



Research article

Sustainable brownfield redevelopment and planning: Bibliometric and visual analysis



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ABSTRACT

Environmental and urban sciences have shown that brownfield problems significantly impact human behavior and the environment. Understanding the sustainable planning and redevelopment of brownfields can help governments and financial partners consider sustainable urban policies a key priority. This study presents a bibliometric analysis of research publications on the sustainable redevelopment of brownfields through the Scopus database since 1990. The redevelopment of brownfields has an essential role in urban sustainability, so research trends on the sustainable redevelopment of brownfields in previous literature are revealed. To our knowledge, the bibliometric analysis of the term sustainable redevelopment of brownfields is not yet an accentuated field of research. To do this, this study aims to fill this gap by offering a broad overview of the bibliometric analysis of the literature relating to this term. Brownfield and contaminated land are used as keywords in the article titles taken from the Scopus database on September 07, 2021. A total of 7197 scientific articles (Scopus) were reviewed to show how the research on “brownfields or contaminated land” has emerged and developed. Social media analysis (VOSviewer) was used for data visualization, and Harzing’s Publish or Perish used for metrics and citation analysis.

The results showed an increase in the growth rate of the literature on sustainable brownfield redevelopment since 1990, particularly from 2011 to 2020. Research related to the sustainable redevelopment of brownfields has involved various authors and is published in various languages. There are 160 authors from 126 countries and 160 institutions. China is the largest contributor to this study, followed by the United States and the United Kingdom. The Chemosphere Journal has published the most articles on the sustainable redevelopment of brownfields. Although our results also indicate that studies on the sustainable redevelopment of brownfields are mainly carried out in the field of environmental sciences. Some avenues for future research have been analyzed in three directions so that sustainable development can easily be integrated into a brownfield redevelopment project.

1. Introduction

Brownfield is generally found in urban or rural areas, and especially the consequences are negative on the environment [1,2], which requires an intervention to reorganize it for beneficial use and to reduce pollution [1]. Our study assesses abandoned and underused spaces or constructions, but not necessarily post-industrial or even contaminated. In the current context of urbanization,

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where the expansion of cities is expanding at an accelerated pace, different spatial planning policies are developing for a concept of a sustainable and viable city [3]. Then in the field of sustainable brownfield redevelopment planning and design, recent studies have assessed the interaction of crucial human behavior on the environment. Thus, since the dawn of time, many cities worldwide have suffered severe damage to human health and the ecological environment, which forces us to understand human actions, such as laws, standards, and the economic dimension for sustainable brownfield development or former commercial sites. This observation was noticed in literature in 1974, the researcher related the emphasis placed by the United States on geography as a spatial organization, which has evolved over the last fifty years [4]. Then another emphasis on human-land relations is followed by a focus on differentiation in the territory [4]. According to the research by Khan [5], the impact of the population growth rate on Bangladesh's economy has an evident influence of lousy planning in which the population has never been included as an endogenous variable. Then a large part of the rural population consists of farmers and landless sharecroppers, so the land ownership model contributes to low productivity. This leads us to ask ourselves how to understand and evaluate the underused spaces in urban or rural areas, otherwise called brownfields. These latter notions have evolved so that many countries of the world have very different conceptions if it a question of defining them. After a long period of soil contamination, the "sustainable development of brownfields or contaminated land" begins with a particular indulgent curiosity and a more or less real impact on urban development practices. This is particularly the case in land use planning and local urban policies, where we can see that this concern is integrated nowadays, under the pressure of visible realities or negative impacts on abandoned industrial sites.

As in most research disciplines, various theoretical and methodological approaches have addressed sustainable brownfield redevelopment. However, some methods lack or are insufficient for properly integrating sustainable development in the planning or sustainable redevelopment of brownfields. For example, issues related to the impact and consequences of brownfields on the city's economy, environmental pollution, and deterioration of urban functions [6]. Brownfields also give the city a bad image. Thus, this study is part of the continuation of research on evaluating the sustainable development or redevelopment of brownfields. It aims to provide a vision of the progress of scientific research by analyzing the literature on the sustainable brownfields redevelopment and planning using bibliometric indicators. Then, specified the main areas for future research using the pooled analysis of the search results of the most cited articles by citation topic from each country, and the following evaluation steps are considered for further bibliometric analysis:

1.1. What do we mean by brownfield sites?

Brownfields are like land forgotten due to severe and real contamination [7], then financial and social complexities prevent their redevelopment [8–10]. They are generally identified as struggling urban areas and are found mainly in urban centers, peri-urban and rural areas that were once heavily industrialized [7,10]. In Canada, the unanimously accepted definition of "brownfields" comes from the National Round Table on the Environment and the Economy [5], "brownfields" are abandoned, unused, or underused commercial or industrial buildings. Although they contain or may contain environmental pollutants due to previous use, they have significant development potential [7,11]. In the United States, the term "brownfields" received attention in the 1990s, but its definition [11] was adopted in January 2002. They refer to abandoned, inactive, or underused industrial or commercial lands and facilities [12,13]. These lands' redevelopment processes and use are often more complex than other land use planning processes due to objective or anticipated environmental pollution [14]. The USEPA (the United States Environmental Protection Agency) estimates that more than 450,000 brownfield sites are present across the United States [7,15]. However, the National Brownfield Association states that more than one million brownfield sites may exist in the United States alone. As much as \$2 trillion of real estate may be undervalued due to contamination [7]. This explains that the land is an essential part of the life support system and a crucial factor of production and precious resource in economic systems [8,16]. Unlike the United States, the United Kingdom reports that these lands are not necessarily industrial or contaminating but were once used for other purposes and now lies unused. They may include former industrial areas and former commercial areas, petrol stations, ports, terminals, airports, and other industrializations left by the process, equipment, buildings, factories, or the whole area.

Developing brownfield sites in the United Kingdom requires site investigation for contamination as part of the regulatory planning process [17]. The HOMBRE shift in thinking relates not only to the redevelopment itself, but also to gain better understanding in early recognition and prevention of land that might become a BF(brownfields) in the future, and how to monitor this as part of (and closing) the land use cycle (<https://cordis.europa.eu/project/id/265097/reporting>).

Although there are different definitions, we note that they emphasize "brownfields" as land in an "abandoned" state whose development momentum is "slowed down". However, traces of the past remain and place constraints on municipal planning [18]. The contaminated spaces are found in developed large cities, which are a burden on municipalities. Some methods adopted to redevelop contaminated areas are deficient or insufficient in the planning and sustainable redevelopment of brownfield sites. For example, problems related to multi-component metal alloys on the site, population and urban growth, pollution or potential of the environment, deterioration of urban function, and policies and regulations on using such contaminated or abandoned land. Not only, from an aesthetic point of view [19], the recycling and reuse of these abandoned areas improve the image of a city, but above all, in a logic of adequate soil management, it ensures a measured consumption of the soil, clean up the contaminated earth and reduce urban sprawl synonymous with peri urbanization and source of many problems.

1.2. Sustainable brownfield redevelopment planning

In the current context of sustainable redevelopment of brownfield, transforming existing contaminated or precarious built-up fabric

has become an appropriate solution to limit urban expansion and its harmful effects. Brownfield sites (common examples of brownfields include former gas stations, metal plating facilities, and dry cleaners.) or contaminated sites (common examples of contaminated sites means any contiguous land, sediment, surface water, or groundwater area that contains contaminants that may be harmful to human health or the environment), often located in the urban center, are a major urban development issue, but we note at certain levels a lack of investors. The divergent ideas of the project, specific rules, and land-use planning laws do not facilitate the redevelopment of sustainable brownfield sites. Beyond these shortcomings, we hope for a scientific idea that can integrate sustainability into the redevelopment of brownfield sites. For example, an empirical case study shows that the redevelopment of the Army Club in Vrsac, Serbia, is based on the collaboration between various national institutions, local entrepreneurs, and local authorities. The model was adopted as a possibility of making all the stakeholders cooperate collaborative planning based on communication without distinction between the various stakeholders to make the project sustainable [20–22]. This approach is based on a collaboration of information and expertise of the various stakeholders in order to harmonize the different intentions (called the common social interest) [21–24]. According to the research by Jacques Theys [25], sustainable development requires “to focus, as a priority, on spaces of discontinuity: no man’s land between two neighborhoods, brownfields, cutoff effects, border areas.” These vacant or underused urban spaces provide communities with land reserves within a city center with fewer opportunities for building development. According to the research by Malika Wyss et al. [26], “brownfields” relate those brownfields “undoubtedly constitute a significant potential of under-exploited land or infrastructure (even abandoned) and an opportunity for urban requalification and densification.” For our case study, to talk about the sustainable planning of the redevelopment of a brownfield, first an analysis of the factors that enter into the planning or the redevelopment of this brownfield, then that influence the development of this process, to evaluate the process of its planning or redevelopment at the district, city and country level, all to be able to verify, correct, and complete the hypothetical variables of the sustainable project.

2. Materials and methods

2.1. Library analysis

Library analysis has become the most commonly used method for researchers to evaluate advances in scientific research in various

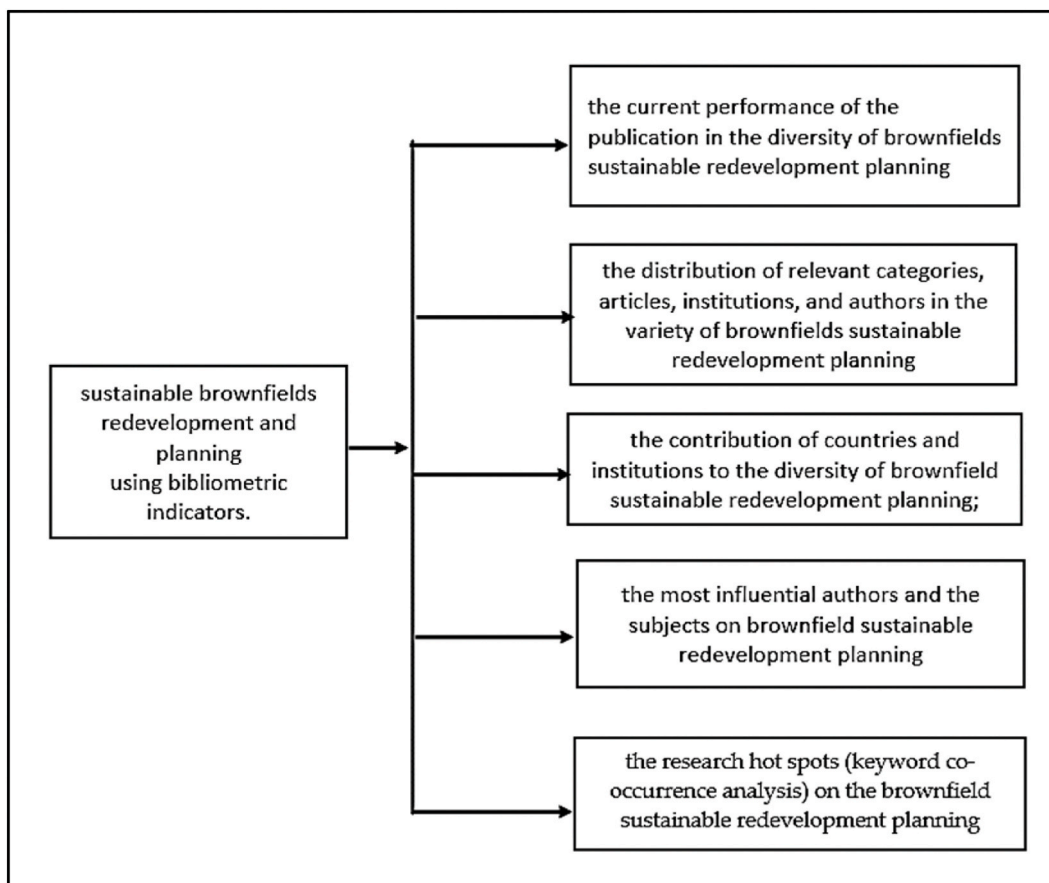


Fig. 1. Evaluating of progress on the sustainable brownfield’s redevelopment and planning.

areas of specialization. Previous research has adopted library analysis to relate existing literature through research topics on different urban issues, such as urban renewal, remediation of contaminated land, sustainability, renewable energy, and environmental management. The overall objective of this work is to undertake a library analysis on the progress of research in the planning and sustainable redevelopment of brownfield sites. This means showing research trends, affiliations, country of authors, searches for citations in articles, identifying how these citations relate to various research on sustainable brownfield redevelopment topics, and how shared citation patterns developed. We will also review the arguments of the previous literature to highlight the weaknesses in formulating innovative proposals so that sustainability can easily be integrated into the planning and sustainable redevelopment of brown fields. From a methodological perspective, bibliographic coupling, quotation and co-citation techniques, and analysis of tasks and co-authors have been commonly adopted in previous research based on library analyses [27–29]. That is to say, we used a web of science, the scopus databases, as analytical tools based on collaboration between authors and publications to measure and compare researchers' results across institutions and countries [30,31]. Then, Harzing's Publish or Perish is used for citation metrics and analysis. Finally, the visual analysis of the network was carried out using the VOS viewer software (version 1.6.16) as a tool that develops the library's data to obtain maps based on clusters which allow presenting the collaborative relationship depending on the number of documents [32–34]. Once research interest is emphasized, various actions can be taken to analyze the collaborative research network, the performance of researchers, and the direction of future research areas related to brownfield remediation, planning, and sustainable brownfield redevelopment. Through our approach, shown in Fig. 1, we can present and consider the literature on sustainable brownfield redevelopment planning.

2.2. Data sources

The literature selection for this library study consists of four steps: digitization, triage, conservation, and sample presentation [35].

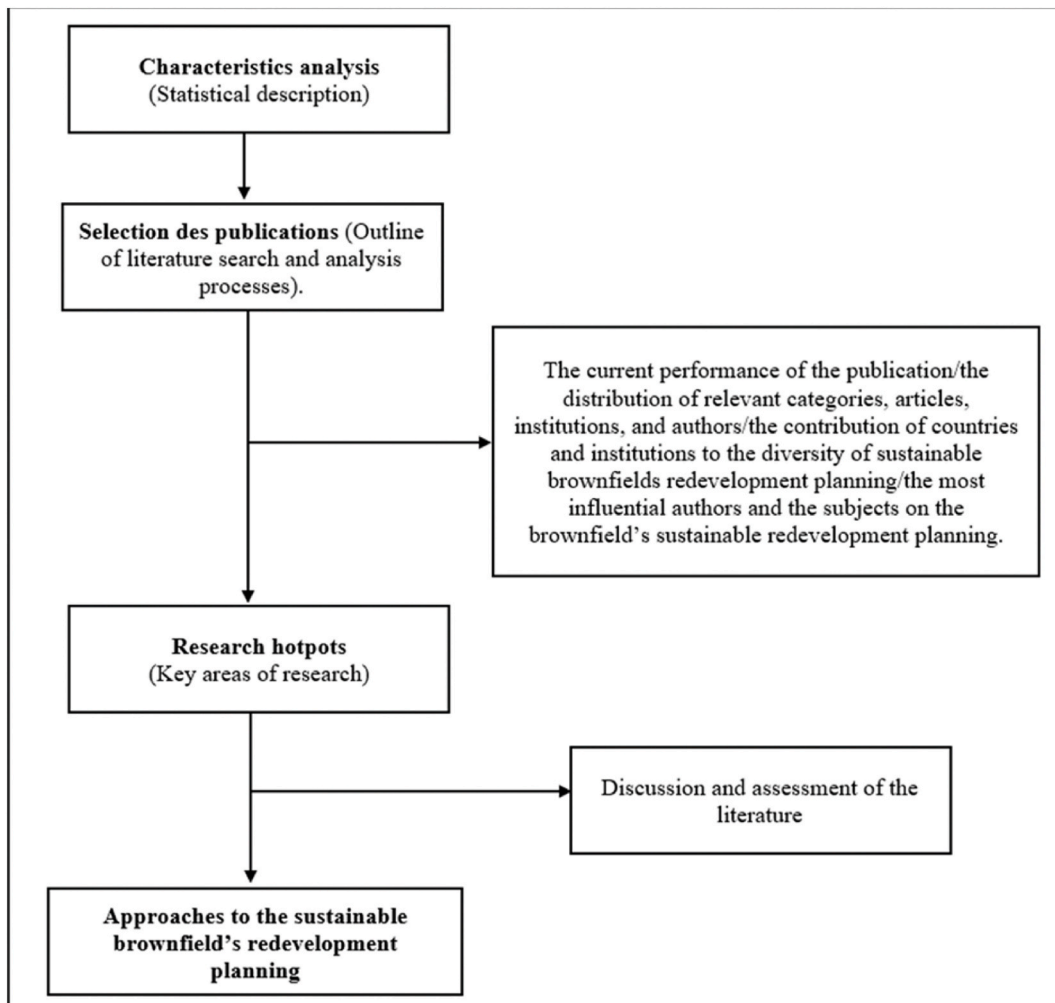


Fig. 2. Research content (methods).

Scopus' ability to provide comprehensive coverage of available resources is an essential data source for academic research. We have selected scientific papers in fields related to the planning and design of sustainable brownfield redevelopment. This study used the following research strategy to retrieve the data (deliberations reports, editorials, and book reviews) were not considered. Subsequently, on September 07, 2021, at 5:05 p.m. (Beijing Time), we extracted documents using the "advanced search" method. The parameters were as follows: the type of literature was "article and reviews," the search term was "titles, abstracts, and subject keywords," and the keywords used were "brownfields" or "contaminated land." The time interval was "1990–2021," and the "source category" was "all articles and reviews." The other terms of the system were by default. For example, 7197 articles were used after excluding transcripts from specific interviews, newsletters, and literature that did not match our themes. Figs. 2 and 3 illustrate the technique of retrieving the literature on the planning and design of sustainable brownfield redevelopment.

3. Results of library analyses and discussions

3.1. The current performance of the publication on the diversity of brownfield sustainable urban renewal

The period lasts 30 years, with publications in very progressive quantities. The overall results show that the total number of annual papers related to the planning and design of sustainable brownfield redevelopment, the average number of authors for each article, and the references cited by the article have increased significantly. 7197 publications. As shown in Fig. 4, in addition to the gradual increase in the annual number of publications between 1990 and 2020, the annual total of citations peaked six times, from 1990–1992, 1993–2000, 2002–2004, 2005–2006, 2007–2009 and 2011–2020. Then also decreased six times, from 1992–1993, 2000–2002, 2004–2005, 2006–2007, 2009–2011, and 2020 to 2021. The number of all documents published per year went from 9 in 1990 to 620 in 2020 and 459 in 2021.

As the number of publications has been estimated annually, we note that the question on the sustainable redevelopment of brownfields remains a field of research for the future of sustainable cities and a difficult area for researchers, from 1990 to 2000. This shows little attention from urban actors and public authorities to brownfields' design and sustainable redevelopment. Nevertheless, scientific research is often associated with certain critical phenomena or even significant events during the same period that influences its course. However, despite the growing number of cities, sustainable redevelopment of brownfields was still not the research hotspot. The factors that explain the lack of publications or the low number of publications could be because urban development was carried out under the influence of the reconstruction of post-war cities, dominated by projects of new urban construction, reduction of human masses in cities, sanitation projects, etc. Today, more than ever, the sustainable redevelopment of brownfields must influence and attract the attention of researchers, in the sense that we are opening up a thematic for future research, namely: 1) studies on the fight against soil pollution; 2) problems and principles of brownfield redevelopment; and finally, 3) the requalification of brownfields for sustainable urban development.). Fig. 4 illustrates the research progress of sustainable brownfield redevelopment planning and design by year (1990–2021).

3.2. Distribution of relevant categories, articles, institutions, and authors

The library analysis of the citations revealed the most productive journals, articles, relevant institutions, and authors. Table 1 describes the main categories of subjects, their documents, and their disciplinary attributes (h-index and their impact factors) during

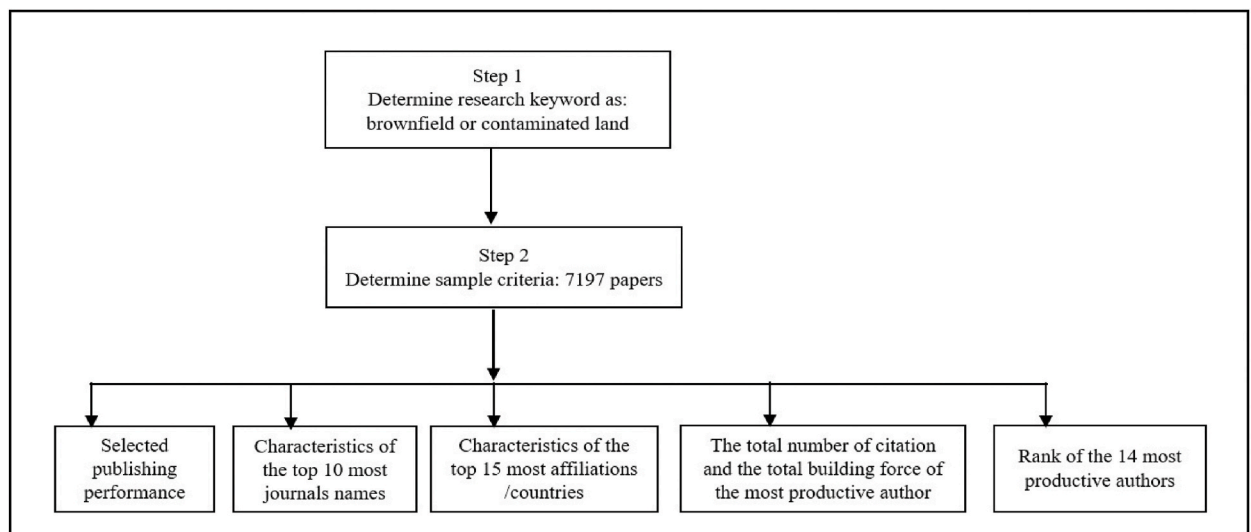


Fig. 3. Outline of literature search and analysis processes.

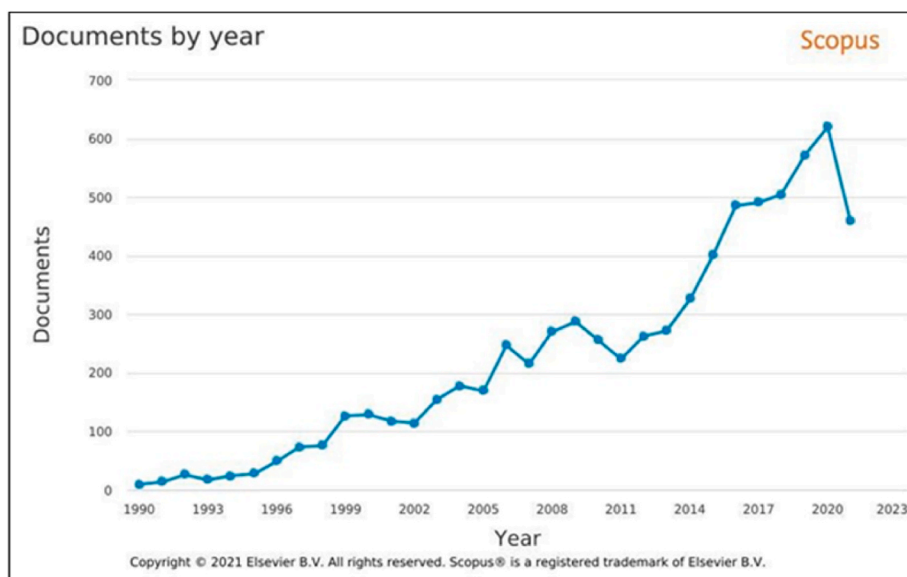


Fig. 4. Research progress of sustainable brownfield redevelopment planning and design by year (1990–2021).

the study period on sustainable planning and redevelopment of brownfields. Since brownfield remediation is interdisciplinary, subject reviews belong to various academic fields such as urban management, environmental, agriculture, and health. For our case study, a total of 6207 publications were recorded in this study of 160 data reviews. The top five journals were *Chemosphere* (520 publications), *Environmental Science and Pollution Research* (434 publications), *Science of the Total Environment* (367 publications), *Journal of Hazardous Materials* (322 publications), and *Environmental Pollution* (222 publications). Fig. 5 shows the number of articles published in the top ten journal categories during the study period. The period 1990–2021 was divided into three classes, aiming to assess the research trend related to urban renewal and sustainability in several classes. For each class, the number of publications has increased and decreased over time, except in *Science of the Total Environment*, for which the research trend in sustainable brownfield renewal has not diminished. The results also show that the annual number of total publications has fluctuated in publications related to sustainable brownfield renewal. There is promising research progress in some dominant classes, notably in *Chemosphere* and *Environmental Science and Pollution Research*.

The 15 most productive institutions that publish research on the planning and sustainable redevelopment of brownfield sites in terms of the number of publications are the *Chinese Academy of Sciences* (403 papers), *Ministry of Education China* (170 papers), *University of Chinese Academy of Sciences* (142 papers), *Zhejiang University* (78 papers) and the *United States Environmental Protection Agency* (75 papers). Most institutions that produce research on the subject are based in developed countries. Of the 15 most relevant institutions (Table 2 and Fig. 6), China ranks first with 1145 publications or a rate of 15.90% of the total research progress of sustainable brownfield redevelopment planning and design. This meant that research on the sustainable redevelopment of brownfields had become a hot topic in China's environmental, urban and geography studies.

Fig. 7 shows the global distribution of publications of the 15 most productive countries related to brownfields' planning and sustainable redevelopment, covering 126 countries. Among the 126 countries, the country with the most important scientific production is China (1585 papers), representing 22.02% of the total, followed by the USA (1228 papers), representing 17.06% of the total, and the United Kingdom (860 papers), representing 11.95% of the total (see Fig. 7). These results indicate visibly developed countries with a large number of documents. Of all the global distributions of related publications on sustainable brownfield planning and redevelopment since 1990, China and the United States are the most significant contributors to the advancement of research on sustainable brownfield redevelopment planning and design.

Table 3 and Fig. 8 show the 15 most productive papers in terms of citation and degree of contribution links with other authors on the Sustainable brownfield redevelopment and planning. Because they had the most significant impact on total local quotes and

Table 1

The top 5 journals' names.

Ranks	Journals	1990–2000	2001–2010	2011–2021	Total of documents	Impact factor (2019)	h-index
01	<i>Chemosphere</i>	X	95	425	520	7.086	126
02	<i>Environmental Science and Pollution Research</i>	X	X	434	434	3.056	113
03	<i>Science of The Total Environment</i>	17	86	264	367	7.96	180
04	<i>Journal of Hazardous Materials</i>	X	71	251	322	9.52	120
05	<i>Environmental Pollution</i>	X	78	144	222	8.071	132

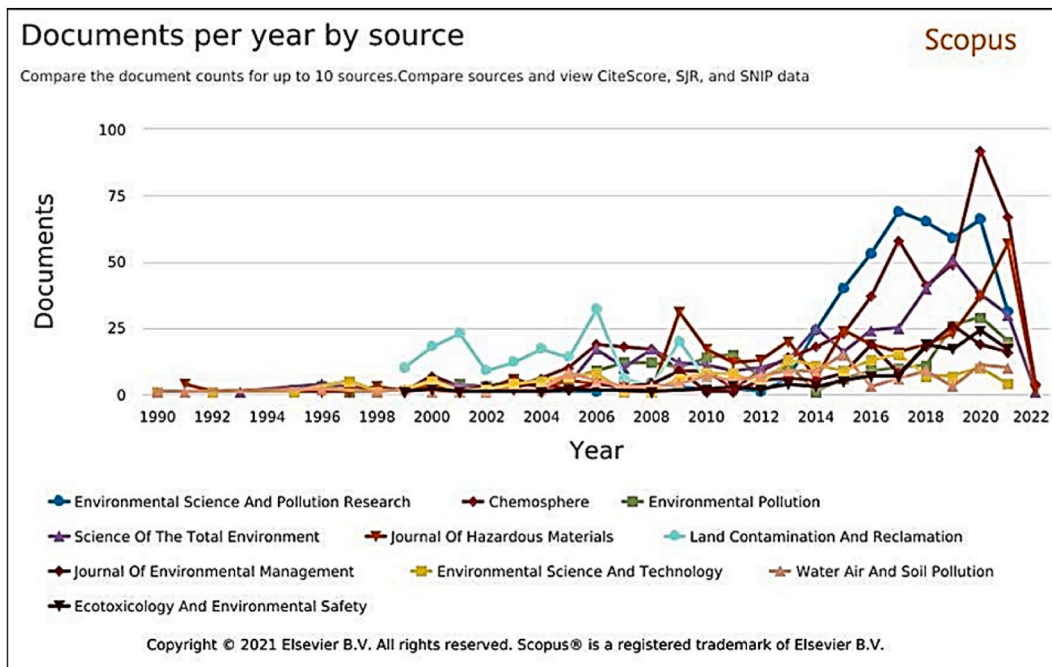


Fig. 5. The top 10 journals' names.

Table 2

The top 15 worldwide affiliations of publications related to research progress of sustainable brownfield redevelopment.

AFFILIATION	TP	TP (%)	Country
Chinese Academy of Sciences	403	5.59	China
Ministry of Education China	170	2.36	China
University of Chinese Academy of Sciences	142	1.97	China
Zhejiang University	78	1.08	China
The United States Environmental Protection Agency	75	1.04	USA
CNRS	72	1	France
Ministry of Agriculture of the People's Republic of China	70	0.97	China
Chinese Research Academy of Environmental Sciences	63	0.87	China
Consejo Superior de Investigaciones Cientificas	61	0.84	Spain
Research Center for Eco-Environmental Sciences Chinese Academy of Sciences	61	0.84	China
University of Lorraine	58	0.80	France
University of South Australia	57	0.79	Australia
Sun Yat-Sen University	53	0.73	China
Tsinghua University	53	0.73	China
Nanjing Agricultural University	52	0.72	China

international academic cooperation. The most influential article in this literature is that of De Sousa (2003) [36], with a total of 203 citations, entitled “Transforming Brownfields into Green Spaces in the City of Toronto,” published in Landscape and Urban Planning. This article examines the issues, obstacles, and processes involved in the remediation of potentially contaminated urban brownfield sites. Their conversion to green spaces identifies the benefits of these green spaces to the community and culture and understands the specific planning processes. Then was followed by Christopher G. Wedding (2007) [37] with a total of 137 citations, entitled “Measuring site-level success in brownfield redevelopments: A focus on sustainability and green building,” published in the Journal of Environmental Management. This research has achieved all four objectives within a broader framework of characterization and quantification of the success of brownfield revitalization:

- to define 40 total indicators that define and determine the success of brownfield redevelopments in four categories: environment-health, finance, livability, and social-economic;
- to use these indicators to develop a partially automated tool that stakeholders in brownfield redevelopment may use to more easily access and communicate success (or failures) in these projects;
- to integrate “green” buildings as an important aspect of successful brownfield redevelopments;

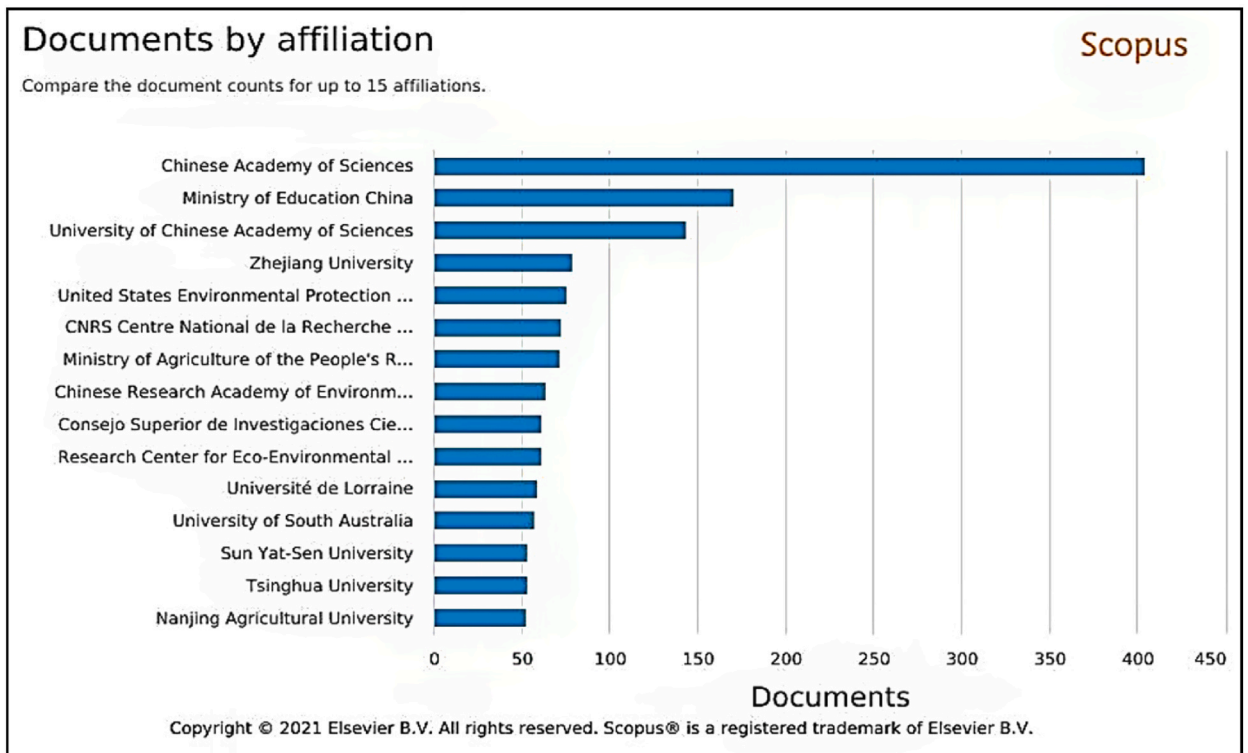


Fig. 6. The top 15 worldwide affiliations of publications related to research progress of sustainable brownfield redevelopment planning and design.

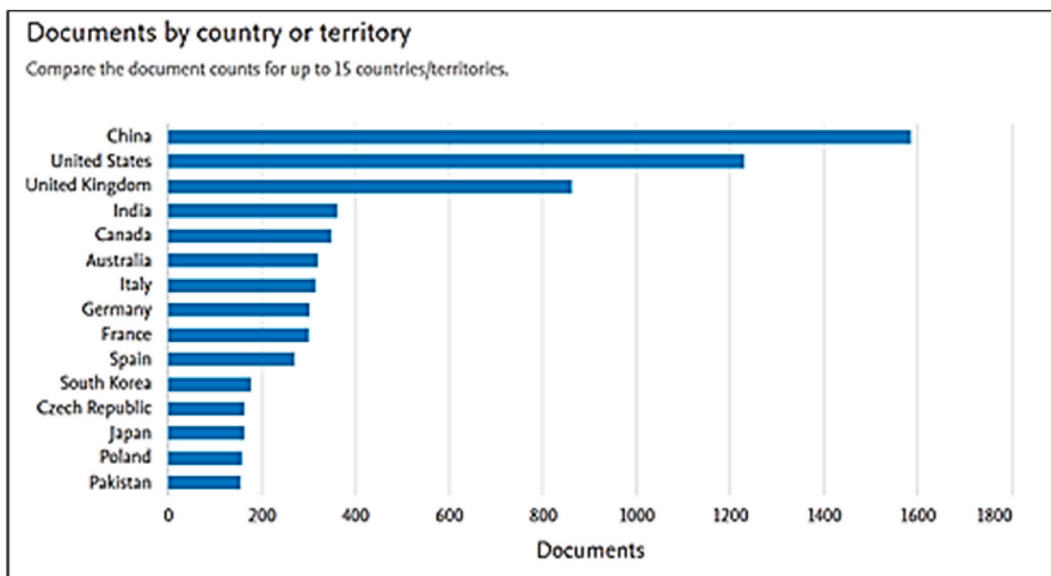


Fig. 7. The international academic cooperation of the 15 most productive countries.

> and to develop this tool within a specific multi-attribute decision method (MADM) framework, the hierarchical analytical process (AHP).

This being the case, future research should include the operationalization and application of this tool to specific sites [38]. Most of the most influential articles deal with industrial wasteland or soil pollution and environmental protection.

By analyzing researchers' information using Vosviewer software, 3049 authors published articles on sustainable brownfield

Table 3

The total number of citations and the links between articles, measured by (reciprocal) quotations of the most productive authors.

Years	links	papers	journal	citation	author	refs
2003	5	Turning brownfields into green space in the City of Toronto	Landscape and Urban Planning	203	Christopher A. De Sousa	[36]
2007	2	Measuring site-level success in brownfield redevelopments: A focus on sustainability and green building	Journal of Environmental Management	137	Christopher G. Wedding	[37]
2007	3	The challenge of sustainability: incentives for brownfield regeneration in Europe	Environmental Science Policy	124	Gareth Thornton	[39]
2011	2	Creative intervention in a dynamic city: A sustainability assessment of an interim use strategy for brownfields in Leipzig, Germany	Landscape and Urban Planning	105	Emily L. Rall	[40]
2005	1	The role of liability, regulation and economic incentives in brownfield remediation and redevelopment: evidence from surveys of developers	Regional Science and Urban Economics	91	Anna Alberini	[41]
2000	6	Lessons from Private Sector Brownfield Redevelopers	Journal of the American Planning Association	81	Peter B. Meyer	[42]
2002	4	The brownfield dual land-use policy challenge: Reducing barriers to private redevelopment while connecting reuse to broader community goals	Land Use Policy	76	Linda McCarthy	[43]
2006	4	Unearthing the benefits of brownfield to green space projects: An examination of project use and quality of life impacts	Local Environment	62	Christopher A. De Sousa	[44]
2016	4	Timbre Brownfield Prioritization Tool to support effective brownfield regeneration	Journal of Environmental Management	51	Lisa Pizzol	[45]
2005	5	Policy performance and brownfield redevelopment in Milwaukee, Wisconsin	The Professional Geographer	43	Christopher A. De Sousa	[46]
2015	3	Factors affecting brownfield regeneration in post-socialist space: The case of the Czech Republic	Land Use Policy	40	Robert Osman	[47]
2011	5	An integrative methodology to improve brownfield redevelopment planning in Chinese cities: A case study of Futian, Shenzhen	Computers, Environment, and Urban Systems	38	Fangfang Cheng	[48]
2006	3	Understanding brownfields regeneration in the US	Local Environment	33	Lauren Heberle	[49]
2010	4	Cleaning up the mess: Redevelopment of urban brownfields	Economic Development Quarterly	24	Richard C.Hula	[50]
2020	3	Mapping the obstacles to brownfield redevelopment adoption in developing economies: Pakistani Perspective	Land Use Policy	07	Naveed Ahmad	[51]

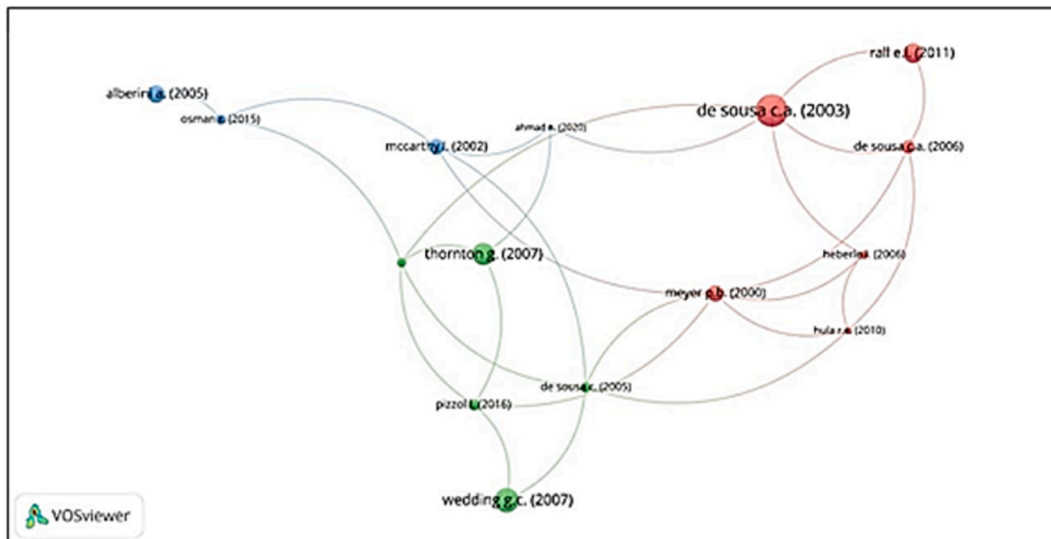


Fig. 8. The total number of citations and the links between articles, measured by (reciprocal) quotations of the most productive authors.

redevelopment and planning from 1990 to 2021. For the identification of influential authors, we defined “2 publications” as a threshold and chose the “author” option instead of “first author” via Vosviewer software. We have selected 14 authors relevant to researching brownfield sites’ design and sustainable redevelopment. Stanislav Martinat is the most productive author, publishing 32 articles with 288 total link strength collaboration. Petr Klusacek published 22 papers and placed second with 270 total link strength collaboration. Jan Kunc came third with 17 papers with 200 total link strength collaboration. Krejci T. ranked fourth with 11 papers with 94 total link strength collaboration, Robert Osman placed fifth with ten papers and his total link strength collaboration is 183, and so on. 8 authors have published 5–9 articles each (Table 4, shows the documents published by authors and them total link strength). However, the authors contributed between 5 and 32 papers, indicating that many researchers have made substantial contributions to

this area.

3.3. Research hot spots (keyword co-occurrence analysis)

3.3.1. Keys word

As long as sustainable urbanization is a challenge for the world's cities, they face various challenges, such as urban degradation, land pollution, environmental degradation, lack of infrastructure, social problems, and economic decline. The analysis of the planning or redevelopment of brownfield sites in different regions or countries is necessary to identify the brownfield problems in the world. This is how urban actors must always continue to improve the planning or redevelopment of brownfield sites to develop sustainable cities. Based on cluster analysis by the methods of co-occurrence analysis of the keywords of the subject since 1990, namely: "brownfields" and "contaminated land," which are the essential indicators and allow to express the current search trends and the areas of future research [52,53].

According to Peter Drucker, "the best way to predict the future is to create it." Thus, based on the analyses of the subjects collected in the VOSviewer, we have chosen the keywords related to the planning and redevelopment of sustainable brownfield sites. For each of the keywords found by a pooled analysis of the search results, the total strength of the co-occurrence links with other keywords was calculated in Vosviewer. The number of keywords for each post has been estimated between 3 and 5. We specify here, although some keywords have similarities. However, they helped us analyze the intellectual structure of future research. We looked at the 7657 individual (brownfield) and 16,582 (contaminated land) keywords with strong links. Figs. 9 and 10 illustrate the main research fields with brownfield and contaminated land, respectively. By synthesizing common words and analyzing sample databases in clusters, the captions illustrate the keyword network of publications frequently related to sustainable planning and brownfield redevelopment since 1990.

We chose the keywords related to urban renewal and sustainable urban development, which were analyzed using the VOS viewer to identify hot spots for future research. The 7657 individual keywords (brownfield) and 16,582 (contaminated land) with strong links for further analysis, as shown in Figs. 9 and 10. Each cluster is marked with a different color; the size of the circle reflects the impact in terms of the number of occurrences of the keyword (the larger the circle, the more it appeared in our research) [49]. The thickness of the links between the keywords indicates the link's strength (the thicker the line, the stronger the links, or the more links between the two keywords) [49].

Keywords (brownfield and contaminated land): cluster 1 (red colored nodes) revolves around the pollution of the earth and its risk to the quality of human health. Second, cluster 2 (green-colored nodes) focuses much more on the sustainable development of brownfields and their economic and social effects. Cluster 3 (nodes in blue) concerns the sustainable redevelopment of brownfields, particularly in the United States and Canada. Finally, cluster 4 (nodes in yellow) concerns the definition of the technical and financial conditions of interventions in the recycling and remediation of polluted sites.

3.3.2. Classification scheme

Based on the clusters identified by the analysis of the keywords brownfield and contaminated lands (Vosviewer, see Figs. 9 and 10), it should be noted that many articles certain clusters (soil pollution and its risks for the quality of human health) and other clusters (sanitation, contamination, and sustainability) usually deal with similar issues. The subjects often relate to the improvement of brownfields, the decontamination of sites linked to sustainable development, or the risks to human health. Thus, the contaminated sites or lands have principles of themes, namely, the remediation of contaminated lands or brownfields and means or policies for an efficient and sustainable redevelopment of brownfields or contaminated lands. Our analysis also relates that these clusters are linked to contamination and the redevelopment of brownfields for sustainable development. They can therefore be considered as four significant groups (contamination and pollution of brownfields, remediation of polluted land, remediation of contaminated sites, sustainable redevelopment of brownfields, and good governance based on laws and regulations). Table 5 below presents a literature review template that has helped guide future research topics.

Table 4
Ranking of the 14 most productive authors.

Rang	author	documents	citations	total link strength
01	Stanislav Martinat	32	498	288
02	Petr Klusacek	22	388	270
03	Josef Kunc	17	400	200
04	Tomas Krejci	11	139	094
05	Robert Osman	10	222	183
06	Bohumil Frantal	10	329	161
07	Christopher A. De Sousa	9	459	092
08	Stephan Bartke	9	355	146
09	Scrabal J.	7	029	085
10	Nevima Jan	7	23	61
11	Yi Zhu	7	56	51
12	Josef Navratil	7	48	81
13	Han Q.	6	62	40
14	Kamila Tureckova	5	55	103

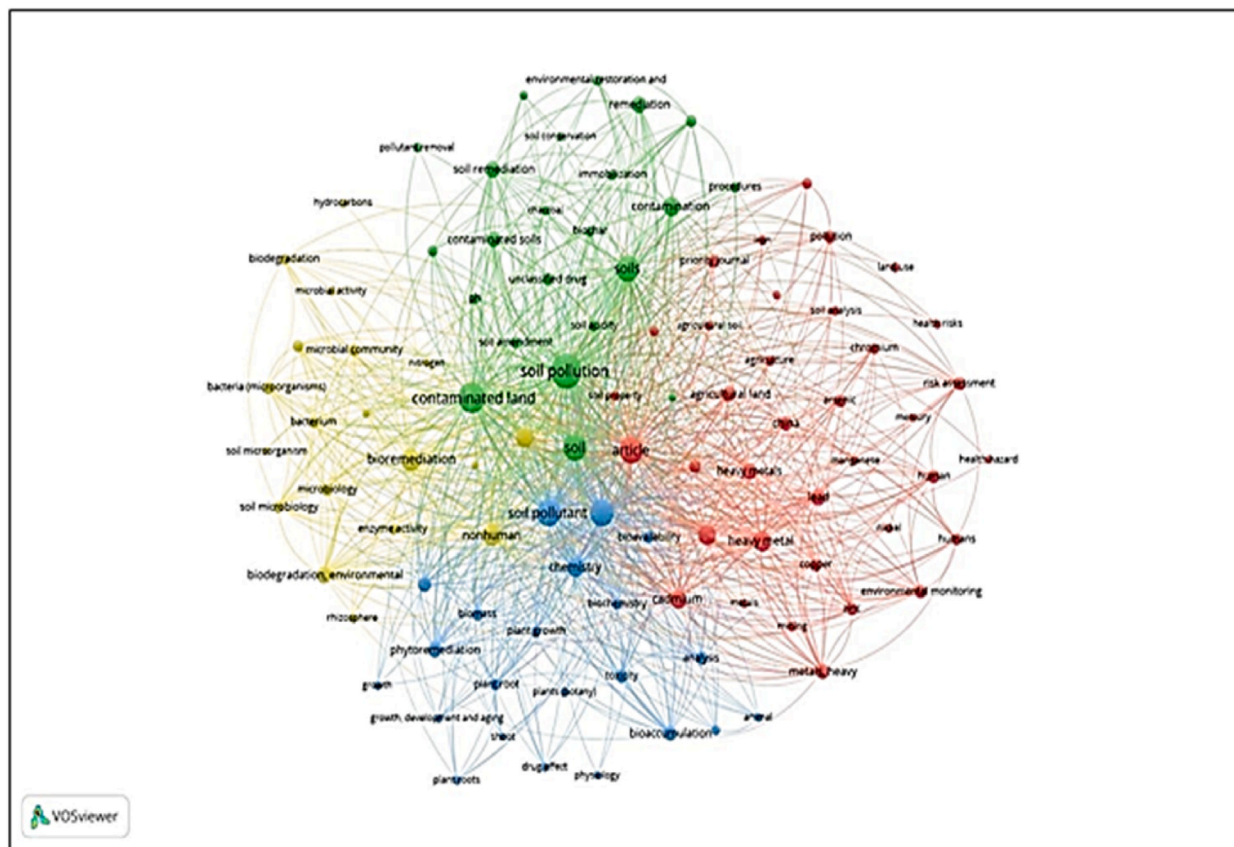


Fig. 10. Key areas of research (contaminated land).

and chemical innovation activities cause landslides, scarring of landscapes with untreated wells or pits, air pollution by dust, and pollution of the earth’s environment through the liquid, solid and gaseous waste [59,60]. However, many methods are offered to recover areas that have lost their characteristics due to such activities. Sustainable land remediation and management projects are increasingly popular in the urban world, especially in recent years. The process of sustainable brownfield reclamation is a rather complex undertaking, requiring the cooperation of different disciplines and the occupants.

3.4. Assessment of the literature

This discussion section will summarize by reviewing the literature on the redevelopment of sustainable brownfields and then highlight the key ideas and policy issues for sustainable planning. This brownfield redevelopment assessment facilitates a vision in decision-making to make brownfield redevelopment more sustainable. To do this, based on the analysis of the annual citations of articles and their research axis concerning brownfields and the practice of sustainable redevelopment of brownfields, we have selected 15 of the most cited articles in Table 4. Our debate revolves around the results (dynamic of quality and visibility) of the four articles (greater than or equal to 100 citations) by introducing a vision of sustainability in brownfield redevelopment projects.

One of the current issues for major North American cities concerns converting brownfield sites and, more explicitly, requalifying them as public green spaces. In this sense, among these articles, the one written by Christopher in 2003 [36], published in *Landscape and Urban Planning* and entitled “Turning brownfields into green space in the City of Toronto,” is the most cited publication in research on the planning and sustainable redevelopment of sustainable brownfields, with approximately 203 citations. The main contribution of this paper is to examine the issues, barriers, and processes related to the remediation of potentially contaminated urban brownfields and their conversion into green spaces, to identify the benefits that these green spaces can bring to the community and culture, and to understand the specific planning processes involved [61]. Heather Campbell suggests that the best space for communities in the process may be identifying sites that need remediation [62]. Thus, urban collective gardens are considered alternatives to solve the environmental problems generated by urbanization, thus contributing to the sustainability of cities. However, the greening of brownfield sites in urban center redevelopment projects across North America should be given high priority in the policy, planning, and community economic development process if the quality of life in these centers is to be maintained or sustainably improved. The interaction between brownfield redevelopment and public spaces has been highlighted in numerous studies. A study assesses whether converting old brownfields into places that serve society again is appropriate and does not present any potential health risk [63]. One

Table 5
Literature review scheme and directions for future research.

Cluster: key areas of research (brownfield).	Terms	Cluster: key areas of research (contaminated land).	Terms	Themes
Cluster 1 (11 papers)	Biodegradation, bioremediation, soil pollutants, contamination soil, china, health risk, brownfield, ecology, pollution, environmental health, environmental monitority.	1 Cluster 1 (36 papers)	Agricultural land, agricultural robots, agricultural soil, agriculture, arsenic, article, cadmium, China, chromium, concentration (composition), concentration (parameter), copper, environmental monitoring, environmental pollution, health hazard, health risks, heavy metal, heavy metals, human, humans, iron, land use, lead, manganese, mercury, metals, metals, heavy, mining, nickel, physical chemistry, pollution, priority journal, risk assessment, soil analysis, soil property, zinc.	Securing by removal and treatment/recovery of waste, securing contaminated sites, environmental pollution, remediation of polluting land, recycling brownfields, environmental management, definition of technical and financial conditions for interventions, etc.
Cluster 2 (15 papers)	Brownfield redevelopment, brownfield sites, contained sites, decision making, environment impact, environment manager, geographic information, groundwater pollution, health risk, law and legislation, recycling, risk assessment, sustainable development, urban growth, land use.	Cluster 2 (23 papers)	Adsorption, biochar, charcoal, comparative study, contaminated land, contaminated soils, contamination, ecosystem restoration, environmental restoration and remediation, immobilization, ph, pollutant removal, procedures, remediation, soil, soil acidity, soil amendment, soil conservation, soil pollution, soil pollution control, soil remediation, soils, unclassified drug	Risks of contaminated sites, environmental decontamination, local rules and institutions, recycling of brownfields, sustainable development, maintenance of decontamination facilities, definition of technical and financial conditions for interventions, etc.
Cluster 3 (17 papers)	Abandoned land, biodiversity, brownfield site, Canada, Czech Republic, environmental policy, Europe, urban renewal, Germany, ecosystem restoration, united states, land use planning, urban planning, urban development, environmental planning, green space, land management.	Cluster 3 (22 papers)	Analysis, animal, animals, bioaccumulation, bioavailability, biochemistry, biomass, chemistry, drug effect, growth, growth, development and aging, hydrocarbons, metabolism, physiology, phytoremediation, plant growth, plant root, plant roots, plants (botany), shoot, soil pollutant, soil pollutants, toxicity	Local rules and institutions, Harmonization of legislation, studies and assessments of impacts and risks, remediation of polluting land, recycling of brownfields, definition of technical and financial conditions for interventions, etc.
–	–	Cluster 4 (19 papers)	Bacteria, bacteria (microorganisms), bacterium, biodegradation, biodegradation, environmental, bioremediation, controlled study, enzyme activity, microbial activity, microbial community, microbiology, nitrogen, nonhuman, phosphorus, rhizosphere, soil microbiology, soil microflora, soil microorganism	recycling and remediation of polluted sites, maintenance of decontamination facilities, definition of technical and financial conditions for interventions recycling of brownfields, etc.

of the less risky options for health is the redevelopment of brownfields into urban parks [64–66]. The planning and redevelopment of brownfields into green spaces bring social, economic, and environmental benefits [67] because, in most countries, they are seen as an essential means of restoring urban ecology and have social and environmental value [68]. The development of green spaces can increase the water storage capacity of the plot, regulate the temperature, create habitats for animals, make the roots of the vegetation biodegradable, maintain the health of the site's soil [69,70], and create spaces for entertainment and recreation [2]. Between 1988 and 1993, 19% of UK brownfields were converted to green spaces [61]. Among the ten brownfield research samples in Sao Paulo, Brazil, 40% of the land has a high potential for green space development, and 40% has a medium potential [69].

Sustainable development and sustainability have become increasingly popular although amorphous concepts in recent decades, and many governments, businesses, and institutions are adopting them as an urban development policy. The second most cited article is “Measuring site-level success in brown field developments: A focus on sustainability and green building” [37], written by Christopher and Wedding in 2007 and published in the Journal of Environmental Management, with around 137 citations. The main contribution is the formulation of four objectives within the framework of the more critical research topic to characterize and quantify the success of brownfield revitalization. They are like places of sociability and creativity, giving time to prepare a project while preventing the site from falling into disrepair. Other work to assess the success of brownfield redevelopment in the light of sustainability has focused on decision support and soil remediation at the policy level, with little attention being paid discussed measuring other areas of benefits or impacts. According to the research by Otsuka, N., and Abe, H. [71], in their brownfield study, compared the

brownfield policies of Japan and the UK and stressed that Japan should learn from the UK, create a spatial brownfield database, and link the policy of the urban renaissance to the redevelopment of brownfields. While most researchers agree that few public policies can boast of tangible success in terms of gender diversity, it would appear that, in the Canadian case, residential diversity situations - probably temporary - are more common. Of course, Canada is not yet in a position to compete with certain European countries, such as the United Kingdom, Germany, or Sweden, which are pioneering in the redevelopment of wasteland, or even the United States, which appear to be the most productive country in the reconversion of industrial wasteland [72]. Developing brownfields as residential land benefits economic benefits and promotes urban regeneration in many countries. The British government proposed in 2008 that at least 60% of new housing be built as part of brownfield reconstruction projects. The property development sector is a crucial project in the regeneration of brownfields in the UK and occupies a relatively high proportion nowadays. Brownfield redevelopment has generally played a positive role in the value of surrounding residential buildings. However, some studies have shown that the gentrification of land caused by the redevelopment of brownfields in cities has forced locals to leave the land, and the elderly and tenants are easily affected. In short, the challenge to be taken up was to rearrange an industrial past emblem and contribute to the economic revitalization of a region's residential development.

The third most cited article is "The challenge of sustainability: incentives for brownfield regeneration in Europe" [39], written by Gareth Thornton in 2007 and published in the journal *Environmental Science Policy*, with around 124 citations. The site's economic, environmental, and social barriers frequently hamper the reuse of brownfields. This is how the main contribution of this article presents the existing incentives at the level of the European Union, Germany, the United Kingdom, and France; then it discusses the effects and the gaps, and further, it makes suggestions for instruments. More effective in promoting the sustainable redevelopment of brownfields. Indeed, the problem posed by the transformation of brownfields represents a considerable stake for all European countries. A series of research has therefore been launched in the various countries concerned to gather information on brownfields (texts and projects) and take stock of interesting examples; analyze ongoing or completed conversion processes; understand the policies implemented; to identify the actors of these conversions, to better clarify and understand the situation and the specificities of France.

The fourth most cited publication is titled "Creative intervention in a dynamic city: A sustainability assessment of an interim use strategy for brownfields in Leipzig, Germany" [40], written by Emily and published in *Landscape and Urban Planning* in 2011, with 104 quotes. This study addresses this question in the context of the city's sustainability goals, use, and public perception of sites, thus providing planners with insight into the effectiveness of this planning tool for neighborhood revitalization. This study shows that temporary use sites scored higher overall than their closest counterparts, recently demolished brownfields. They also have a much higher utilization rate. The author concludes that public acceptance and support for interim use can be bolstered with more seating, punitive measures for homeowners, and increased communication about the strategy and its potential as a planning tool. A study was carried out in the north of the Ruhr, and the Emscher valley remains very marked by the relics of the steel industry. The damage site covers 750 km², from Duisburg to Dortmund, and concerns 2.5 million inhabitants. The IBA team, which advocates an ecological approach, identifies around a hundred highly differentiated strategic actions as solutions, namely: the rehabilitation of the river system, the creation of parks, the modernization of workers' housing estates, etc. The conversion of old installations (headframes, gasometers) into a culture or leisure center is preferred to their destruction, which is not too costly. The rule is to use only the urbanized space and build the existing one, there are few new constructions, and the re-landscaping of the wastelands is on public funds.

4. Conclusion

Urban brownfield planning has been practiced worldwide to recover more secondary resources. Redeveloping abandoned land is an ideal approach to enhance the urban fabric and improve the sustainability of the urban environment. More academic efforts have been proposed for brownfields' planning and sustainable development. This study aimed to study research trends and developments in sustainable brownfield development using bibliometric analysis. By adopting this method, the productivity of research and publications in a particular field can be assessed [73]. This is because the literature review results can provide information to assess the performance of a certain area of research. Thus, agencies can formulate policies related to research funding allocations and compare scientific inputs and results [74–76]. After summarizing the research progress, we have proposed future research directions on brownfields' planning and sustainable development. The results show that 7197 articles were published, but few were published before 1990. However, annual publications increased rapidly after 2010, reflecting a global concern on such a topic. These publications were published in 160 journals, indicating a good diversity of research. *Chemosphere*, *Environmental Science and Pollution Research*, *Science of the Total Environment*, and *Journal of Hazardous Materials and Environmental Pollution* were ranked the top five reviews in publications. In addition, 3049 authors have published their articles on brownfields' planning and sustainable development. The five most productive authors are Stanislav Martinat, Petr Klusacek, Jan Kunc, Krejci T. and Robert Osman. Collaboration in brownfields' planning and sustainable development is unfavorable, and researchers tend to cooperate in small groups. Productive authors such as Stanislav Martinat, Petr Klusacek, and Jan Kunc are the most active authors in collaboration. Co-citation's cluster analysis revealed the underlying intellectual structure of brownfield planning and sustainable development research. Finally, an analysis of keywords made it possible to propose three axes of future research in terms of sustainable development or the redevelopment of brownfields. Overall, this study provided valuable information and future research directions in sustainable brownfield planning and redevelopment so that researchers in this area can better identify their research topics and seek suitable partners.

Author contribution statement

Bohong Zheng: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed; Wrote the paper.

Francis Masrabaye: Performed the experiments; Analyzed and interpreted the data; Contributed; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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