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Effects of COVID-19 on Residential Planning and Design: A Scientometric Analysis

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Abstract: Coronavirus disease has caused city blockades, making people spend longer in residential areas than ever before. Human well-being and health are directly affected by the suppression of the epidemic through residential planning and design. In this regard, scholars from all over the world have made significant efforts to explore the links between COVID-19 and residential planning and design, trying to adjust the states in time to cope with the effects of COVID-19 in the long run. This study is based on Bibliometrix to conduct a scientometric analysis of the literature on "Effects of COVID-19 on residential planning and design (ECRPD)" published in Web of Science and Scopus from 2019 to October 2022. The aim of this study is to comprehensively present the scientific knowledge of ECRPD research through general characteristics' analysis, citation analysis, and horizontal conceptual structure analysis, and try to summarize how residential planning and design responds to COVID-19, so as to provide support and advice for urban planners, builders, and policy makers. According to the results, ECRPD research is growing significantly, and the scientific productivity of it has increased exponentially. The main effects and feedback are characterized by three aspects: residential environment, residential building space and planning space, and residential traffic and community management. Generally, ECRPD research has expanded beyond the disciplines of architecture and planning. Environmental and energy concerns have attracted the most attention, though practical research into residential building space is relatively limited. To fully deal with COVID-19's multiple negative facets, it is imperative to promote cross-disciplinary and multi-field collaboration, implement new technologies and methods for traditional disciplines, develop bioclimatic buildings to cope with environmental changes, and strengthen practical research in residential building and planning to ensure that a sustainable and resilient living environment is created in the post-pandemic era.

Keywords: COVID-19; residential planning and design; scientometrics

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1. Introduction

Worldwide, Coronavirus disease 2019 (COVID-19) has caused severe impacts [1], with most governments taking the strictest measures to prevent its spread. [2,3]. Architects and planners have been looking at new and existing residential health paradigms as well as how COVID-19 impacts residential environments as a result of COVID-19. With the long-distance transmission capability and complex flow mechanism of COVID-19 [4], the spread of the epidemic has been greatly accelerated. The transmission mechanism of the virus fundamentally affects the spatial organization pattern and configuration of residential planning and buildings. The most effective preventive measure following an epidemic remains social distancing [5]; however, unreasonable building factors may increase the risk of virus transmission [6]. In the long run, urban planning and architectural design are more effective at preventing the spread of COVID-19 and other viruses in advance.

The links between COVID-19 and residential planning and design have been explored in various ways around the globe. In planning, scholars have studied the statistical relationship between urban spatial characteristics (density, connectivity, streets and open spaces, and so on) and COVID-19 [7]. It has been observed that viruses are more likely to be contracted in densely populated and crowded cities. Therefore, providing more open space, green space, and reducing urban density are critical to preventing the spread of the epidemic [8]. At the building level, remote work is an unavoidable means of isolation during and after the epidemic. It is thus necessary to improve the spatial layout and use strategy of residential units, and to create more internal partitions and redundant spaces to adapt to the changing daily life of post-epidemic residents [9]. It is also necessary to improve the physical environment of living units by utilizing natural light, ventilation, plants, and other natural materials. This is done to reduce the risk of infection by viruses [10]. In transportation, the spread of the virus has seriously affected the normal operation of public transportation [11], causing residents to lose confidence in such travel. Therefore, the establishment of safe and resilient public transportation and material supply chains will facilitate the maintenance of sustainable socio-economic development. In the community, improper community management can lead to the spread of the virus. In order to better respond to public health risks, the community is responsible for implementing specific prevention and control activities, collecting epidemic information, and coordinating management with national policies [12]. Additionally, the establishment of vertical gardens, urban gardens, and agricultural lands within the community to create an economically self-sufficient community will enhance its resilience [10].

Presently, people are anticipating the development of specific drugs and vaccines to completely suppress the effects of COVID-19. However, the vaccine is only targeted at one type of virus, and the development of the disease is a result of the interaction of numerous factors (human activity, climate change, environmental pollution, and so on). We should re-plan and design the residential area to resist the epidemic and other natural disasters from a broader perspective, in order to allow the residential area to respond and feedback to changes in the outside environment. This study seeks to quantify the scientific knowledge of residential planning and design approaches in response to COIVD-19 and to make predictions regarding future development directions. Currently, there have been very few studies that have examined scientific knowledge regarding the "effects of COVID-19 on residential planning and design". This study aims to conduct a review based on relevant published literature in the Web of Science (WoS) and Scopus databases; perform scientometric analysis using RStudio and Bibliometrix packages; evaluate correlations between internal knowledge; and describe science knowledge using horizontal conceptual structures, citation analysis, and visual networks. The purposes of this research can be interpreted in two aspects: 1. In scientometric analysis, it is helpful to determine the status of the current content of the overall impact of COVID-19 on the residential planning and design. 2. By comparing the horizontal conceptual structure, we will be able to better understand how residential planning and design responds to COVID-19 and provide design approaches to urban decision-makers to promote safe and sustainable residential development.

The research theme is "Effects of COVID-19 on residential planning and design (ECRPD)", and the search strategy in the next section indicates the scope of the study, which includes the planning and design aspects of residential areas, residential districts, communities, residential quarters, residential clusters, residential buildings, and residential units. To indicate the research theme, abbreviations (ECRPD) will be used below.

2. Methodology and Data Collection

Literature data from WoS and Scopus databases were analyzed based on scientometric methods to evaluate ECRPD relevant articles. In order to more precisely cover the research scope of residential planning and design described in the previous section, the ECRPD search strategy (Table 1) and the ECRPD screening criteria (Table 2) were developed. In recent decades, the explosion in the number of researchers, journals, and scientific productivity has created a flood of information. As a result, there is an urgent need to analyze and quantify scientific knowledge in a particular field. In the first batch of pioneers, Price and

Garfield established the field of scientometrics [13,14], which is concerned with conducting statistically complex assessments of scientific knowledge from an objective viewpoint, in order to assess the speed and trends of scientific knowledge development as well as speculate on the outcome of scientific research in the future. Moreover, structured quantitative analysis of scientific knowledge can assist government decision-making departments in using research funds more efficiently and effectively, thus improving research efficiency. As a result of these perspectives, scientometric analysis of frontier scientific knowledge fields is extremely significant, and computerized systems have enabled scientometrics to process a large amount of scientific data.

Table 1. ECRPD search strategy.

Database	Search Strategy	Records
Web of Science	TS = ((corona* or COVID* or SARS-CoV-2 or 2019-nCoV) and (“residential” or “community”) and (planning or design))	n = 6038
Scopus	TITLE-ABS-KEY ((corona* or COVID* or SARS-CoV-2 or 2019-ncov) and (“residential” or “community”) and (planning or design))	n = 8019

Table 2. ECRPD screening criteria.

Criterion	Eligibility	Exclusion
	Web of Science	
Document type	Article	Review, conference paper, book chapter, review, etc.
Research areas	Engineering, Urban Studies, Construction Building Technology, Architecture	Medicine, Nursing, Mathematics, Business, Management and Accounting, Chemical Engineering
Language	English	Non-English
Period	2019–October 2022	<2019, &>October 2022
	Scopus	
Document type	Article	Review, conference paper, note, book chapter, etc.
Subject area	Engineering, Environmental Science, Multidisciplinary	Medicine, Nursing, Mathematics, Business, Management and Accounting, Chemical Engineering
Language	English	Non-English
Period	2019–October 2022	<2019, &>October 2022

2.1. Database

As a means of circumventing data limitations, this paper performs data retrieval using two databases, WoS and Scopus. As of now, WoS includes three well-known citation indexes (SCI, SSCI, and A&HCI) that include authoritative journals in a wide range of disciplines and are managed by Clarivate, and is the largest literature database. The Scopus database from Elsevier is considered one of the top contenders to WoS. It is a peer-reviewed [15], interdisciplinary database of the social sciences, including more than 22,800 journals published by 5000 publishers worldwide, together with the world’s largest database of abstracts and citations. As a result of WoS and Scopus’ stringent selection criteria and citation indexing mechanisms, they have become a critical evaluation object in scientometrics as well as retrieval tools.

2.2. Research Framework

The framework of this study is shown in Figure 1, and the scientometrics part uses the Bibliometrix package in RStudio (V.4.2.0) to quantitatively analyze the data. A search strategy application and database selection (WoS and Scopus) are conducted first, followed by the export of WoS and Scopus data into BibTeX. After searching, 14,057 documents (n = 6038, 8019) were found in WoS and Scopus (Table 1). Data were screened (n = 228, 177), merged (n = 405), and duplicated (n = 5) based on the screening criteria. A total of 400 documents will be used for quantitative analysis. Using the library module (Bibliometrix) in Rstudio, data analysis was performed and the results were visualized. Finally, the general characteristics of the results, the horizontal conceptual structure, and the citation data of ECRPD were summarized.

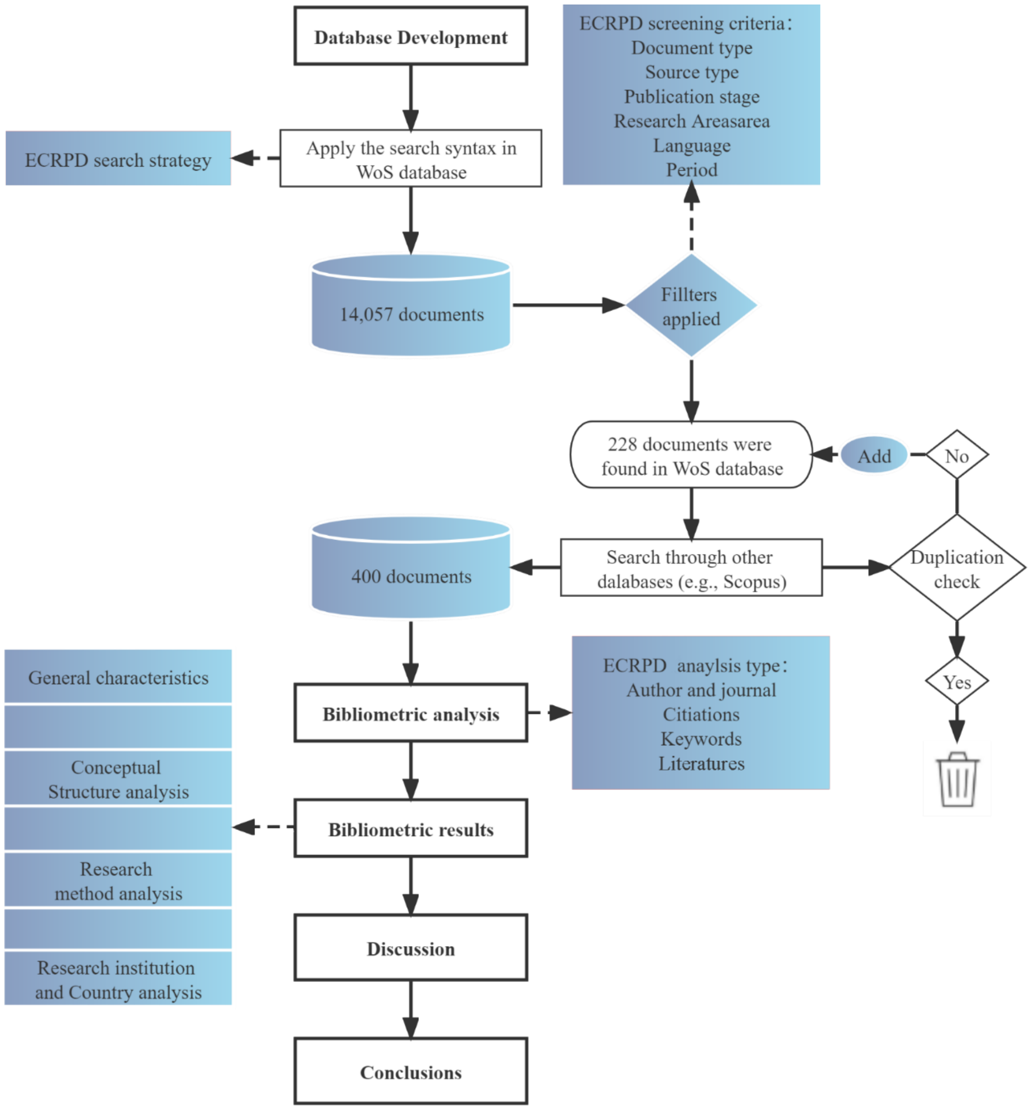


Figure 1. ECRPD research framework of the methodology.

3. Results

3.1. General Characteristics

The general characteristics of ECRPD-related studies during the evaluation time span are shown in Table 3. Figure 2 shows ECRPD annual scientific productivity and average total citations per year. In addition, the scientific productivity of ECRPD research has grown exponentially, reflecting the rapid development of ECRPD research. Scientific productivity peaked in 2021 (171), citations peaked in 2020 (19), and then declined in subsequent years. Citations in 2022 are set to 0 (less than one year).

Table 3. ECRPD general characteristics.

General Characteristics	Results
Documents	400
Timespan	2019–2022
Sources (Journals)	171
Average years from publication	0.731
Average citations per documents	9.682
Average citations per year per doc	4.599
Keywords plus (ID)	1512
Author's keywords (DE)	1456
Authors	1403
Author appearances	1683
Authors of single-authored documents	50
Authors of multi-authored documents	1353
Documents per author	0.285
Authors per document	3.51
Co-authors per documents	4.21
Collaboration index	3.97

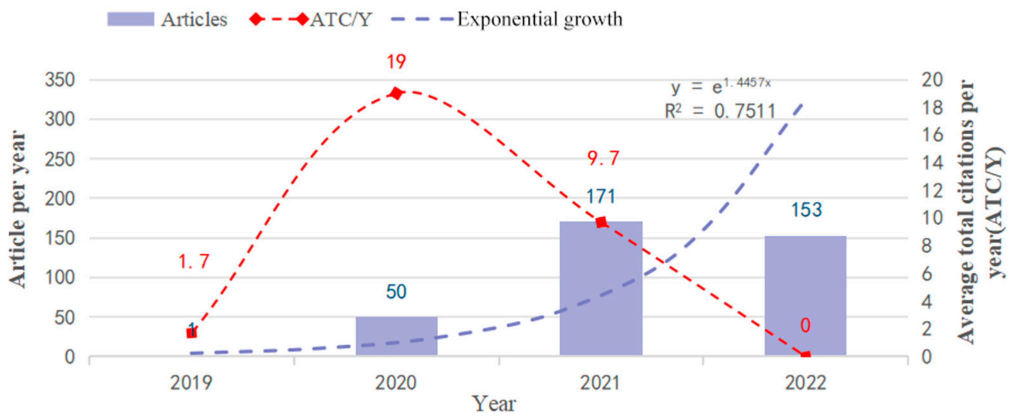


Figure 2. ECRPD annual scientific productivity and average total citations per year.

3.2. Fractionalized Frequency

The study identified the most relevant ECRPD authors TOP10 in the time span, including their main contribution areas, representative article, and areas of contribution (Table 4). In order to avoid the one-sidedness caused by the evaluation of authors solely based on scientific productivity, the author's contribution rate is further evaluated by fractional authorship, which is expressed as a fractionalized frequency [16]. This measure quantifies the author's own contribution to the publication. As a result, Yigitcanlar, Tan has the most scientific productivity and published four articles; Spennemann, Dirk H. R. has the highest fractionalized frequency (3.0); and the literature of high-frequency and high-productivity authors will be the focus of the conceptual structure analysis in the follow-up. Some reviews of works in the literature that are similar to this study will be included in the Discussion in order to provide a comparison to the findings.

Table 4. Most relevant ECRPD authors TOP10 (author/articles).

SN	Author	Articles	Areas of Contribution	Representative Article	Frac Freq
1	Yigitcanlar, Tan	4	Community vulnerability; Strategic decision-making	Pandemic vulnerability knowledge visualisation for strategic decision-making: a COVID-19 index for government response in Australia	0.67
2	Fedorczak-Cisak, Małgorzata	3	Residential retrofits; Building automatics control; Thermal comfort	Position Paper Introducing a Sustainable, Universal Approach to Retrofitting Residential Buildings	0.65
3	Hsu, SC	3	Net-zero energy building	Photovoltaic rooftop's contribution to improve building-level energy resilience during COVID-19 work-from-home arrangement	0.75
4	Kim, Jeongseob	3	Urban and regional planning; Housing	COVID-19 impact on city and region: what's next after lockdown?	1.25
5	Kohsaka, Ryo	3	Green infrastructure; Green area	Access and use of green areas during the COVID-19 pandemic: Green infrastructure management in the "new normal"	1.50
6	Li, Bin	3	Building performance	Sustainable passive design for building performance of healthy built environment in the singnan area	0.58
7	Miller, Wendy	3	Energy management	Has COVID-19 lockdown impacted on aged care energy use and demand?	0.58
8	Mouratidis, Kostas	3	Built environment; Livable cities	How COVID-19 reshaped quality of life in cities: A synthesis and implications for urban planning	2.50
9	Spennemann, Dirk H. R.	3	Adaptive architecture; Environmental control	Residential architecture in a post-pandemic world: Implications of COVID-19 for new construction and for adapting heritage buildings	3.00
10	Ajitha A.	2	Energy forecast; Artificial neural networks	Design and development of Residential Sector Load Prediction model during COVID-19 Pandemic using LSTM based RNN	0.40

The formula for fractionalized frequency is as follows:

$$Frac\ Freq\ (AU_j) = \sum_{h \in AU_j} \frac{1}{n.\ of\ CoAuthors\ (h)} \tag{1}$$

Frac Freq represents the fractionalized frequency, (AU_j) represents the documents co-signed by author j, $n.$ represents the number, and h represents one document in (AU_j).

3.3. Citation Analysis

Citation analysis reveals the number of times the article has been cited, and highly cited articles are usually key articles [17]. As a result of Eugene Garfield's seminal work on citation indexes as tools for investigating the association of ideas [14], scientometrics techniques have been employed to identify and explore emerging research areas. To obtain this type of insight, one can probably analyze the content of the most cited papers in a particular period of time. Comparisons based on citation measures, however, are appropriate only within a single field or among disciplines that share similar citation exchange dynamics. It is important to note that citation counts cannot be considered entirely objective measures of intellectual influence and research quality [18], but examining high-performing papers provides a valuable framework for identifying and distinguishing key and emerging topics, centers of excellence, and influential researchers [19].

Table 5 shows the most cited articles Top 15, which will be highlighted for analysis [20]. Among the highly cited literature on ECRPD, the most prominent are the environmental field (climate, air, water, energy), the planning field (spatial features, green space), the transportation field (travel, blockade), the management field (community, policy), and the field of architecture (functional use, spatial behavior, remote work), among others. In the preliminary review above, very few discuss residential buildings alone, but the environment, planning, transportation, and community management are more commonly discussed.

Table 5. Most cited articles Top 15.

SN	Article (Title, Author, Year, Journal)	Total Citations	TC per Year
1	"SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area", Walter Randazzo, 2020, Water Research	508	169.333
2	"Spatial analysis and GIS in the study of COVID-19. A review, Ivan Franch-Pardo", 2020, Science of The Total Environment	247	82.333
3	"The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review", Milad Haghani, 2020, Safety Science	121	40.333
4	"COVID-19: Impact analysis and recommendations for power sector operation", Rajvikram Madurai Elavarasan, 2020, Applied Energy	120	40.000
5	"An emerging source of plastic pollution: Environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city", Justine Ammendolia, 2021, Environmental Pollution	94	47.000
6	"Reproducibility and sensitivity of 36 methods to quantify the SARS-CoV-2 genetic signal in raw wastewater: findings from an interlaboratory methods evaluation in the U.S.", Brian M. Pecson, 2021, Environmental Science: Water Research & Technology	91	45.500
7	"Healthy movement behaviours in children and youth during the COVID-19 pandemic: Exploring the role of the neighbourhood environment", Raktim Mitra, 2020, Health & Place	83	27.667
8	"Strategic assessment of COVID-19 pandemic in Bangladesh: comparative lockdown scenario analysis, public perception, and management for sustainability", Mashura Shammi, 2020, Environment, Development and Sustainability	78	39.000
9	"Changes in recreational behaviors of outdoor enthusiasts during the COVID-19 pandemic: analysis across urban and rural communities", William L Rice, 2020, Journal of Urban Ecology	72	24.000
10	"Energy transition in a lockdown: An analysis of the impact of COVID-19 on changes in electricity demand in Lagos Nigeria", Norbert Edomah, 2020, Global Transitions	50	20.000
11	"Key questions for modelling COVID-19 exit strategies", Robin N. Thompson, 2020, Biological sciences	55	18.333
12	"SARS-CoV-2 in environmental perspective: Occurrence, persistence, surveillance, inactivation and challenges", S. Venkata Mohan, 2021, Chemical Engineering Journal	54	27.000
13	"Mapping community-level determinants of COVID-19 transmission in nursing homes: A multi-scale approach", Margaret M.Sugg, 2021, Science of The Total Environment	53	26.500
14	"Impact of COVID-19 lockdown on air quality in Chandigarh, India: Understanding the emission sources during controlled anthropogenic activities", Suman Mor, 2021, Chemosphere	46	23.000

Table 5. *Cont.*

SN	Article (Title, Author, Year, Journal)	Total Citations	TC per Year
15	"Spatial-temporal potential exposure risk analytics and urban sustainability impacts related to COVID-19 mitigation: A perspective from car mobility behaviour", Peng Jiang, 2021, Journal of Cleaner Production	45	22.500
16	"Building a Social Mandate for Climate Action: Lessons from COVID-19", Candice Howarth, 2020, Environmental and Resource Economics	44	14.667
17	"Access and Use of Green Areas during the COVID-19 Pandemic: Green Infrastructure Management in the "New Normal", Yuta Uchiyama. 2020, Sustainability	44	14.667
18	"Stay-at-home works to fight against COVID-19: International evidence from Google mobility data", Hakan Yilmazkuday, 2021, Journal of Human Behavior in the Social Environment	44	22.000
19	"Neural Network Based Country Wise Risk Prediction of COVID-19", Ratnabali Pal, 2022, Applied Sciences	43	14.333
20	"A preliminary simulation study about the impact of COVID-19 crisis on energy demand of a building mix at a district in Sweden", Xingxing Zhang, 2020, Applied Energy	39	13

3.4. Conceptual Structure

COVID-19 may pose a wide range of threats to all aspects of residential areas. Through horizontal conceptual structure analysis, it is possible to determine the current effects of COVID-19 on residential planning and design and to better understand current residential planning and design how to deal with the threat posed by COVID-19. COVID-19 was first identified in December 2019, so the research time span is short and scientometric analysis in terms of time has limited significance. Therefore, longitudinal development trend analysis will not be utilized. This figure illustrates the core topics of ECRPD research by depicting keyword co-occurrence networks based upon author keywords (Figure 3). As a result of setting the keyword co-occurrence threshold at 3, 87 keyword nodes appear (when set to 2, 380 keyword nodes appear, which is difficult to visualize). The node size represents keyword frequency, the link between each node represents similarity and correlation strength, and similar nodes are emphasized using the same color scheme. An intuitive representation of the current state of ECRPD research can be found in Figure 3, which depicts thirteen clusters, each serialized for better identification. It was decided to reset thirteen clusters based on the key articles derived from citation analysis and the key nodes in the keyword co-occurrence network in order to sort out and summarize the research results. Additionally, clusters involving interdisciplinary intersections were taken into account. The reset results are "Residential area environment ①②③④⑤"; "Residential area architectural space and planning space ⑥⑦⑧⑩⑪"; and "Residential area traffic and community management ①⑤⑨⑫⑬", which represents comprehensive content of the ECRPD research.

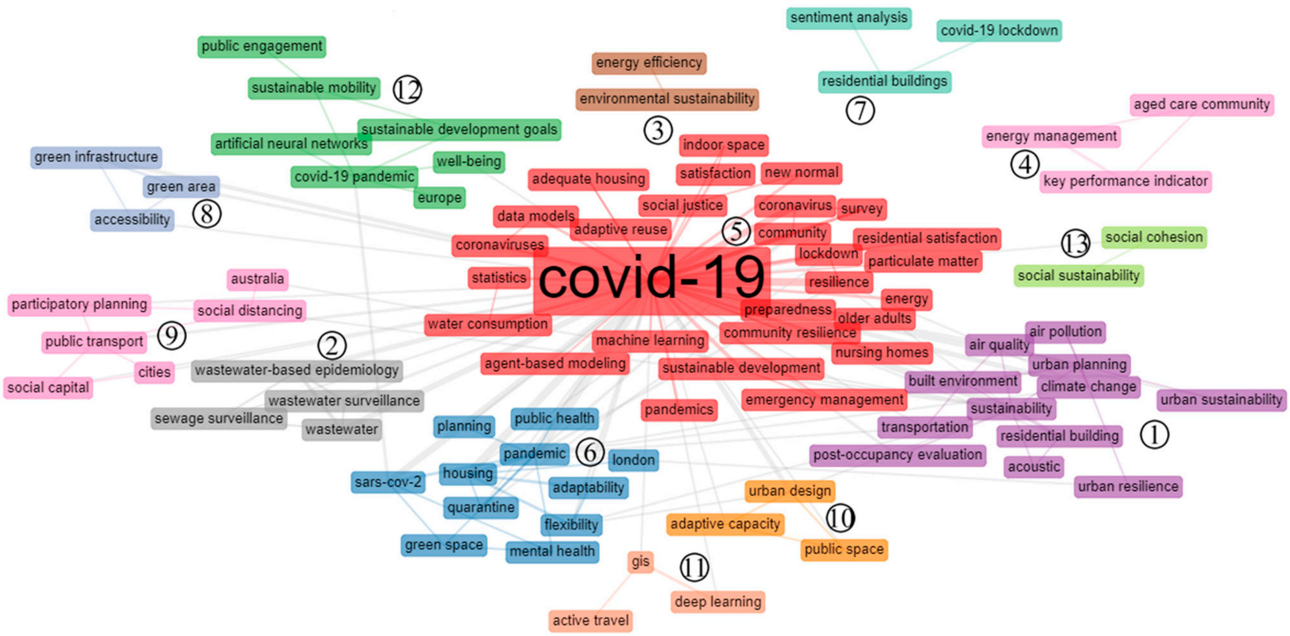


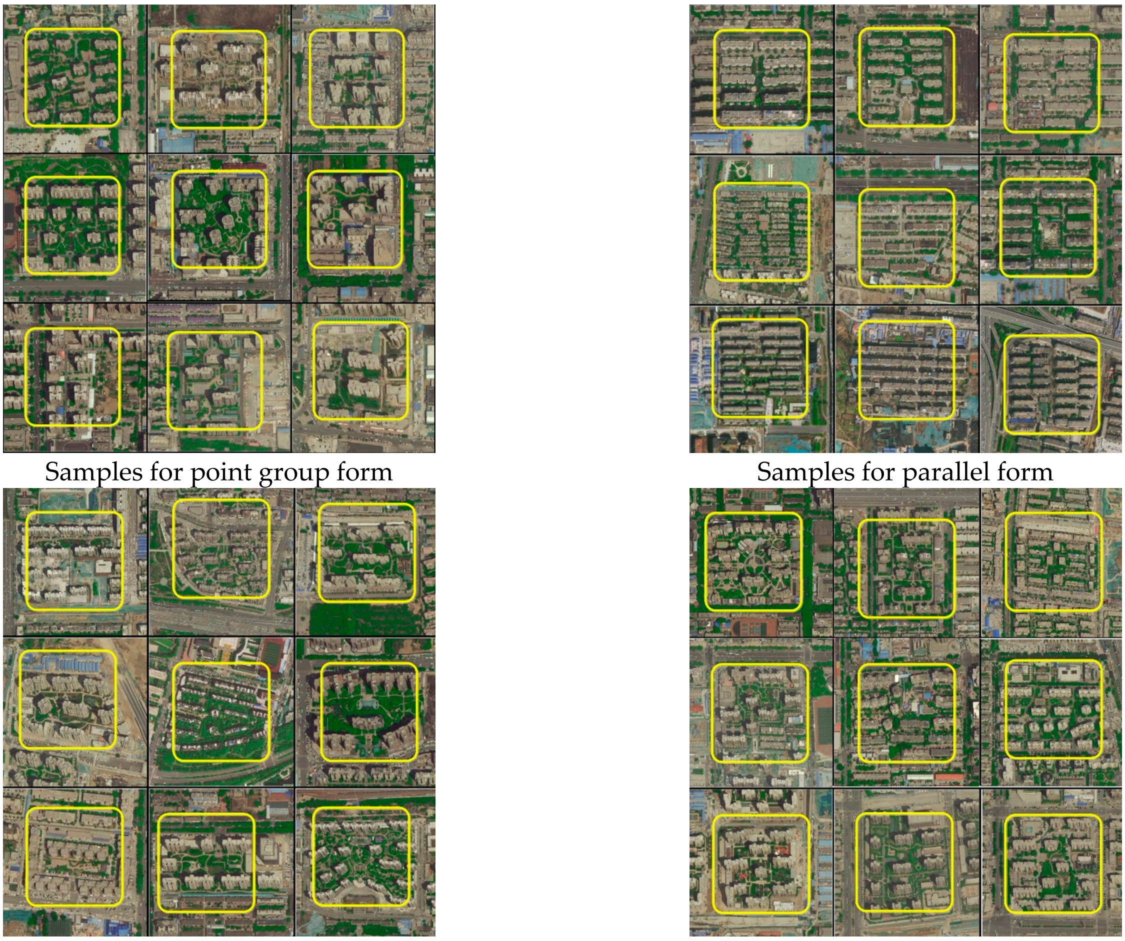
Figure 3. ECRPD keyword co-occurrence networks.

3.5. Residential Environment

3.5.1. Air

As the infected person speaks or coughs and sneezes, droplets carrying the COVID-19 virus float in the air as a mist, then move over long distances as smoky aerosols, which may remain in the air for several hours. According to relevant studies [4,21], aerosols play a significant role in spreading the epidemic. (a) Airborne transmission of the virus does not only affect the indoor space of residential buildings. (b) It also affects the outdoor space of residential buildings. In the indoor part, a study used air sampling data to demonstrate the ability of people with COVID-19 to spread the virus from a house isolation room to other rooms via aerosols [22]. In a residential building in Guangzhou, an infected individual had no direct contact with other residents, but transmitted the virus to upper-level residents who resided on vertically arranged floors [23]. The airflow velocity of the airflow transfers COVID-19-carrying gas to the upper layers, and similar studies have also demonstrated that the chimney effect of airflow can spread the virus [24]. It is possible to prevent the spread of viruses indoors by using the following methods. (a) Negative pressure isolation can prevent the spread of viruses in the room [22]. (b) Separate toilet drains and exhausts and seal floor drains to reduce virus transmission between vertical buildings. (c) Additionally, active purification methods such as ISO 29463-1:2017 high-efficiency particulate capture filters (HEPA) can be utilized, which are capable of removing 99.9993% of particulates from the air, depending on the setting location [25].

In the outdoor part, (d) a positive outdoor wind environment can quickly reduce the overall aerosol concentration in the residential area, reasonably design and optimize the shape of the residential area, promote natural ventilation of the outdoor area, and help reduce the risk of people being infected by aerosol viruses [25]. For instance, through the prediction model of residential building form and ventilation efficiency, it is found that the height difference shape index has the greatest influence on the wind speed ratio at different heights [26]. The spatial layout of urban residential areas is analyzed based on POI data, and the natural ventilation potential (NPV) of four typical layouts is evaluated by LCDM [27]. Moreover, the results indicate that the natural ventilation potential of the point layout and the center-centered layout is the most effective. It has been demonstrated that urban residential areas in northern China have higher ventilation volumes, including point and mixed ventilation [28] (see Figure 4).



Samples for point group form

Samples for parallel form

Samples for enclosed form

Samples for hybrid from

Layer	Name	Weight	Mean	Standard Deviation
1	Point-group form	0.0775	259.5	149.54
2	Parallel form	0.6420	2146.5	1238.99
3	Enclosed form	0.1110	371.5	214.20
4	Hybrid form	0.1695	567	327.07

Figure 4. Very high-resolution remote-sensing-based mapping of urban residential districts to help combat COVID-19 [28].

3.5.2. Water

The impact of COVID-19 on the water environment can be categorized into three aspects. (a) Water-mediated virus transmission. (b) Increased residential water consumption during the pandemic [29]. (c) Frequent water use amplifies the risk of virus transmission in overcrowded settlements with a lack of water and infrastructure [30]. Based on COMSOL Multiphysics, a CFD pollutant diffusion simulation was carried out on the drainage pipes of a local 12-story residential building. It is assumed that the seventh floor is the source of virus transmission. When the water seal of the trap fails functionally, the virus will spread to the adjacent four within an hour [31]. Additionally, if the outdoor sewage pipe ruptures, fecal water containing the virus will also pollute the environment, infecting residents nearby. Results based on regression models show that water consumption in non-residential buildings decreased as a result of restrictions during the epidemic, while water consumption in residential buildings increased [29]. On the one hand, it is due to the increase in time at home as a result of the epidemic blockade and the change in work mode and, on the other hand, because of residents' awareness of disease prevention, water consumption has become more frequent [32]. In informal settlements in India, 43% of households do not have access to water in their houses and 34% of households cannot use toilets in their houses. Frequent water use has caused virus infection [30].

To sum up: (a) Improve local water facilities and water conditions. (b) Regularly inspect and maintain water pipes in residential buildings to avoid the spread of viruses caused by water pollution. (c) Minimize shared water use as much as possible to meet the daily needs of residents living, reducing the vulnerability of informal settlements and contributing to healthy and sustainable settlement environments. In addition, (d) the epidemiological monitoring of residential wastewater is advantageous to provide numerical information for early virus prevention and control [33], and its qualitative diagnosis of COVID-19 is generally accepted in the literature [34]. Daily virus sampling contributes to improving epidemic prevention and control [33]. For informal settlements lacking kits and testing facilities, wastewater testing also reduces the manpower and material consumption required for daily testing [35].

3.5.3. Energy

(a) The COVID-19 lockdown has resulted in a change in occupant work patterns, occupancy rates, and behaviors [36], which has resulted in fluctuating residential building energy consumption [37]. As a result of the rise in home offices, remote working, and working from home, household energy consumption has increased. Those who are vulnerable, such as the elderly, must spend more time on health protection, thereby increasing the amount of energy consumed [38,39]. (b) Overall, the impact of COVID-19 on different energy sectors has been dramatic, such as reduced energy demand in transportation, as well as industrial and commercial buildings, and a large increase in energy demand in residential buildings [40,41]. For the three weeks prior to the lockdown (business as usual), partial lockdown, and complete lockdown, Figure 5 shows the average hourly instantaneous electricity demand in Lagos, Nigeria. As a result of the fluctuations in energy consumption across different sectors, it is important to note that a significant increase in energy consumption had already occurred three weeks prior to the lockdown (business as usual). As the differences in energy consumption between different parts of the city will be offset, the overall impact on the city's energy consumption will be small and the specific cause of the problem is the restrictive policies enacted by different governments [42].

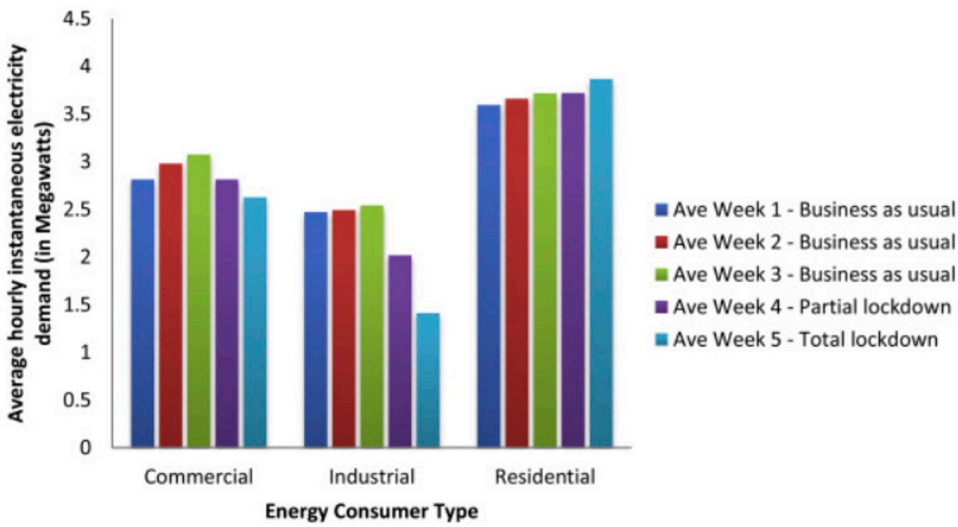


Figure 5. Changes in electricity demand in Lagos, Nigeria [42].

Three primary methods are available for alleviating energy pressure in residential areas: (a) energy forecasting, (b) energy management systems for intelligent buildings, and (c) distributed energy. It is imperative to predict energy consumption accurately in order to ensure a stable supply of energy. Currently, there are two types of energy consumption prediction models available: data-driven models and physical simulation models. Machine learning and deep learning algorithms are utilized in order to optimize calculation speed and accuracy. Compared with the non-data-driven model, the data-driven model performs better. In one study, an energy simulation model based on a GIS-based dynamic energy model is used to predict the energy performance of residential areas in the presence of COVID-19 and energy use behavior, while a machine learning model is used to improve the accuracy of energy simulations [36]. To predict energy consumption during outbreaks, scholars have also proposed combining data processing, support vector machines, and multi-objective optimization algorithms. After discriminator verification, the prediction accuracy of MAPE is 0.49% [43]. There is also a long-short-term memory network (RNN-LSTM) model based on a recurrent neural network to predict residential energy consumption [44]. The fitting degree R^2 is 0.9683 and the MAPE is 1.5%, and its fitting and accuracy are guaranteed.

The Energy Management System for Intelligent Building [45] will improve the energy efficiency of home life. Using Internet of Things (IoT) technology, the traditional building environment can be transformed into an energy-efficient environment, enabling automatic control of the building environment, resulting in significant energy savings for building equipment and enhancing indoor comfort. The operation logic of the existing intelligent building energy management system is to obtain environmental data through one or more sensors and then use the built-in static algorithm or dynamic algorithm of the integrated control system to provide real-time feedback to the data, and finally change the building system state through the automatic control system. The key technologies for improving building energy performance have been classified and discussed in detail in numerous studies, including HVAC systems, lighting, plug loads, window systems, energy optimization systems, and so on [45].

In order to solve the energy supply shortage and reduce carbon emissions, distributed energy must be developed and government-led energy transition policies can encourage this [46]. Distributed energy mainly includes renewable energy generation systems and power storage systems located at the point of use to provide electricity independent of the grid, such as combined heat and power (CHP), rooftop solar photovoltaics (PV), micro wind turbines, ground and air source heat pumps, and solar water heating.

3.6. Residential Building Space and Planning Space

3.6.1. Building Space

In the face of constant changes in external conditions, such as the extreme impact of epidemic isolation, climate change, and so on, (a) the demand for residential space usage changes and people will spend more time at home. Some scholars have used interviews to investigate the changes in residents' housing use during the epidemic isolation period [47], such as the difficulty of disinfection caused by insufficient entrance space, the use of open space caused by outdoor noise and privacy problems, and the single function of rooms caused by structural constraints. Insufficient lighting and natural ventilation because of balcony restrictions. (b) Cross-traffic in public spaces within residential buildings (such as apartment lobbies, stairs, elevators, or indoor spaces) can also contribute to the spread of COVID-19 [48].

(a) Residential buildings must respond to changes in a flexible manner. Housing flexibility has now become a key tool in the response to the pandemic [9,48]. (b) Design single housing units by creating transition spaces [49], redundant spaces, and flexible elements (sliding doors, lightweight walls) that are capable of dividing spaces. (c) Consider the sustainability of the building (including sunlight, natural ventilation, mechanical ventilation systems, and building materials that have high thermal mass) from the beginning of the design process to respond to the environment outside, which can be referred to as bioclimatic architecture. (d) Separate passages should be provided in residential buildings. Nevertheless, low density does not promote the city's economic development. Thus, multi-story single-family residential buildings can be constructed, preventing urban sprawl that can result from single-family housing [48]. In the post-epidemic era, there is little discussion about building space and there is no complete strategy system for residential building design. This will be a research topic of practical importance.

3.6.2. Planning Space

Numerous empirical studies have attempted to explore the association between urban spatial characteristics and the spread of COVID-19. It has been established that there is no association between urban density, population density, and the spread of the virus [50]. (a) Public space, urban green space, and the number of COVID-19 cases are strongly associated [51]. Aggregated urban public spaces can facilitate the spread of viruses. (b) After the start of the epidemic, the number of accessible public spaces decreased, such as shopping malls, cafes and other public spaces that became no longer "public", and online shopping gradually replaced such public spaces [52]. In early studies, urban density and population density were considered to be key factors affecting the COVID-19 infection rate and case fatality rate. For example, a study from China found that COVID-19 cases in Beijing and Guangzhou frequently occurred in areas with high population density [52]. Research from Italy has also found increased rates of virus transmission in areas with higher population densities in Italy [53]. The post-pandemic remote work model avoids the disadvantages of being too far apart from work and living, and people also tend to migrate from high-density cities to lower-density urban suburbs or rural housing [54]. However, the idea of density has been denied in recent research. Based on principal component analysis and Pearson correlation, a statistical analysis of the number of infections and built environment data in King County, Washington revealed that urban density, population density, and the number of cases were not directly related [50]. Some studies have also found that the COVID-19 fatality rate in high-density areas has also been shown to be lower than those in low-density areas [7]. Additionally, a survey of 337 participants in Istanbul that examined changes in perceptions of public spaces found that people tend to prefer open spaces that can be accessed on foot, such as pocket parks [51]. Based on an ArcGIS empirical study of changes in green space usage among 418 people in Helsinki, it was determined that, during the epidemic, people were more inclined to enter low-density green spaces because social distancing could be provided within the space [55].

To summarize: (a) Increase the area of urban green space. (b) Provide accessible public spaces. (c) Provide low-density green spaces to ensure social distance, which is conducive to reducing the spread of the virus. However, the complexity of epidemic transmission also relates to epidemiological theory. Different types of viruses have different transmission mechanisms. A quantitative relationship between urban spatial characteristics and COVID-19 incidence has not been fully explained in the existing literature. Although the factors leading to the spread of COVID-19 are not only urban spatial characteristics, but also non-spatial characteristics such as social factors, political factors, and so on, empirical research on the relationship between space and the virus is imperative for urban planners and architects.

3.7. Residential Transportation and Community Management

3.7.1. Transportation

Transportation infrastructure and population mobility play an important role in socio-economic development [56]. These factors promote connections between and within residential communities. Public transportation is also considered as a key method of spreading COVID-19 because it is difficult to achieve the social distance of 2 m per capita recommended by epidemiologists in intensive travel modes such as public transportation. (a) The epidemic has changed the daily travel patterns and living habits of residents, which has damaged the confidence of residents in public travel and turned the main problem of public transportation from personal safety caused by traffic accidents to the risk of infection caused by COVID-19. (b) The frequency of car trips decreases, while the frequency of walking and bicycling increases [57]. In fact, bike sharing has become an effective vector for the spread of COVID-19 as it can survive on rough surfaces for hours or even days [56]. To investigate the travel situation of Mediterranean people during the epidemic blockade and the main factors influencing their choice of travel mode, relevant scholars utilized an online structured questionnaire. Overall, about 30% of people chose sustainable modes of transportation (walking, cycling, public transportation, and so on) in lieu of car travel [57]. In addition, deep learning models can be used to make short-term forecasts of bicycle demand during the COVID-19 pandemic as well as evaluate the accuracy of different algorithms to support the healthy operation of shared bicycles [58]. It is also possible to track the travel of infected people and control the physical distance of virus transmission based on proxy models to reduce the risk of virus transmission [59].

In light of the substantial socio-economic impact of transportation, the issue of how to ensure the safety and health of public transportation and shared mobility in the post-pandemic era as well as restore residents' confidence is of paramount importance. In order to prevent the spread of the virus, (a) social distance remains a necessary measure. The realization of social distance, however, (b) must be viewed from the perspective of improving pedestrian and vehicular conditions. (c) Establish a smart travel system based on data analysis and algorithm models to intelligently restrict travel to curb the spread of the virus. This will enhance the city's immunity to future disease events and achieve sustainable transportation development and healthy resident mobility.

3.7.2. Management

As the capillaries of the modern urban system, the community is the first-level governance unit to deal with emergencies. Community management must consider multiple factors, such as the combination of COVID-19 and climate change, other diseases, and the political economy. (a) Inefficient community management models. (b) Fragmented urban governance. (c) Lack of psychoeducation can facilitate community transmission of the virus. Research from Bangladesh reports that the government's decision-making failures and poor community management have led to severe community transmission of the virus, including unreasonable administrative procedures: laboratory testing facilities are only available in urban areas, leaving ordinary areas without adequate COVID-19 testing services, while ordinary and impoverished areas should receive government assistance because of a lack of various infrastructures; lack of community psychological quality education: the panic of clinic and hospital administrators makes them reluctant to admit COVID-19 patients [60]. Ordinary residents died without treatment, further causing religious confusion and psychological panic among residents.

Although COVID-19 has had a serious negative impact on community management, it is also a benign opportunity for reform of the community governance system. It is imperative that the reform does not occur as a one-time action, but rather that it begins from a long-term, sustainable perspective. In order to combat the pandemic, the government must make comprehensive top-down decisions, but they are most effective when they are implemented in partnership with local communities. The following approaches can be used to mitigate the risk of community transmission. (a) Transparent and open government decisions. (b) Strengthening the community medical system and community psychological education. (c) Government decision-making can intervene in public health events to control epidemics. The Chinese government's top-down governance system combined with community-based emergency management units is considered a core mechanism for successfully responding to public health crises [12]. The Chinese government administrators have fully allocated resources to ensure the normal operation of units at all levels. In addition, (d) increase people's attention and participation based on social media and enhance the decision-making effectiveness of management through mass feedback [61]. (e) Rapid collection, segmentation, diagnosis, and medical monitoring photos of patients based on artificial intelligence [62]. (f) In order to make communities more resilient in the post-pandemic era and to better transition to a new normal of pandemic lockdowns, remote work, and travel restrictions, a range of AI approaches must be employed. The above-mentioned smart city technologies built on big data analysis, information transmission, and machine learning algorithms will play an increasingly crucial role in improving the well-being of community residents and maintaining urban functions.

4. Discussion

It is imperative to review the existing literature to highlight the current state of research, as well as to provide recommendations for future research that will contribute to the field's development. It is evident from the literature review that there is a shortage of studies that comprehensively describe the content of ECRPD. This paper provides scientometric methods in order to present various aspects of ECRPD research comprehensively. According to the available evidence, ECRPD research productivity has increased exponentially. As a result of the epidemic, residential planning and design have been severely impacted. Several scholars have entered the field and made extensive efforts, which have contributed to the overall positive trend of ECPRD research. There are three main topics that can be summarized from the scientific knowledge of ECRPD research: the residential environment, residential building space, residential transportation, and community management. In some early literature [63–65], scholars examined the effects of COVID-19 on urban planning and design, and examined design approaches. In that, we pay more attention to the residential area. To enhance the presentation of the results, we arranged the links (impacts, feedback/suggestions) between COVID-19 and residential planning and design through summary (Table 6).

Table 6. Links (effects, feedback/suggestions) between COVID-19 and residential planning and design.

Topics		Effects	Feedback/Suggestions
Residential environment	Air	(a) Virus transmission in residential indoor air (b) Virus transmission in residential area air	(a) Negative pressure isolation in a single room (b) Independent setting of drain pipes, exhaust pipes, water-sealed floor drains (c) Active air purifier (d) Optimize the shape of the residential area
	Water	(a) Virus transmission through water in residence (b) Residential water consumption increases (c) Water scarcity makes informal settlements more vulnerable	(a) Improve water facilities and water conditions (b) Regular inspection and maintenance of drains (c) Reduce shared water use (d) Epidemiological data monitoring based on domestic wastewater
	Energy	(a) Energy consumption fluctuations caused by changes in residents' behavior (b) Residential energy consumption has risen sharply	(a) Energy forecast (b) Energy management system for intelligent building (c) Distributed Energy

Table 6. *Cont.*

Topics		Effects	Feedback/Suggestions
Residential building space Planning space	Building space	(a) Changes in residential space use demand (b) Virus transmission in public spaces of residential buildings	(a) Promote housing flexibility (b) Provide variable space, redundant space, flexible components (c) Bioclimatic architecture (d) Provide a separate entry channel
	Planning space	(a) Virus spreads in public spaces and dense urban green spaces (b) Low-quality public spaces facilitate virus spread	(a) Increase urban green spaces (b) Provide accessible urban public spaces (c) Maintain social distance in spaces
Residential transportation Community management	Transportation	(a) Residents' confidence in public travel takes a hit (b) Fewer public transport trips, fewer car trips, more walking and cycling trips	(a) Maintain social distance (b) Improve pedestrian environment and traffic environment (c) Build a smart travel system
	Community management	(a) Inefficient community management model contributes to the spread of the virus (b) Fragmented urban governance contributes to the spread of the virus (c) Deficient psycho-educational contributes to the spread of the virus	(a) Transparent government decision-making (b) Strengthen the construction of community medical systems and psychological education (c) Government decision-making on public health event intervention (d) Mass feedback on social media (e) Rapid medical treatment based on artificial intelligence

ECRPD research has long extended beyond the architectural and planning disciplines, which encompass a variety of fields, including the environment, transportation, management, and computer science, as determined by citation analysis and conceptual structure analysis. As ECRPD research is complex, we encourage interdisciplinary collaboration in the future and we strongly advocate bioclimatic architecture—that is, residential areas should be designed and planned in such a manner that its impact on the local environment and energy is fully considered, and it is an essential tool for adapting to natural disasters and climate change. The results demonstrate that environmental factors are research hotspots, in agreement with Sharifi's viewpoint [65]. We also discovered that energy is a research hotspot. Furthermore, there is relatively scant research on residential buildings, and there are few descriptions of building space in the highly cited literature and keyword co-occurrence network, as compared with other topics. Residential buildings should be considered with flexibility, providing independent entryways and so on, in line with Spennemann's research [49]. In the future, residential buildings will be carefully designed, including equipment and space, as the first line of defense against external disasters and change.

Despite the fact that this study emphasizes the horizontal conceptual structure of ECRPD, its review content does not cover all aspects of the program. In the conceptual structure analysis, for example, artificial intelligence, big data processing, machine learning prediction, smart cities, and building management systems are mentioned. In fact, several new technologies have emerged, and we encourage the use of digital technologies as well, which supports Hassankhani's perspective [66]. However, this study does not summarize ECRPD research methods, which is an intriguing topic worth examining.

In view of the limitations of the scientometric assessment in this study, such as the use of only two databases (Scopus and WoS), retrieval methods, and screening criteria (e.g., conference papers, book chapters, reviews, abstracts, conferences and notes, among others), future efforts should be made to incorporate other databases (such as ScienceDirect) or other literature types (such as conference papers) into the assessment to better understand the coupling between COVID-19 and residential planning and design.

5. Conclusions

Since the outbreak of COVID-19, researchers in various fields around the world have made profound efforts to fight the epidemic. Residential planning and design directly affects the health, comfort, and sustainable development of the living environment. By utilizing scientometrics, this paper evaluates the WoS and Scopus literature data on "Effects of COVID-19 on residential planning and design (ECRPD)" for the period 2019 to October 2022, attempting to demonstrate the scientific knowledge of ECRPD research by analyzing general characteristics, citations, and horizontal conceptual structures. In this study, we intend to explore the links (influences, feedback, and suggestions) between COVID-19 and residential planning and design, as well as to provide advice for urban planners, builders, and decision makers regarding the creation of a more comprehensive residential environment in the post-epidemic period.

In the general characteristics analysis, the overall situation of ECRPD-related data is described, including annual scientific productivity and average number of citations per year. It has been found that the scientific productivity of ECRPD has increased exponentially in recent years, reflecting the significant advancement of the field. Specifically, scientific productivity peaked in 2021 and the average number of citations to literature peaked in 2020. Following this, the TOP10 most relevant ECRPD authors were determined by counting their scientific productivity over the time period. Fractional authorship is also used to evaluate the author's contribution in order to avoid one-sided evaluations based on scientific productivity. Furthermore, this study identified the top ten most relevant ECRPD authors based on citation analysis. Subsequent chapters also focused on the above authors and papers. The main focus areas of ECRPD research are preliminarily identified, with research involving multiple fields, exhibiting obvious interdisciplinary and blended characteristics.

As part of the investigation into the deep links between COVID-19 and residential planning and design and how residential planning and design responds to COVID-19, a conceptual structure analysis of ECRPD research was conducted based on the keyword co-occurrence network to fully illustrate the content of ECRPD research. The overall links (effects, feedback/suggestions) between COVID-19 and residential planning and design are outlined in Table 6. Several aspects of ECRPD research can be characterized, including the residential environment, residential building and planning space, residential transportation, and community management. As evidenced by existing research, the ECRPD field extends outside of architecture and planning, and various fields are making timely adjustments and feedback on the effects of COVID-19, including the environment (air, water, energy), building and planning (use demand, spatial features, green space), transportation (travel, blockade), management (community, governance, decision-making), and computer science (artificial intelligence, machine learning, smart cities), among others. In view of the importance of the environment and energy, we believe that future residential areas should focus on bioclimatic architecture. Planning and design strategies should be fully responsive to local climatic conditions. Moreover, the keyword co-occurrence network shows relatively few research works on building space. Only the flexibility of housing is discussed and there is no complete housing design strategy system in the post-epidemic era.

To fully respond to the impacts of COVID-19 on residential planning and design in the post-epidemic era, it is essential to improve the comprehensive performance of residential planning and design. In the future, policymakers and researchers should promote the integration of disciplines; fully consider the influence of residential area planning and design on the climate, environment, and energy; and strengthen the practice of interior and exterior spaces in residential buildings. At the methodological level, it is necessary to combine new technologies, as well as actively use artificial intelligence and machine learning methods to promote the development of traditional disciplines, which are conducive to handling residential issues effectively, and preparing rational decisions regarding urban governance.

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