotations of RCs as a simple abstraction of objective things and phenomena. However, due to differences in research perspectives, most RC studies are conducted from a single point of view of disaster mitigation, ecology, and society, with little careful consideration. Thus, they fail to reveal the mechanism of action among urban elements in any depth and suffer from poorly defined concepts, confusing connotations, and a lack of a unified theoretical framework.

The leading role of typical cities, on the contrary, is a critical link in promoting empirical research on RCs. At present, some cities in developed countries, such as New York's *One New York: The Plan for A Strong and Just City*, London's *London Plan*, and Tokyo's *Creating the Future: The Long-Term Vision for Tokyo*, have begun to actively explore the path of building RCs and seeking mitigation and adaptation solutions. Urban risks from climate change and natural disasters are actively addressed by establishing resilience policy implementation agencies and multisectoral coordination mechanisms. However, established RC policies are still in the exploratory stage, and there are fewer applied empirical studies. Locally tailored applied RC programs must be investigated and analyzed on a case-by-case basis. At the macro-level, we need to strengthen policy guidance for building RCs. Society and individuals must improve their scientific understanding of RC at the micro-level. We need to strengthen the applied governance research of RCs at the planning and construction levels.

Therefore, further research in the theoretical framework would provide an effective strategy for clarifying the connotation of RCs, grasping the evaluation object, and building a scientific evaluation system. In addition, it would provide great potential in multi-objective, multi-level, and multi-perspective system evaluation research. Similarly, by focusing on the multidimensionality of elements, the interdependence of elements, the interactive coupling between systems, and spatial visualization techniques, new breakthroughs will be provided in RC impact mechanisms, dynamic simulation, and decision making and early warning. Guided by empirical research based on various uncertain risks, multidisciplinary theoretical methods, trend forecasting, and scenario analysis methods continue to strengthen multidisciplinary integration and explore application models. At the same time, this paper has some limitations:

1. The data sources were relatively limited, and the core set of the WoS database was mainly selected as the data source;
2. Although this research included titles, abstracts, authors, keywords, and so on, some relevant literature may not have been included in the statistics;
3. The citation rate of articles has a cumulative effect over time and the citation rate of papers published in recent years may be low, meaning that they could not be effectively extracted and analyzed by relevant software;
4. Due to the dynamic online update of the database, the results of bibliometric analyses have a certain timeliness.

We need to maintain a constant and dynamic focus on research related to RCs. Moreover, we should keep an eye on the dynamic evolution laws of next-generation information technologies such as big data, artificial intelligence, cloud computing, 5G, and IoT. Furthermore, we should continue to monitor the progress of RC research in interdisciplinary fields to ensure the comprehensiveness of the literature and more accurately summarize the research evolution of RCs as a whole.

5. Conclusions

In summary, this paper conducted a bibliometric analysis of the last 20 years, indexed by the WoS database SCI-E using CiteSpace software. This paper analyzed, classified, and interpreted the (1) research progress, (2) research hotspots, and (3) research strategies in RCs over the last 20 years. Moreover, the research hotspots were revealed under the topic

clustering of the co-occurrence network based on keywords. Finally, the thematic evolution trend of RCs was summarized according to the time zone distribution characteristics of keywords, and the following conclusions were drawn:

1. From the author's point of view, the author of highly cited literature has lower productivity, but it has a greater impact on the research of RCs.
2. A comprehensive analysis of the distribution of research in countries and regions shows that research is mainly concentrated in countries with high urbanization levels or rapid urbanization processes. Research teams and research institutions are concentrated in universities, but there is a lack of cooperation with non-university institutions and professional research institutions.
3. Based on the highly cited literature, in recent 20 years, the research on RCs mainly focuses on the concept and dynamic evolution law of urban resilience, the analysis framework of RCs in urban problems, and the evaluation index. With the integration and development of the concept, the research and practice in urban design began to change comprehensively, and the corresponding goals, thinking, and methods, etc. However, from the dynamic evolution of the theory of RCs, the analytical framework, and the analysis results of evaluation indicators, although the exploration of the integration of the concept of resilience in urban design has achieved diversified development, the scientificity and accuracy of the application of the concept of resilience need to be improved.
4. From the perspective of research hotspots and research strategies, the current research status of RCs is analyzed: since 2016, it has been widely concerned by academic circles, and many scholars have made in-depth research on the evolution mechanism, disaster prevention and mitigation, climate change, urban area, and economic resilience, and achieved fruitful results. With the adoption and application of the concept of elasticity in various fields, the research topics of RCs have become more and more extensive, from the early psychological resilience and ecological resilience to the diversified research of different dimensions and processes in the social field. The problems studied have also been extended from the early restoration of natural ecology and spirit to urban regional planning, infrastructure construction, reconstruction of the built environment, water supply, and other issues. The concept of resilience can be applied in many fields, such as economy, society, cultural ethics, resources, environment, etc. Resilient cities also replace traditional urban emergency or contingency research as the focus of follow-up urban development research. In addition, the subjects discussed in terms of the evaluation system and action mechanism are diverse, and not only the government level, macro-planning level, but also social forces and people have a large degree of participation.
5. From the perspective of research strategies and methods, the relevant research mainly focuses on three aspects: Theoretical framework, evaluation measures, and action mechanisms. In the study of the dynamic evolution of the concept of RCs, qualitative and quantitative research are used to study the evaluation strategies and contents of RCs. However, the related research still focuses on the static evaluation and theoretical construction, focusing on theoretical analysis, ignoring dynamic mechanism analysis, and planning practice. In conclusion, this paper showed that future research needs to combine the empirical research and exploratory analysis of relevant cases and focus on the comprehensive research of basic theories, evaluation systems, and action mechanisms.
6. Future urban research trends focus on areas such as risk assessment of RCs, RCs index, dynamic mechanism analysis, and ecosystem services. The research shows that urban ecological infrastructure is an important measure to deal with global climate change and solve the problem of RCs, and the integrated development of smart cities and RCs and the risk assessment of natural disasters based on resilience theory are the general trends of research in recent two years.

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