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How urban renewal affects the sustainable development of public spaces: trends, challenges, and opportunities

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The process of urbanization has spurred economic growth and social challenges, necessitating research on public spaces in urban renewal to optimize design, enhance functionality, promote sustainable urban development, and improve residents' quality of life. However, existing studies lack in-depth discussions on development trends and research focal points. This study addresses the gap in existing literature, by conducting a bibliometric analysis using data from the Web of Science Core Collection database from 1 January 2000, to 1 April 2024. Using visualization tools such as VOSviewer and CiteSpace, the study examines publication trends, collaborative networks among countries, institutions, and authors, co-citation relationships among key journals and articles, and emerging research hotspots through keyword analysis. A total of 393 papers were analyzed, with China contributing the highest number (65), followed by the United States (51). Leading contributors include Zazzi Michele and Anguelovski Isabelle. The top three journals for publications are Sustainability, Cities, and Land. Key research trends highlight themes such as space syntax, nature-based solutions, and sustainable transportation. These findings have significant implications for urban planning and policy, suggesting that future urban development strategies should increasingly incorporate sustainable design practices and nature-based solutions to address both environmental and social challenges. By identifying global research trends and highlighting future challenges, this study provides a comprehensive overview that will help policymakers and practitioners in urban planning align their efforts with cutting-edge research and emerging best practices for more sustainable and resilient cities.

KEYWORDS

urban renewal, public space, VOSviewer, Citespace, bibliometric analysis

1 Introduction

With the acceleration of urbanization, urban renewal has emerged as a vital strategy for cities globally to combat urban decline, improve quality of life, and achieve sustainable development (Zheng et al., 2021; Wang et al., 2020; Wei and Ewing, 2018). Public spaces, integral to urban structures, serve not only as stages for urban life but also as important platforms for cultural expression, social interaction, and environmental sustainability

(Eizenberg, 2012; Van Herzele and Wiedemann, 2003; Colding and Barthel, 2013). Given the backdrop of population growth, economic progress, and social transformations, the continuous expansion and revitalization of urban spaces have placed a spotlight on the study and optimization of public spaces within urban renewal initiatives (Davies et al., 2021; Kędra et al., 2023; Okeke and Ifeoma, 2019). Consequently, the effective utilization and enhancement of public spaces have become a topic of widespread interest among researchers, professionals, and government entities, serving as a focal point for both academia and practitioners (Walshe and Rundall, 2001; Moser, 2016).

Urban renewal is a complex process that aims to revitalize urban areas by improving societal, economic, physical, and environmental aspects (Kim et al., 2020; Yu and Kwon, 2011; Grodach, 2007; Hassan and Lee, 2015). Hawley (1963) discusses how power dynamics within social systems impact the effectiveness of urban renewal efforts (Hawley, 1963). Lee and Chan (2008) focus on urban decay in Hong Kong, highlighting the importance of urban renewal in enhancing living standards and physical environments. They suggest using the analytic hierarchy process (AHP) to select sustainable design proposals. Larsen and Hansen (2008) study the socioeconomic changes in Copenhagen due to urban renewal policies. Holm and Kuhn (2011) examine the relationship between squatter movements and urban renewal strategies in Berlin, emphasizing the connection between urban regime crises and movement conjunctures. Recent research has shifted towards sustainable urban renewal, with Wang et al. (2014) providing a critical review of studies from 1990 to 2012, emphasizing the need to understand the mechanisms driving urban renewal for promoting urban sustainability. Yung et al. (2016) investigate the social needs of elderly individuals in public open spaces in urban renewal areas, evaluating the adequacy of planning and design guidelines in addressing these needs.

Public spaces play a pivotal role in urban renewal, impacting cities' aesthetic appeal, residents' wellbeing, sustainable development, and social harmony (Sheikh and van Ameijde, 2022; Cattell et al., 2008; Wang and Aoki, 2019; Xiang et al., 2020). Van Melik and Lawton (2011) emphasize the importance of public spaces in urban renewal strategies, as seen in Rotterdam and Dublin. Luo and Guo (2012) delve into the reasons for the decline of urban public spaces and propose renewal strategies like improving street traffic and prioritizing human-centered design. Benkő and Germán (2016) provide a Central-European viewpoint by examining the crime prevention aspects of public space renewal in Budapest. Tchoukaleyska (2018) scrutinizes conflicts arising from differing interpretations of public space, especially in urban renewal projects. Eom and Suzuki (2019) study the spatial distribution of pedestrian spaces in central Tokyo and their relationship with urban renewal efforts. Arteaga (2021) evaluates the social and physical impacts of public space projects in the urban renewal of informal settlements in Medellin. Advancements in technology are also influencing urban renewal practices. Wan and Shi (2021) explore the use of convolutional neural network models for designing urban spaces based on a database of urban cases. Xia et al. (2021) focus on sustainable renewal methods for urban public parking spaces in the shared autonomous vehicle era, emphasizing the importance of demand forecast analysis and decision-making on function replacement. Yu et al. (2021) analyze micro-renewal planning for urban communities using the Datang Xiang community in Hangzhou as a case study to enhance community public spaces. Furthermore, He et al. (2021) investigate the relationship between installation art and urban renewal, underscoring the role of art intervention in reshaping urban public spaces.Collectively, these studies demonstrate the diverse approaches and considerations involved in urban renewal endeavors, particularly in the context of enhancing public spaces within cities.

Current research on urban renewal primarily focuses on the functionality, social participation, and sustainable design of public spaces (Zhang et al., 2023; Bogdanović Protić et al., 2020; Lei and Zhou, 2022). Studies delve into the multifunctionality of these spaces, catering to leisure, cultural activities, and markets. Involving residents in the design process ensures that public spaces align with the actual needs and expectations of the community (Dubbeling et al., 2009; Stanley et al., 2012). Additionally, public spaces are increasingly utilized for ecological restoration and environmental enhancement through initiatives like urban green spaces, rain gardens, and rooftop gardens, which support biodiversity and offer ecological services (Oberndorfer et al., 2007; Bąk and Barjenbruch, 2022; Russo et al., 2017). However, while these studies explore a wide array of topics, many are limited in scope. They often focus on specific regions or case studies, which restricts the broader applicability and generalizability of their findings (Robinson, 2011). Furthermore, comprehensive bibliometric analyses in this field remain scarce, particularly those that investigate emerging trends and the intricate relationship between public spaces and global urban challenges (Marvuglia et al., 2020). This study aims to address these gaps by providing a global review of research trends, identifying key contributors, institutions, and thematic areas in public space research within the context of urban renewal.

Therefore, this study will utilize the Web of Science (WoS) Core Collection to retrieve relevant literature and employ VOSviewer and CiteSpace visualization software to establish a knowledge network (Xia et al., 2024a). Bibliometric analysis will be conducted to create scientific knowledge maps of publications spanning from 2000 to 2024. The primary research questions (RQs) of this study will focus on:

- RQ-1: What is the publication status of research articles on public spaces in urban renewal?
- RQ-2: Which countries are the leading contributors to research on public spaces in urban renewal?
- RQ-3: What are the key institutions driving research on public spaces in urban renewal?
- RQ-4: Who are the principal researchers in the field of public spaces in urban renewal?
- RQ-5: What is the distribution of core journals in the field of public spaces in urban renewal?
- RQ-6: What are the emerging trends and hot topics in research on public spaces in urban renewal?

Answers to the research questions are provided in Section 3. Specifically, responses to RQ-1 can be found in Section 3.1, RQ-2 in Section 3.2, RQ-3 in Section 3.3, RQ-4 in Section 3.4, RQ-5 in Section 3.5, RQ-6 in Section 3.7 and Section 4. The findings of this study will be valuable resources for the academic community, encouraging theoretical advancements and practical applications

TABLE 1 Search keywords.

TS	Search terms
urban renewal	"urban renewal" OR "urban regeneration" OR "urban revitalization" OR "urban reconstruction" OR "urban revival" OR "urban renovation" OR "urban transformation" OR "urban innovation" OR "urban improvement" OR "urban renaissance" OR "city renewal" OR "city regeneration" OR "city revitalization" OR "city reconstruction" OR "city revival" OR "city renovation" OR "city transformation" OR "city innovation" OR "city improvement" OR "city renaissance"
public space	"public area" OR "common area" OR "community space" OR "open space" OR "communal space" OR "shared space" OR "civic space" OR "public square" OR "public zone" OR "public realm" OR "public space" OR "Collective space"

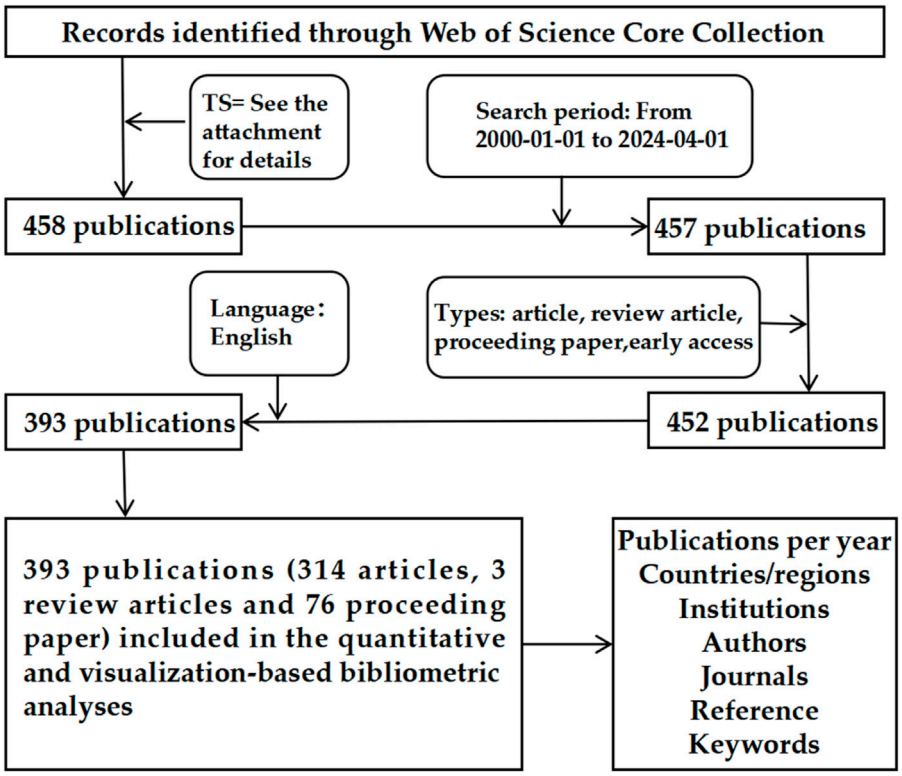

FIGURE 1
Data retrieval flowchart.

in the field of public space research (Jones et al., 2018). Additionally, they will offer both theoretical insights for promoting sustainable urban development and fostering societal harmony.

2 Research methods

2.1 Data source

The main data for this study were obtained from the Web of Science (WoS) Core Collection, which is a comprehensive academic platform for citation search and analysis (Martín-Martín et al., 2018; Huang et al., 2023). The WoS includes many influential journals and is widely used in academic research for literature retrieval, academic evaluation, and research trend analysis (Mongeon and Paul-Hus, 2016). Therefore, the WoS is regarded as the leading source for global bibliometric analyses (Gao et al., 2019).

2.2 Data search strategy

A thorough online search was conducted over 1 day to ensure the accuracy of the database, considering its daily updates. This study is centered on the topic of "public space research in urban renewal." The search strategy employed involved simultaneously incorporating both "urban renewal" and "public space" components, utilizing subject terms. To encompass keywords with synonymous meanings, the expressions for these components were broadened. "Urban renewal" and "public space" were linked using AND, while within each group, terms were connected using OR, as illustrated in Table 1.

The term "TS" refers to the research topic. The search was conducted in English, covering the period from 1 January 2000, to 1 April 2024. The document types included in this search were limited to articles, review articles, proceedings papers, and early access publications. A total of 458 documents were initially retrieved. Following a comprehensive data cleaning

process—encompassing format standardization, removal of incomplete entries, and exclusion of irrelevant or duplicate articles based on titles, abstracts, and full texts—393 articles were ultimately selected for further analysis. The detailed search process is illustrated in Figure 1.

2.3 Data analysis

Bibliometrics is a domain that utilizes statistical as well as mathematical techniques to provide a quantitative assessment of literary information. It particularly concentrates on evaluating the amount, significance, influence, and interrelations among scientific research publications (Durieux and Gevenois, 2010). Utilizing modern big data and computer technologies, bibliometrics enables efficient searching, mining, analysis, and summarization of large datasets. Through the creation of clear and concise visual knowledge maps, it facilitates a comprehensive comprehension of quantitative data related to publications, authors, journals, countries, institutions, references, and keywords (Olawumi and Chan, 2018). The advancements in bibliometrics have provided valuable data support for academic research and scientific management, contributing significantly to the progress and oversight of scientific research as a whole (Mukherjee et al., 2022).

This study utilized VOSviewer 1.6.18 (Centre for Science and Technology Studies, Leiden University, Netherlands) and Pajek 64 5.16 (University of Ljubljana, Slovenia) to analyze the co-occurrences of countries, institutions, authors, journal publications, and keyword frequencies (Xu et al., 2024). The visualizations generated by these software tools represent nodes as spheres and text labels, where the size of the spheres indicates the magnitude of the nodes and different colors signify distinct clusters. Lines connecting nodes show co-occurrence relationships, with the thickness of the lines reflecting the strength of these relationships. In the journal publication heat maps, the volume of journal publications is positively correlated with the size and intensity of the red patches.

Utilizing CiteSpace 6.3.R1, a co-citation analysis was performed in this study, resulting in the generation of visual maps (Zhou et al., 2024). The parameter settings used in CiteSpace included time slicing from 2000 to 2024, annual slices set to 1, and selection criteria limited to the Top 20 per slice. Each sphere in the visual maps represents co-cited references, with the size of the sphere indicating the number of citations received by a publication. Lines connecting spheres represent co-citation relationships. Additionally, within each sphere, the size and color of concentric rings reflect the quantity of citations and their respective time periods.

In our research, we chose VOSviewer and CiteSpace for bibliometric analysis due to their advanced features and specific relevance to our study goals. VOSviewer is particularly effective in visually representing intricate bibliometric networks, including co-authorship and keyword networks, which are essential for understanding the structure and trends in the urban renewal field (Darko et al., 2019). On the other hand, CiteSpace provides unique functionalities such as trend analysis and identification of key literature, which help in comprehending the research dynamics (Zhang and Zou, 2022). Both tools are well-integrated with major citation databases and have strong support from the academic community and users, ensuring the credibility and depth of our analyses.

3 Research results

3.1 Publication outputs and trends

At the beginning of any study, it is essential to understand the development of the research topic and its academic relevance (Barth and Rieckmann, 2012). Conducting a bibliometric analysis of the publication years of articles can help in this regard (Donthu et al., 2021). Figure 2 illustrates how analyzing the temporal distribution of articles allows us to answer Research Question RQ-1: What is the publication status of research articles on public spaces in urban renewal?

This study conducted a comprehensive review of 393 publications in the field of public spaces in urban renewal from 2000 to 2024, with an average annual publication rate of 15.72 articles. Analysis of the data revealed notable periodic fluctuations in annual publication rates, showing an overall upward trend over the years. The development of the research field was categorized into four distinct phases. The initial phase, spanning from 2000 to 2006, had lower annual publication volumes ranging from 0 to 4 articles, possibly due to limited interest in the area of study. The second phase, covering 2007 to 2012, witnessed a gradual rise in publication volumes, particularly in 2011 and 2012, when publication numbers increased to 8 and 11, respectively, indicating a growing interest in the field. The third phase, from 2013 to 2017, sustained this growth with publication volumes peaking at 17 in 2013 and 20 in 2014, despite some fluctuations between 2015 and 2017, maintaining relatively high levels. The fourth phase, commencing in 2018, saw a significant surge in annual publication volumes, with 40 publications in 2018 and consistently over 30 publications per year, reaching 52 in 2022 and 51 in 2023, showcasing substantial attention and rapid advancement in the field of public spaces in urban renewal.

A regression analysis of the data from 2000 to 2024 yielded an exponential growth model, $y = 3.9113e^{0.1976x}$, where x represents the number of years since 2000, and y is the corresponding cumulative publication volume. The model's goodness of fit, with an R^2 value of 0.9857, demonstrates extremely high accuracy. This further supports our prediction that the research interest in public spaces within urban renewal not only continues to rise, but also that the growth in cumulative publication volume can be effectively predicted and represented by an exponential function model.

3.2 Active countries

The national cooperation map visually illustrates the collaboration and social relationships between countries in a specific field, offering a unique perspective on academic strength and scientific research (Wenwen et al., 2019). It helps identify countries or regions of interest in scientific research (Harris, 2004). In the realm of public spaces in urban renewal, a total of 393 publications have been contributed by 58 countries worldwide. Analyzing these collaborations allows us to address Research

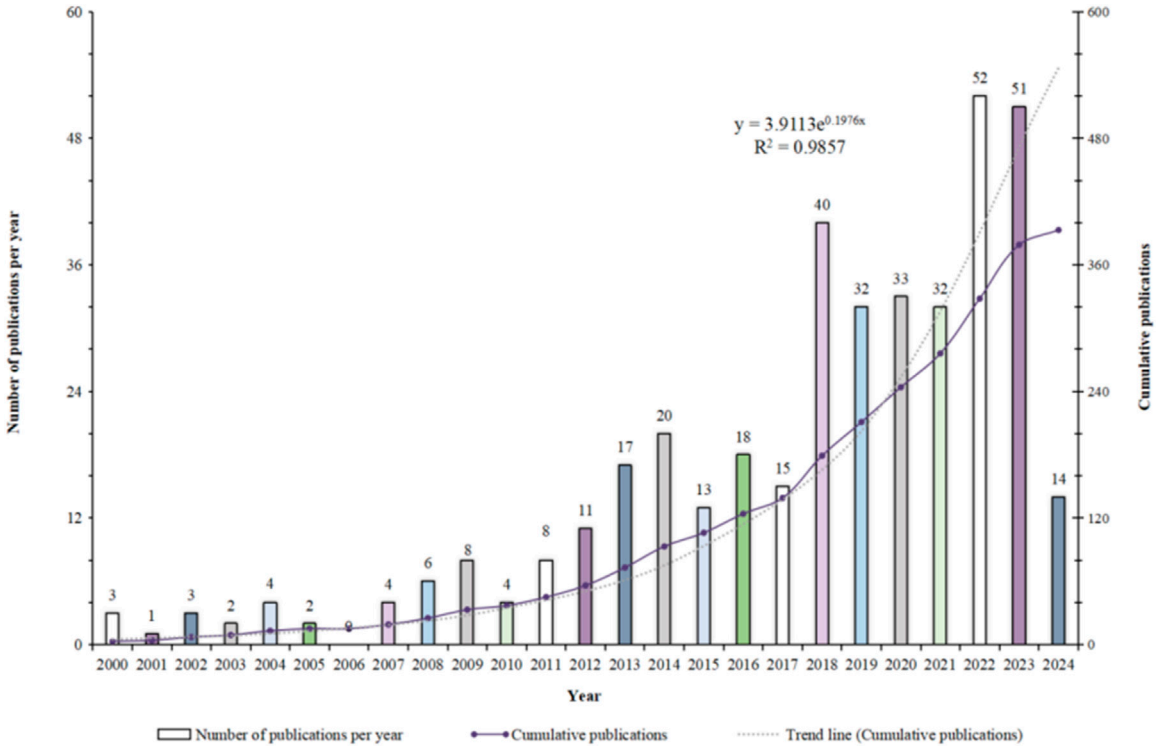

FIGURE 2
Publication volume statistics from 2000 to 2024.

TABLE 2 The 15 most active countries in the research field.

Serial number	Country	Quantity
1	China	65
2	United States	51
3	United Kingdom	50
4	Italy	50
5	Spain	33
6	Australia	20
7	Turkey	16
8	Canada	15
9	Poland	15
10	Germany	14
11	Portugal	13
12	Netherlands	9
13	South Korea	9
14	Chile	8
15	Japan	7

Question RQ-2: Which countries are the leading contributors to research on public spaces in urban renewal? The top 15 contributing countries, as listed in Table 2, have collectively produced 375 publications. It is important to note that publications may involve researchers from multiple countries, potentially leading to duplicated counts. The number of publications and citations per country reflects their influence in this research area. Table 2 reveals that China and the United States are key players, with 65 and 51 related articles published, respectively. China leads in publication volume with 16.5% of the total, showcasing its focus on public spaces amidst rapid urbanization. The United States follows closely with 12.9% of the total, known for its high citation rates and significant international impact. The United Kingdom and Italy, each with 50 articles, highlight their roles in urban renewal research in Europe. Spain, Australia, and Turkey also show substantial research output, reflecting their practical needs and academic interest in public spaces in urban renewal.

To explore collaboration patterns among countries in public spaces urban renewal, this study employed VOSviewer software for visual analysis. A minimum publication threshold of two articles per country was set to enhance reliability and relevance. The resulting national collaboration network map (Figure 3) utilizes gradient colors to show publication volume by country and line thickness to indicate collaboration strength. This visualization effectively showcases cooperative relationships and research activity levels in public spaces urban renewal across nations.

The analysis of the national collaboration network depicted in Figure 3 demonstrates that the UK exhibits the highest level of collaboration with other countries, while Italy and the United States show a close partnership. Moreover, Sweden stands out in terms of citation metrics, boasting an average citation count per article of 104.33, nearly five times higher than the US average of around 21, indicating the significant

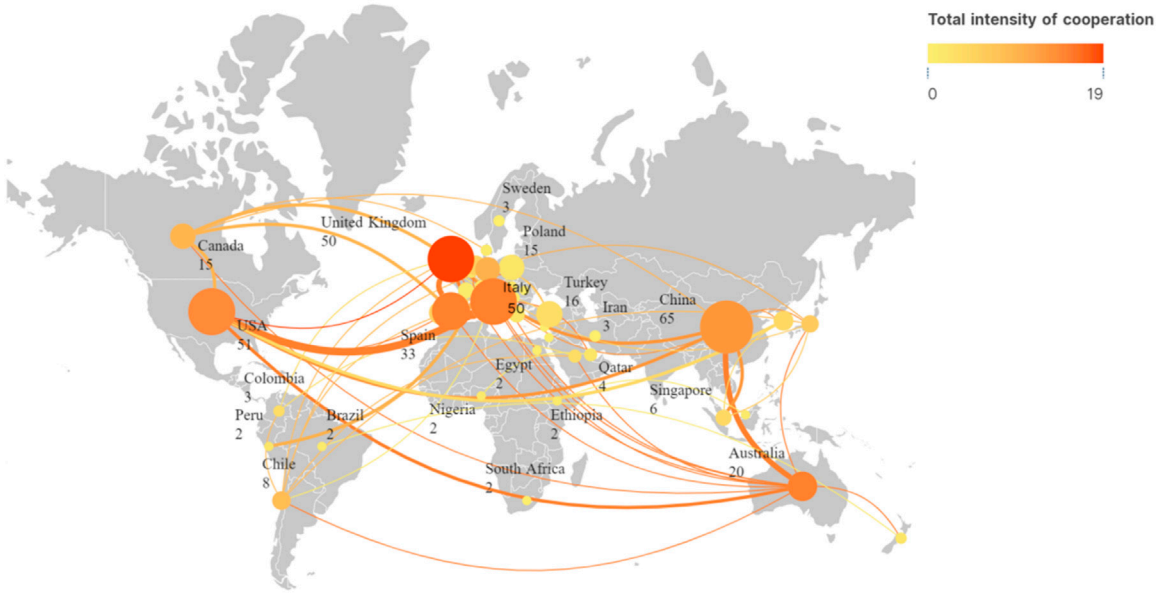

FIGURE 3
Country collaboration analysis chart.

recognition and impact of Swedish research within the academic realm. Conversely, research activities in Peru and Serbia have experienced a notable surge post-2021, suggesting an increasing emphasis on public spaces in urban renewal within these nations in recent years.

The model of international cooperation plays a crucial role in the study of public spaces within the context of urban renewal (Jaszczak et al., 2021). Such collaboration fosters the exchange of knowledge and innovation, offering comprehensive solutions to address urban challenges. Cooperation among countries, including the United States, the United Kingdom, and Italy, underscores the global dialogue surrounding sustainable urbanization. Simultaneously, the growing research contributions from emerging nations such as Peru and Serbia introduce valuable new perspectives for future studies. Moreover, with the advancement of the United Nations Sustainable Development Goals (SDGs), interdisciplinary and cross-regional international cooperation is expected to be further enhanced (Liu J. et al., 2018).

3.3 Contributions of institutions

Institutional collaboration analysis provides insights into highly contributing organizations within a specific field, serving as a strong foundation for future partnerships (Pettigrew et al., 2001). This analysis allows us to investigate Research Question RQ-3: What are the key institutions driving research on public spaces in urban renewal? The study encompasses articles from 465 research institutions, with Table 3 showcasing the top 12 most prolific institutions based on publication count. Gdansk University of Technology emerges as the institution with the highest number of publications, having released 9 articles. Following closely behind are Hong Kong Polytechnic University and University of Lisbon, each with 8 publications. Gdansk University of Technology stands out as a leader in this research domain, boasting the highest publication count and showcasing its substantial research capabilities and contributions to the study of public spaces in urban renewal.

TABLE 3 Top 12 institutions by publication volume.

Serial number	Institution	Quantity
1	Gdansk Univ Technol	9
2	Hong Kong Polytech Univ	8
3	Univ Lisbon	8
4	Politecn Milan	7
5	Univ Politecn Valencia	7
6	Univ Autonoma Barcelona	5
7	Pontificia Univ Catolica Chile	5
8	Univ Melbourne	4
9	Sapienza Univ Rome	4
10	Politecn Torino	4
11	Qatar Univ	4
12	Cardiff Univ	4

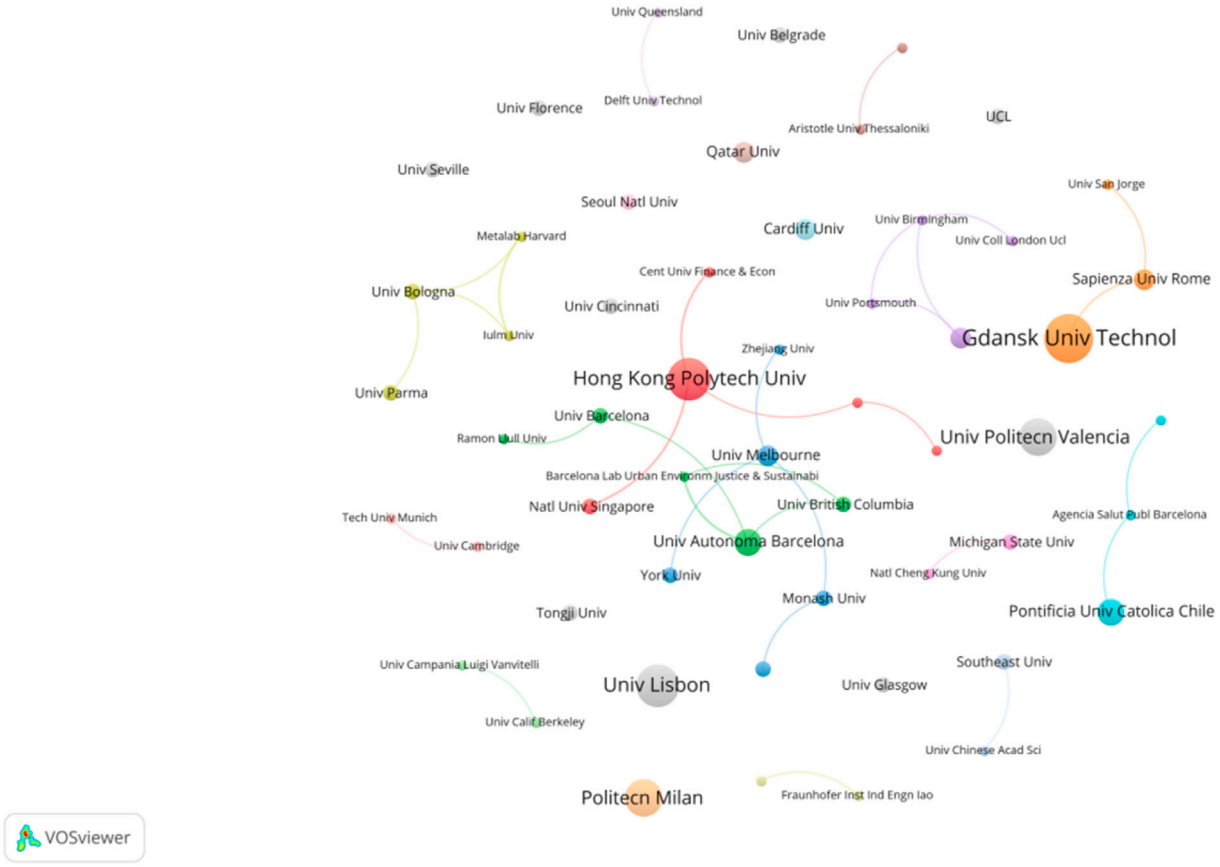

FIGURE 4
Institution collaboration analysis chart.

To enhance the visualization of institutional collaborations in the field of public spaces in urban renewal, we efficiently utilized VOSviewer software, as shown in Figure 4. Each institution is represented by a sphere with a corresponding label, where the size of the sphere reflects the institution's publication volume. The lines connecting institutions indicate collaborative relationships, with the thickness denoting the strength of collaboration. The use of gradient colors helps to emphasize the level of collaboration intensity. The analysis reveals that Hong Kong Polytechnic University demonstrates a strong willingness to collaborate, particularly with the Central University of Finance and Economics. Clusters of high-output institutions form a diverse network of collaborations, indicating a growing emphasis on public space research in urban renewal in recent years (Xie et al., 2020).

Institutional collaboration plays a vital role in advancing research on public spaces within the context of urban renewal, as it fosters the exchange of ideas and interdisciplinary approaches. The analysis of institutional partnerships, exemplified by the collaboration between Hong Kong Polytechnic University and Central University of Finance and Economics, demonstrates that such collaborations are not only crucial for enhancing publication output but also for addressing complex and multifaceted urban challenges. These partnerships facilitate the integration of diverse expertise, which is essential for the future evolution of research trends in urban renewal. As global cities confront increasing pressures from urbanization and climate change, strengthening these collaborative networks will be key to driving innovation and producing sustainable solutions in the field (Blasi et al., 2022).

TABLE 4 Top 10 authors by publication volume.

Serial number	Author	Quantity
1	Zazzi, Michele	3
2	Anguelovski, Isabelle	3
3	Wang, Hao	3
4	Mehdipanah, Roshanak	2
5	Li, Bin	2
6	Liu, Huiming	2
7	Pellicelli, Gloria	2
8	Rossetti, Silvia	2
9	Bottero, Marta	2
10	Samadi, Zalina	2

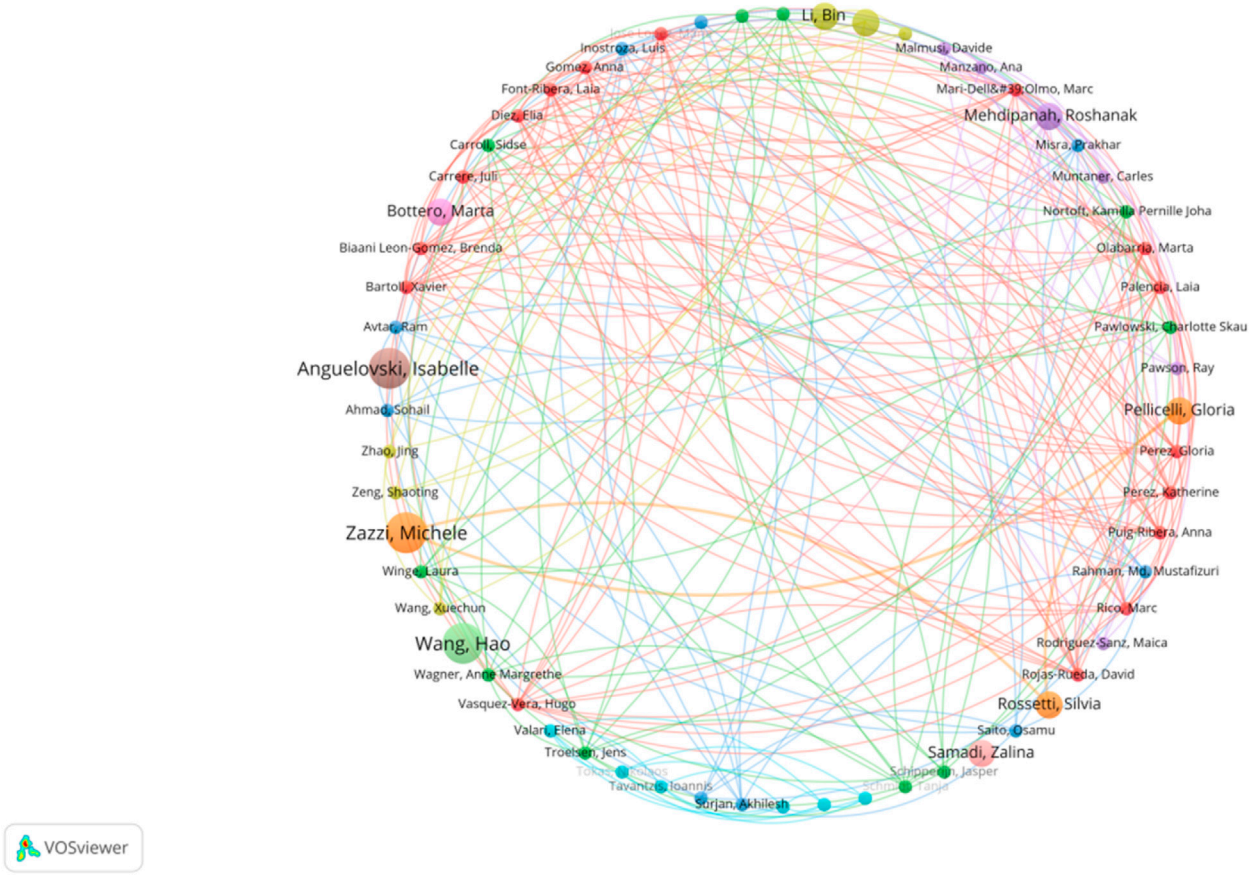

FIGURE 5
Author collaboration analysis chart.

3.4 Analysis of influential authors

The study of public spaces in urban renewal is a growing academic field that has garnered the interest of many researchers (Korkmaz and Balaban, 2020). This paper utilizes VOSviewer software to analyze author collaboration networks within this field. By examining author collaborations, we aim to answer Research Question RQ-4: Who are the key individual contributors in the field of public space research in urban renewal? The study includes 393 publications from 886 authors. An author's productivity in specific areas serves as a significant indicator of their impact in the field. Table 4 provides a ranking of the top ten most influential authors based on their publication numbers.

This study presents a detailed graph illustrating author publications and collaborations (Figure 5). Each node, depicted as a circle with a corresponding text label, is color-coded to represent different author clusters. Analysis of Figure 5 indicates that Mehdipanah, Roshanak shows a strong inclination towards collaborating with other researchers. Among these collaborations, the partnership between Pellicelli, Gloria, Rossetti, Silvia, and Zazzi, Michele appears to be particularly close, as shown by the lines connecting their circles in the graph. The thickness of these lines directly reflects the level of collaboration intensity. Moreover, the size of each circle corresponds to the number of publications by the author, with Wang, Hao, Zazzi, Michele, and Anguelovski, Isabelle having the highest number of publications, each with three. Interestingly, despite their significant publication output, Wang, Hao and Anguelovski, Isabelle did not engage in collaborative efforts with other authors.

Author collaboration is essential for advancing research on public spaces in the context of urban renewal. Strong partnerships, such as those among Pellicelli, Rossetti, and Zazzi, promote interdisciplinary approaches and drive innovation. While high publication numbers indicate individual productivity, limited collaboration—exemplified by Wang, Hao, and Anguelovski—can restrict broader academic impact. To effectively address complex urban challenges and shape future research trends, it is crucial to strengthen collaborative networks (Batty et al., 2012). This analysis not only highlights key contributors and collaboration patterns but also provides valuable insights into the academic framework, assisting researchers in identifying potential partners and enhancing future research efforts.

3.5 The most influential journals

This study utilizes VOSviewer software to conduct a visualization analysis of journal articles in the realm of public spaces within urban renewal. The examination of journal

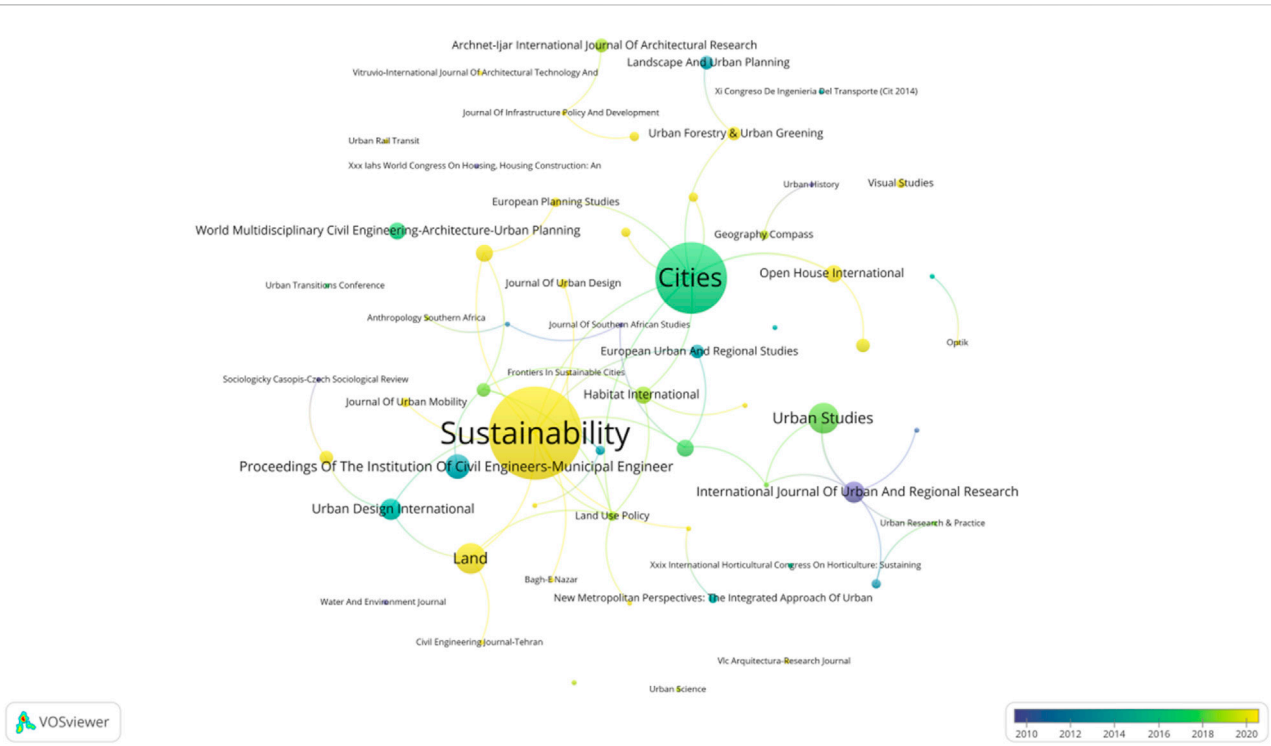

FIGURE 6
Journal publication timeline.

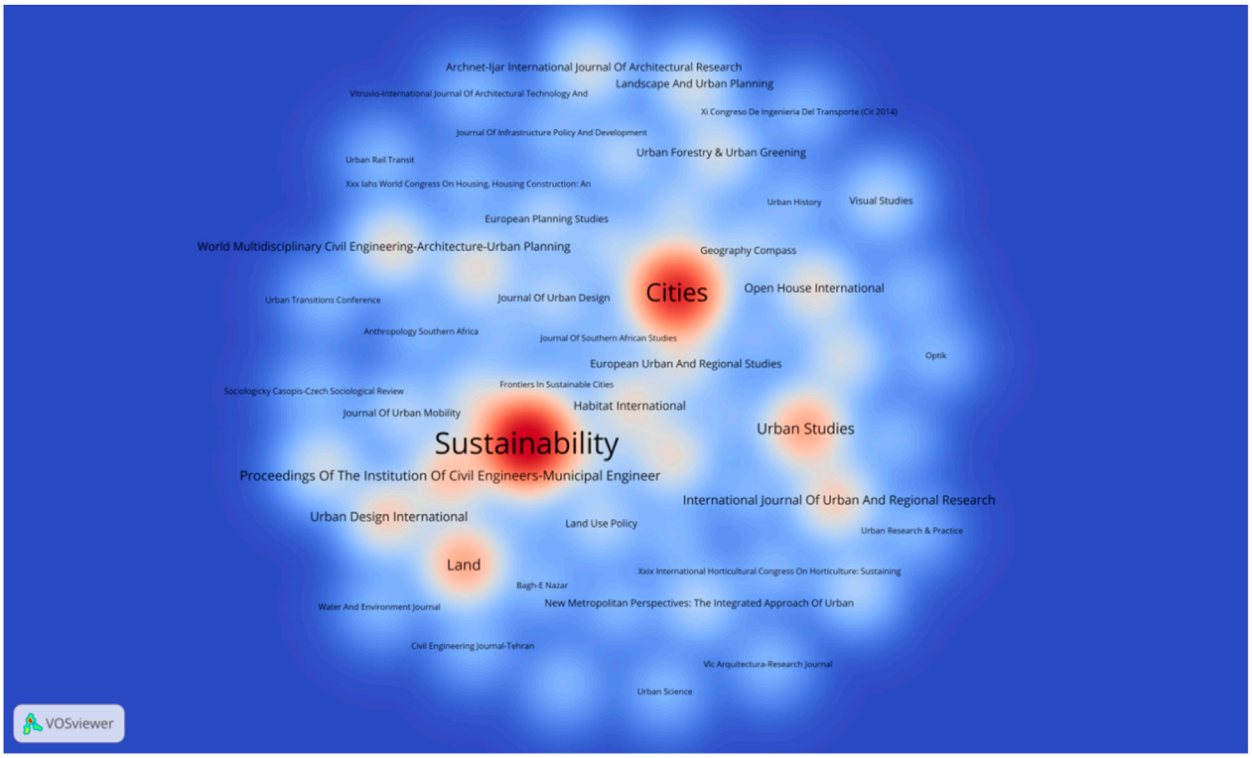

FIGURE 7
Journal publication heatmap analysis.

FIGURE 8
Double overlay analysis of journals.

contributions allows for the exploration of Research Question RQ-5: What is the distribution of core journals in the field of public space research in urban renewal? Out of a total of 393 related research articles, 224 journals were involved in this analysis. To delve deeper into the publication and citation patterns of these journals, the top 60 journals were selected based on citation strength and publication volume for a more detailed investigation. The findings resulted in the creation of two charts: a time trend chart of journal publications (Figure 6), showcasing the publication activities of each journal over time, and a heat map of journal publications (Figure 7), which visually represents the citation intensity among different journals through varying color depths. A darker color signifies a higher number of citations, thus revealing the interconnectedness among journals and their impact within the field.

The visualization in Figure 6 showcases nodes representing each journal, consisting of a circle with a corresponding label. The size of the circle is proportional to the number of publications from that journal. Color variations indicate the average publication year of the journals, with blue representing earlier years and yellow indicating more recent publications. The International Journal of Urban and Regional Research and Proceedings of the Institution of Civil Engineers - Municipal Engineer have earlier average publication years, predating 2015. On the other hand, the journals Land and Journal of Urban Design show more recent average publication years in the field of urban renewal public spaces, suggesting a recent research focus on this topic.

The visualization in Figure 7 illustrates a direct correlation between the size and darkness of the red sections and the publication volumes of the journals. Sustainability leads with the highest publication volume of 30 articles, followed by Cities with 22 articles. Land and Urban Studies are tied for third place, each with eight publications. Cities also boasts the highest total number of citations at 708, with an average of 32.18 citations per article. Additionally, the Journal of Cleaner Production stands out for having the highest citation rate per article, underscoring the academic quality and impact of its published papers.

Figure 8 presents the results of a dual-map overlay analysis of the citing and cited journals from 393 relevant studies. The left side of the figure displays the citing journals, while the right side shows the cited journals. The colored lines represent citation paths, with the thickest lines indicating the primary citation pathways. It is evident from the figure that publications in this field are predominantly concentrated in journals related to psychology, education, health, economics, and politics. Conversely, the cited literature is primarily focused on psychology, education, social sciences, economics, and political science.

The citation relationships depicted in the figure reveal patterns of cross-referencing among different disciplines, reflecting the multidisciplinary nature of this research area. Although the primary emphasis of the studies is on the renewal of urban public spaces, the research encompasses multiple dimensions, including residents' psychology, social health, educational improvements, economic development, and political decision-making.

The relationship between citing and cited journals suggests that future research should pay greater attention to the dynamic interactions among these intersecting disciplines to achieve a more comprehensive understanding of the complexities involved in public space issues during urban renewal processes (Tress and Tress, 2001). This analysis not only underscores the importance of interdisciplinary research but also provides a multidimensional perspective for the study of urban public spaces. Future studies should build upon these findings to further explore the connections and synergies between the relevant fields (Bibri, 2018).

3.6 Co-citation analysis of literature

Research papers play a crucial role in shaping domain knowledge and serve as a reflection of the research standards within a particular field (Abduljabbar et al., 2021). Co-citation analysis of references is an effective method for identifying

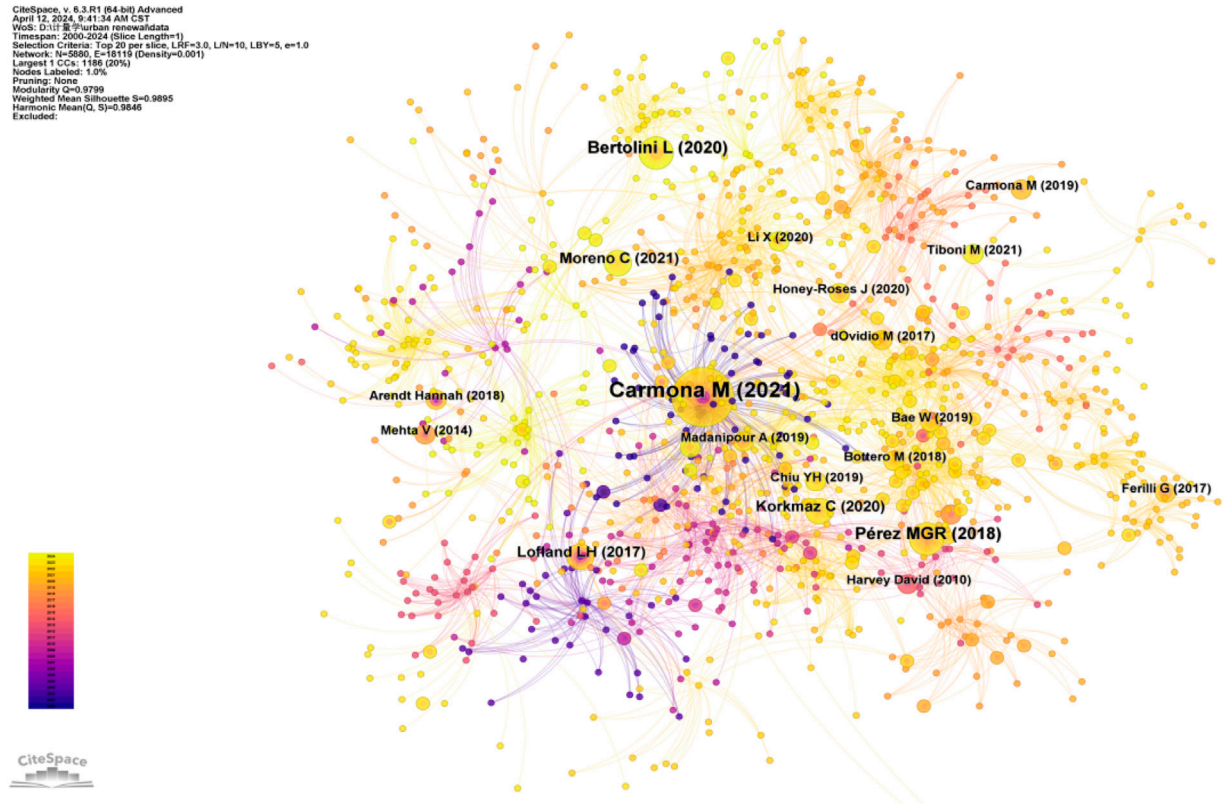

FIGURE 9
Co-citation analysis chart.

prominent research directions within a given area of study (Liu and Hu, 2021). In Figure 9, a co-citation analysis graph is presented, utilizing CiteSpace software to examine co-citations of literature related to public spaces in urban renewal from 1 January 2000, to 1 April 2024. Each publication is depicted as a sphere, with the size of the sphere corresponding to the number of its co-citations. The color gradient of the spheres, transitioning from purple to yellow, signifies the timeline of citations, with purple representing earlier references and yellow indicating more recent ones. The color overlay highlights the citation frequency across multiple years. Moreover, the connections between the publications in the graph reveal the interrelationships and influence of these works within the research domain. Notably, nodes highlighted in magenta in the graph represent key nodes with a centrality exceeding 0.1, signifying their significant impact and central position within the literature network.

The bibliography by Carmona M (2021), cited nine times, is notable for its extensive and significant impact in the field. The central theme of this work underscores urban design as an ongoing process of spatial shaping, influenced by global, local, and political contexts. The book introduces eight key dimensions of urban design and, in its latest edition, incorporates two additional process dimensions: design governance and place production. These enhancements address contemporary issues, including the effects of technology, climate change adaptation, and strategies for managing urban decline (Carmona, 2021).

Secondly, the literature by Pérez MGR (2018) has been cited five times. This study presents a novel spatial decision support system (URBIUS), specifically tailored for urban renewal projects at the neighborhood scale. The system evaluates projects against six sustainability goals and employs a dynamic approach to adapt to the actual conditions and long-term development of each neighborhood. A case study of the "Les Moulins" neighborhood in Switzerland illustrates the potential of the URBIUS system in advancing sustainable urban renewal at the neighborhood level (Pérez et al., 2018).

Additionally, Bertolini L (2020) is also cited five times. This paper investigates the "people-centered streets" experiments, analyzing how these initiatives facilitate a transition in urban transport from a "car-centered" to a "people-centered" paradigm. This transition is accomplished through the rebranding of streets, repurposing of parking spaces, and modification of the usage of entire streets or sections. The study assesses the positive impacts of these experiments on promoting physical activity, social interaction, and traffic safety, and proposes a framework to evaluate their potential for systemic change (Bertolini, 2020).

These analyses provide valuable insights for researchers, aiding them in identifying key literature and emerging research trends in the field, thereby fostering the development of new research directions and enhancing academic exchange.

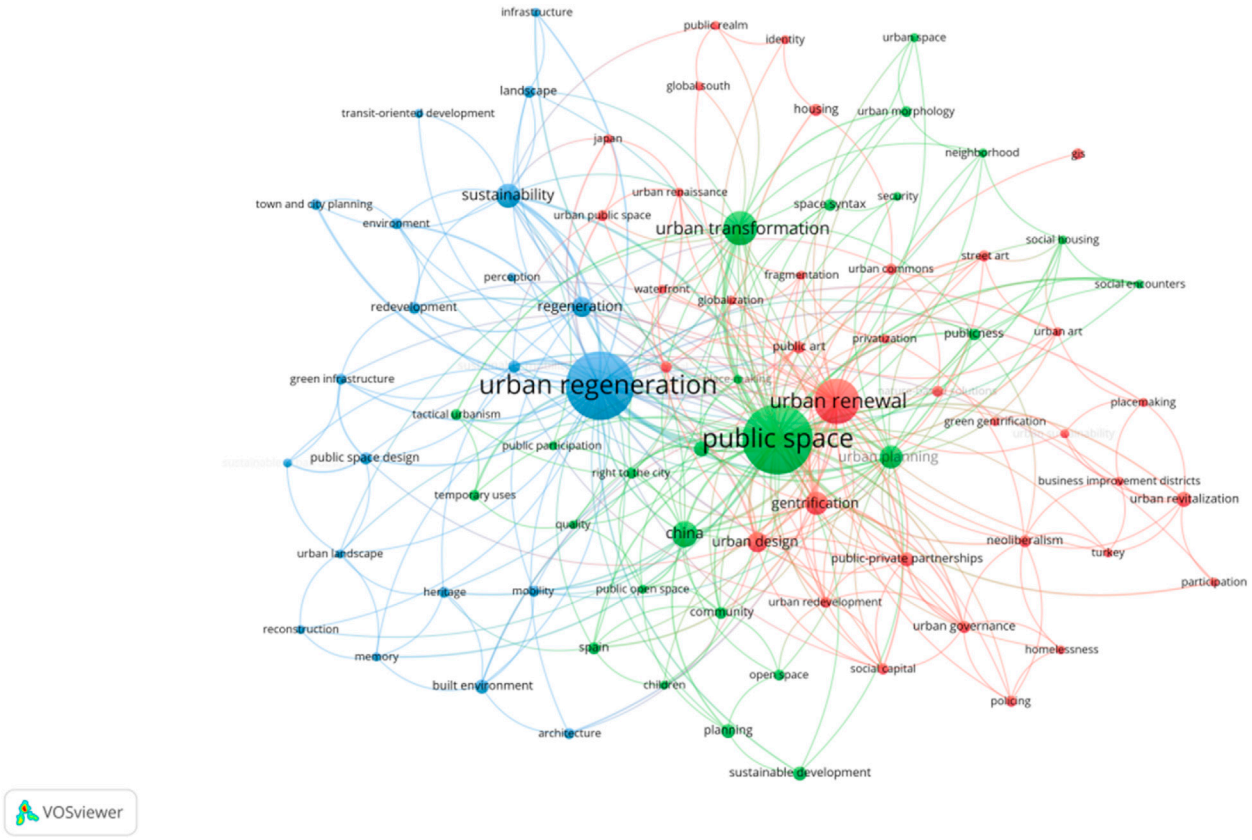

FIGURE 10
Keyword clustering analysis chart.

3.7 Keywords analysis of research hotspots

Keywords play a crucial role in academic research, representing the central themes and areas of focus within a particular field (Xia et al., 2024b). By analyzing keyword co-occurrence networks and tracking the distribution and evolution of high-frequency keywords, researchers can visually identify the emerging trends and key areas of interest in the study of public spaces within urban renewal (Zhang et al., 2020). This analysis specifically addresses Research Question RQ-6, aiming to uncover the hot topics and emerging areas within this research domain. Figure 10 illustrates a keyword co-occurrence visualization network, where nodes represent keywords and their frequency of occurrence, with line thickness indicating the strength of association between different terms. Nodes are color-coded to highlight distinct research clusters, such as the blue cluster focusing on urban regeneration, the green cluster on public spaces, and the red cluster on urban renewal. The size of these clusters reflects the frequency of keyword occurrences, providing insights into the research landscape and trends over time.

From the size of the nodes and the density of the connections in the diagram clearly indicate that "urban regeneration" and "public space" are two core concepts situated at the center of the entire network. This positioning underscores their significance in research within this field. Importantly, the robust connections between public space and other keywords—such as social capital, civic participation, and sustainability—highlight the increasing academic emphasis on issues related to spatial dynamics, social interaction, urban governance, and equity in urban spaces.

The clustering of keywords not only highlights current research hotspots but also indicates potential directions for future studies. The cross-linkages between different clusters reveal that an increasing number of scholars are focusing on interdisciplinary research, particularly the relationship between sustainable development and green infrastructure, as well as the impact of gentrification on social equity and social capital. This suggests that future research may increasingly prioritize the balance between environmental sustainability and social equity in the urban renewal process. Moreover, as the role of the public in urban governance becomes more significant, enhancing civic engagement and social cohesion through urban design and planning has emerged as a crucial research direction (McCormick et al., 2013).

Figure 11 illustrates the timeline of keywords in the field, providing insights into the frequency and evolution of keywords over time. The size of each node correlates with the frequency of the keyword, while the color gradient from blue to yellow signifies the chronological appearance of keywords, with blue denoting earlier keywords and yellow denoting more recent frequent keywords. The figure delineates significant shifts in research focus, delineated into four stages.

The initial stage, predating 2015, concentrated on the core principles of urban design and planning, with keywords like

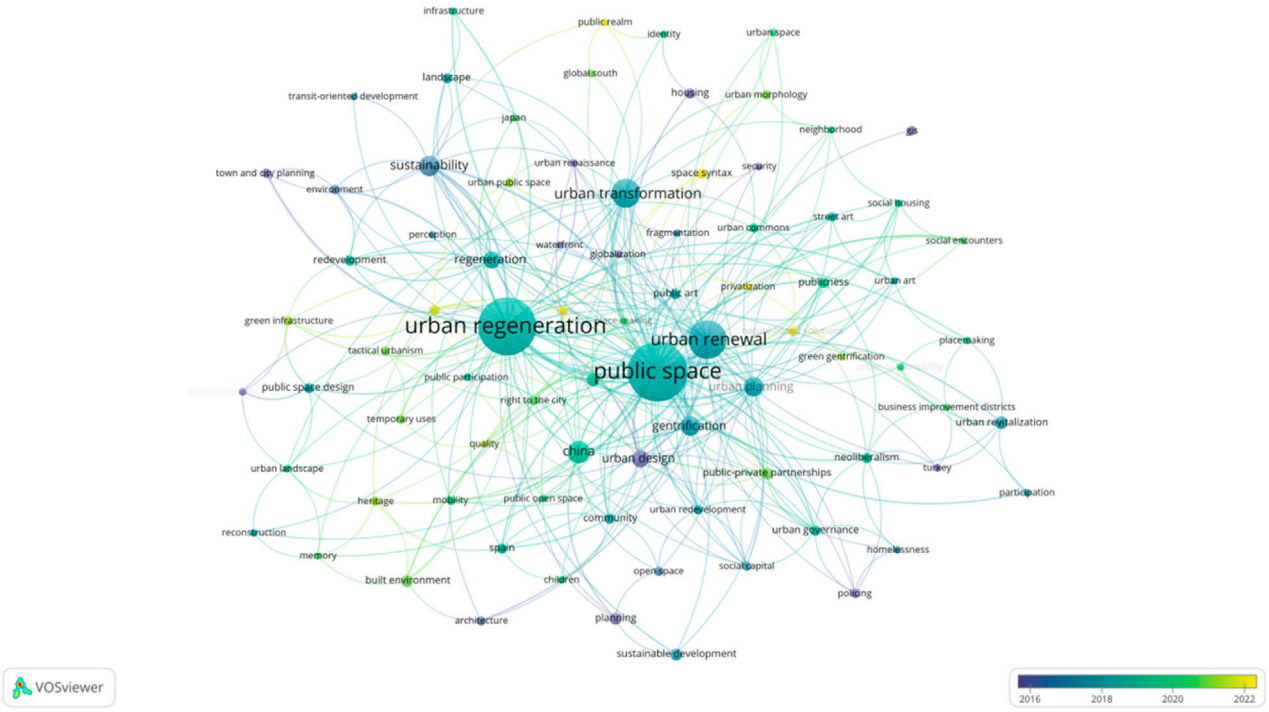

FIGURE 11
Keyword timeline.

"urban design," "planning," "sustainable urban design," and "GIS" reflecting the necessity of establishing a theoretical and methodological groundwork for urban revitalization. This phase underscored the importance of laying down theoretical underpinnings and methodological tools to tackle the challenges and requisites brought about by swift urbanization (Puchol-Salort et al., 2021).

The subsequent stage, spanning from 2016 to 2018, witnessed a transition towards the conceptualization and design of public spaces, with keywords such as "public space," "urban regeneration," "landscape," and "community" gaining prominence. This phase mirrored the increasing scholarly focus on the social and spatial dynamics of public spaces, highlighting their role in fostering community interaction, bolstering social cohesion, and enhancing urban life quality (Bernardi and Diamantini, 2018). Research delved into the theories and applications of landscape urbanism and community-oriented design, setting the stage for subsequent more specialized and diversified investigations (Shu et al., 2024).

The third stage, spanning from 2019 to 2020, witnessed a significant expansion in research topics, delving into more nuanced areas such as social justice, governance, and community involvement. Keywords like "social housing," "neoliberalism," "urban commons," and "public participation" underscored a strong emphasis on social equality and participatory methodologies during this phase. This research shed light on the significance of public spaces in fostering social justice and democratic governance, examining the repercussions of neoliberal urban policies on these spaces, and how participatory approaches in design and governance can boost the fairness and inclusivity of public areas (Jian et al., 2021).

Moving into the fourth stage post-2021, the focus shifted towards addressing contemporary environmental challenges through sophisticated analytical techniques. Keywords like "nature-based solutions," "green infrastructure," "sustainable transportation," and "space syntax" illustrated a response to global environmental concerns and the adoption of innovative methodologies. This stage reflected a heightened awareness of climate change and environmental sustainability, emphasizing the enhancement of ecological functions and environmental adaptability of public spaces through cutting-edge design and technology (Bibri et al., 2024). The utilization of advanced analytical tools like space syntax further facilitated a comprehensive comprehension and optimization of urban spatial structure and function, signaling new trends and emphases in ongoing research (Xing et al., 2024).

4 Discussion

4.1 Analysis of hot topics

Recent keyword analysis indicates that "urban renewal," "public space," and "urban regeneration" have emerged as primary research hotspots in recent years. These areas reflect scholars' heightened concern regarding the utilization and regeneration of urban spaces amid rapid urbanization (Xu and Lin, 2019). However, existing research tends to emphasize the positive impacts of urban renewal, such as enhancing residents' quality of life and fostering economic development, while insufficiently addressing its potential negative consequences (De Sousa, 2006; Raco, 2000).

For instance, the phenomenon of "symbolic green infrastructure" has been observed in certain urban renewal projects, where there is an excessive focus on ecological imagery that neglects substantial improvements in ecosystem services (Yin and Zhao, 2012; Li et al., 2019). This approach to "surface greening" struggles to effectively enhance environmental quality and may lead to a misallocation of resources (Böhm et al., 2012).

Moreover, some urban renewal projects insufficiently account for the social impacts on vulnerable groups, which may lead to the marginalization of low-income individuals and the elderly within the redeveloped public spaces (Cassarino et al., 2021; Ha, 2007). As a result, future research must thoroughly investigate the multifaceted effects of urban renewal, with particular emphasis on the importance of social equity in the sustainable development of public spaces (Yung et al., 2014).

In the field of public space design and management, there is an increasing focus on 'public participation,' reflecting a transition from traditional top-down planning methods to more democratic, community-oriented approaches (Chen and Qu, 2020; De Carli and Frediani, 2021). Numerous studies have shown that public participation not only enhances the transparency and legitimacy of urban renewal projects but also fosters a sense of belonging and responsibility among community residents (Liu B. et al., 2018; Bartoletti and Faccioli, 2016). For example, Arnstein's Ladder of Participation model outlines various levels of participation (Tritter and McCallum, 2006), ranging from "information" to "resident control." Within this framework, scholars have increasingly explored strategies to achieve deeper public participation in actual projects, thereby enhancing the effectiveness of planning implementation (O'Faircheallaigh, 2010).

4.2 Analysis of Frontier fields

The analysis of recently emerging high-frequency keywords reveals that topics such as "Nature-based Solutions (NBS)," "green infrastructure," "sustainable transportation," and "space syntax" are increasingly becoming cutting-edge areas within this field. The introduction of these concepts signifies a renewed academic perspective on the multifaceted role of public spaces in urban renewal, viewing them not merely as physical areas for reconstruction but as providers of ecological services, catalysts for social interaction, and key enablers of sustainable urban development (Goel and Vishnoi, 2022).

The application of NBS highlights a growing trend among global city managers toward ecological sustainability (Goodwin et al., 2023). These solutions enhance urban resilience against the challenges posed by climate change by integrating natural elements such as vegetation, wetlands, green roofs, and rain gardens (Scott et al., 2016). For instance, Copenhagen's NBS project effectively addresses the risk of urban stormwater flooding through the implementation of green roofs and rain gardens (Langergraber et al., 2021). This approach not only alleviates the burden of stormwater runoff on urban infrastructure but also creates multifunctional public spaces where citizens can relax and socialize (Addas, 2023). The interplay between ecological services and social interaction exemplifies the dual role of NBS in enhancing both the environmental quality of cities and community cohesion (Almenar et al., 2021).

Additionally, Gardens by the Bay in Singapore serves as another successful example of NBS (McNeill, 2022). This project integrates urban greening and sustainable development within a high-density urban context through vertical greening, rainwater collection systems, and energy-self-sufficient "super trees." Gardens by the Bay not only enhances the city's biodiversity and landscape value but also serves as a prominent symbol of the city, attracting numerous tourists and positively impacting the local economy (McDonald et al., 2023). These examples illustrate that incorporating NBS into policy frameworks can significantly enhance ecosystem services while also fostering economic development by improving urban livability and attractiveness (Lafortezza et al., 2018).

Green infrastructure has emerged as a pivotal concept within numerous urban policies (Lafortezza et al., 2013). Its primary objective is to foster the sustainable development of public spaces through the implementation of more ecologically efficient urban design (Jordán and Infante, 2012). This infrastructure manifests in various forms, including traditional parks and green spaces, as well as street greening, green corridors, rain gardens, and the restoration of water bodies (Pitman et al., 2015). For instance, London's Green Roof Policy promotes the installation of green roofs on new buildings to mitigate the urban heat island effect and enhance the urban green area (Carter and Fowler, 2008). Such policies significantly bolster the resilience of urban ecosystems while providing residents with a healthier living environment (Green et al., 2016).

Sustainable transportation plays an increasingly vital role in the design of public spaces, particularly in mitigating urban traffic congestion, air pollution, and carbon emissions (Pojani and Stead, 2015). By prioritizing low-carbon travel options such as walking, cycling, and public transport, cities can reduce their reliance on private cars, thereby freeing up more public space for residents (Mindell et al., 2011). The planning of pedestrian-friendly and bicycle-friendly urban environments not only lessens the negative impact of transportation on the environment but also enhances the utilization of public spaces by providing safer and more convenient travel methods (Ashraf et al., 2022). For instance, the Netherlands and Denmark have successfully integrated sustainable transportation into urban life by establishing efficient networks of bicycle lanes and pedestrian areas, significantly improving the quality of public spaces and fostering social vitality (Pucher and Dijkstra, 2000).

Paris's "Car-Free Day" policy exemplifies the profound impact of sustainable transportation on public spaces (Glazener et al., 2022). By closing roads in the city center during designated periods, Paris has effectively reduced car pollution and allowed citizens to enjoy public spaces more freely. This initiative not only improves air quality but also enhances the accessibility and social vitality of public spaces, thereby laying the groundwork for sustainable transportation policies. Furthermore, these efforts provide innovative demonstrations of effective urban planning (Kennedy et al., 2005).

Technological advances provide innovative tools for the design and analysis of public spaces. For example, "Space Syntax" represents an advanced analytical method that offers a nuanced approach to examining urban spatial structures, allowing planners

and researchers to gain deeper insights into how public spaces affect human behavior and social interactions (Karimi, 2023). The widespread adoption of this method suggests that future research on public spaces will not be limited to qualitative analyses; instead, it will increasingly rely on data-driven methodologies to enhance the scientific rigor and precision of research (Yao et al., 2024). However, an over-reliance on technical tools may lead to the neglect of human factors during the planning process, particularly in contexts where data is scarce. Technology-dependent spatial planning methods may inadequately capture the actual needs of local residents. Therefore, it is crucial for policymakers to integrate these technical tools with community engagement, ensuring that planning outcomes genuinely reflect the needs and expectations of diverse groups (Burby, 2003).

4.3 Challenges and opportunities

Despite significant advancements in this research field, several challenges persist. Firstly, there is a notable imbalance in regional studies. While China and the United States dominate much of the research landscape, public space issues in numerous developing countries and regions remain underexplored. For example, South America, Africa, and parts of Southeast Asia exhibit relatively low research output, leading to an incomplete representation of the diversity of public spaces across various global contexts. The design and management of public spaces are profoundly influenced by local cultural, economic, and social factors (Harrison and Heley, 2015). Consequently, a more inclusive global perspective is essential, with increased attention to the unique characteristics and challenges faced by different regions.

Secondly, despite a growing emphasis on public participation and community governance in recent years, the translation of these concepts into practical implementation continues to pose significant challenges. In the context of rapid urbanization and constrained resources, urban managers and planners grapple with the difficult task of balancing economic development with public involvement (Watson, 2009). Furthermore, as environmental issues become increasingly urgent, green solutions in urban renewal, despite extensive discussion, often face implementation hurdles due to financial constraints or technological limitations (Keivani, 2009).

However, as global attention on sustainable development goals intensifies, research on public spaces within urban renewal is encountering new opportunities. An increasing number of cities acknowledge the vital role that public spaces play in fostering social equity, improving residents' wellbeing, and tackling climate change (Reckien et al., 2017). Enhanced international collaboration and interdisciplinary research present potential solutions to these challenges. By leveraging the successful experiences of various countries, especially those with innovative approaches, the advancement of global public space research can be significantly propelled (Hinds et al., 2011).

4.4 Future research directions

Future research must adopt a more inclusive and diverse approach from a global perspective, particularly with regard to less developed regions, and explore how innovative practices can enhance the quality of public spaces (Ng et al., 2016). For instance, many African cities implement community-led, small-scale greening projects that significantly improve the environmental quality of public areas (Muchiri and Opiyo, 2022). This localized model not only adapts to specific local conditions but also offers valuable insights for other regions. Additionally, considerable differences exist in how various cultures define and utilize public space; therefore, researchers should strive for a deeper understanding of how these cultural distinctions influence the effectiveness of space design. In areas with a strong traditional culture, public spaces often emphasize community interaction and collective activities, in contrast to Western societies that prioritize individual use of space (Deregowski, 1989). Consequently, future research should aim to uncover these diverse spatial requirements and propose more adaptive design strategies.

Interdisciplinary research is poised to become a key trend in the study of public spaces in the future. Public space encompasses not only architecture and urban planning but is also intricately linked to disciplines such as sociology, environmental science, ecology, economics, and public administration (Carr, 1992). By integrating climate change adaptation, social equity, and public space management, this approach addresses multiple challenges in urban regeneration, particularly those concerning social inclusion and environmental crises (Jabareen, 2013). Furthermore, psychological research can elucidate the impact of various spatial designs on residents' mental health, thereby providing a scientific foundation for the creation of beneficial public spaces.

With the rapid development of artificial intelligence (AI), the Internet of Things (IoT), and big data technologies, future research should focus on exploring how these technologies can enhance the design and management of public spaces (Atitallah et al., 2020). For instance, AI can analyze large-scale urban data to accurately identify usage patterns and crowd flow trends in public spaces. This data-driven approach optimizes spatial configurations and enhances the efficiency and safety of these areas (Fang et al., 2021). Additionally, computer vision technology can monitor dynamic changes in real time, enabling city managers to adjust their management strategies promptly, such as deploying additional security personnel or temporary facilities during peak periods (Hancke and Hancke Jr, 2013). By leveraging these technologies, the management of public spaces can become more intelligent and efficient.

As the global climate change crisis intensifies, future research on public spaces must prioritize enhancing environmental resilience (Al-Humaiqani and Al-Ghamdi, 2022). For instance, it is essential to investigate how cities can become more resilient to extreme weather events through nature-based solutions (NBS) and green infrastructure (Conti et al., 2021). This is particularly relevant in high-density urban areas, where the implementation of vertical greening and rooftop gardens can significantly expand green spaces, mitigate the urban heat island effect, and improve air quality (Tan et al., 2016). Furthermore, future studies should assess the long-term maintenance and cost-effectiveness of NBS to facilitate the broader adoption of these solutions.

TABLE 5 Summary table of key trends, challenges, and potential opportunities.

Hot issues	Sustainable design
Key Trends	Nature-based solutions (NBS) and green infrastructure are widely applied in public spaces to address climate change and urban environmental challenges
Challenges	Although green infrastructure is highly regarded, some projects excessively prioritize the ecological image over actual ecological benefits, leading to resource waste
Opportunities	By incorporating ecological elements, the resilience of the urban environment can be enhanced, while also providing multifunctional public spaces
Hot Issues	**Public Participation**
Key Trends	A growing body of research advocates for increased public participation in the design of public spaces, with planning models shifting from a top-down approach to more democratic and community-oriented practices
Challenges	Achieving widespread and meaningful public participation faces limitations in resources and time, and in some areas, there is a low willingness among the public to participate
Opportunities	It contributes to increasing project transparency and legitimacy, while also enhancing residents' sense of belonging and responsibility
Hot Issues	**Technology Application**
Key Trends	Advanced analytical methods, such as space syntax, and new technologies, including artificial intelligence and big data, are increasingly applied in the planning and management of public spaces
Challenges	The widespread use of technology may lead to the neglect of human factors. In areas with limited data, technological approaches may fail to adequately capture the actual needs of residents
Opportunities	Utilizing technological tools can optimize space allocation, improving the efficiency of public space usage and the overall level of management
Hot Issues	**Nature-Based Solutions (NBS)**
Key Trends	An increasing number of cities are enhancing environmental resilience and addressing climate change by introducing natural elements such as vegetation, wetlands, and rain gardens
Challenges	In cases of insufficient funding or technological limitations, the implementation of nature-based solutions (NBS) can be challenging, especially in high-density urban areas
Opportunities	Integrating ecosystem services with social interaction functions can enhance the overall environmental quality of cities and improve residents' wellbeing
Hot Issues	**Green Infrastructure**
Key Trends	Urban policies are increasingly incorporating green infrastructure as a central component, promoting the sustainable development of public spaces through initiatives such as street greening and green corridors
Challenges	The implementation and maintenance of green infrastructure can be costly, requiring long-term policy support and stable funding
Opportunities	Enhancing the functionality of ecosystem services can provide residents with a healthier living environment
Hot Issues	**Artificial Intelligence(AI)**
Key Trends	Artificial intelligence is used to analyze large-scale urban data, identifying public space usage patterns and crowd movement trends to improve the efficiency of space management
Challenges	Overreliance on technology may overlook social and human factors. In areas with limited data or weak technological infrastructure, the application of AI may have limited effectiveness
Opportunities	A data-driven approach can optimize space design and management, enabling real-time monitoring of spatial changes to enhance the safety and usability of public spaces
Hot Issues	**Sustainable Transportation**
Key Trends	A growing number of cities are integrating sustainable transportation into public space design, prioritizing the development of low-carbon travel options such as walking, cycling, and public transit
Challenges	The implementation of sustainable transportation may face challenges related to the high costs of retrofitting existing transportation infrastructure and gaining public acceptance
Opportunities	By reducing dependence on private cars, more public space can be freed up, air quality improved, and urban social vitality enhanced

4.5 Urban renewal's impact on public space sustainability

In the context of urban renewal, the design and management of public spaces have increasingly become focal points for both academics and practitioners. An analysis of current research trends reveals that nature-based solutions (NBS), green infrastructure, and artificial intelligence are pivotal in promoting the sustainable development of public spaces. However, these areas also face numerous challenges in practical implementation, including issues related to funding, technology, and social equity. Despite these challenges, they also present opportunities for innovation. Table 5 summarizes the primary trends, challenges, and potential opportunities associated with urban renewal for the sustainable development of public spaces, serving as a reference for future research and policy formulation.

5 Conclusion

This study presents a thorough bibliometric analysis of literature concerning public space in urban renewal. By gathering and scrutinizing publications from 2000 to 2024 sourced from the Web of Science Core Collection, the study employs VOSviewer and CiteSpace for analytical purposes. The research offers a comprehensive overview of the present research landscape, trends related to public spaces in urban renewal, and suggests potential avenues for future research. Key findings of the research are as follows:

First, the key researchers who have made significant contributions to the study of public spaces in urban renewal include Zazzi Michele, Anguelovski Isabelle, Wang Hao, Mehdipanah Roshanak, Li Bin, Liu Huiming, Pellicelli Gloria, Rossetti Silvia, Bottero Marta, and Samadi Zalina. It is worth noting that Pellicelli Gloria, Rossetti Silvia, and Zazzi Michele have a particularly strong collaborative relationship, working closely together in their research endeavors.

Secondly, significant contributions to the study of public spaces in urban renewal have been made by research institutions such as Gdansk University of Technology, Hong Kong Polytechnic University, University of Lisbon, Polytechnic University of Milan, Polytechnic University of Valencia, Autonomous University of Barcelona, and Pontifical Catholic University of Chile.

Thirdly, from a macro perspective, the countries that have made the most significant contributions to the field of public spaces in urban renewal include China, the United States, the United Kingdom, Italy, Spain, Australia, Turkey, Canada, Poland, and Germany. Notably, China, the United States, the United Kingdom, and Italy have made substantial contributions to research in urban renewal public spaces, reflecting their strong economic capabilities. These four countries appear to benefit from more stable government financial support policies compared to other nations.

Fourthly, in the field of public spaces in urban renewal, key contributions are found in reputable journals like Sustainability, Cities, Land, and Urban Studies.

Fifth, the current research hotspots in the field of public spaces within urban renewal include terms such as "public space," "urban regeneration," "urban renewal," and "urban transformation." Recent cutting-edge topics also encompass "space syntax," 'nature-based solutions," and "sustainable mobility," which are expected to influence research direction in the near future.

In light of the escalating global challenges associated with urbanization and environmental sustainability, research in this field is poised to play an increasingly vital role in shaping urban development policies. Furthermore, future studies should prioritize underrepresented regions, particularly in the Global South, where urban renewal projects are often neglected. Investigating innovative methodologies, such as advanced data analytics and citizen-driven urban design, can yield valuable insights. The intersection of public spaces with climate resilience and equity issues remains a largely unexplored area that warrants priority in future research endeavors.

6 Limitations

The data for this study primarily derives from the Web of Science Core Collection database. While this database is recognized for its extensive coverage and significant academic influence, it does have certain limitations. The Web of Science primarily emphasizes high-impact journals, which may result in the exclusion of some local and regional journals, as well as research published in non-English languages. Consequently, future research should consider expanding to additional databases, such as Scopus, RISS, and CNKI, to provide a more comprehensive representation of the current state of research on public space in urban renewal globally.

Author contributions

JX: Conceptualization, Data curation, Investigation, Resources, Software, Visualization, Writing–original draft, Writing–review and editing. ZZ: Formal Analysis, Investigation, Project administration, Resources, Software, Validation, Visualization, Writing–original draft. LC: Formal Analysis, Investigation, Resources, Software, Visualization, Writing–original draft. YS: Conceptualization, Methodology, Supervision, Writing–original draft.

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