Research Hotspots and Frontier Analysis of Old Industrial Buildings: A Systematic Review Based on Knowledge Mapping

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Abstract. Affected by adjustment of the industrial structure and environmental pollution control, more and more industrial buildings are idle or even abandoned because they no longer meet the needs of social development. Numerous scholars carry out much valuable research on the reuse of old industrial buildings. We want to know the hotspot and evolution path of old industrial building reuse. Therefore, based on the relevant literature retrieved by WOS, this research uses Citespace5.6.R3 to obtain a scientific knowledge map about the old industrial building regeneration field. Based on this, the research hotspots of the reuse of old industrial buildings from 2000 to 2019 are analyzed to obtain the current status and characteristics of the research and predict the development trend.

1. Introduction
Since 1990s, along with the world economic structural transition, the old industrial buildings reconstructuring a climax all over the world[1], a large number of old industrial buildings are left to be idle. After structural safety testing and identification, recycling them is beneficial to the construction industry's low-carbon energy saving and reducing the generation of construction waste. In addition, due to the open and spacious structure of the factory, which can be arbitrarily divided or combined, and can be re-arranged, it is favored by practitioners in creative industries such as artists.[2] It is also conducive to the preservation of the urban industrial development texture [3], so that the memory of the city will be fuller. Therefore, the reuse of old industrial buildings has become a hotly discussed issue in academic circles in recent years. Reuse helps to improve the living environment of residents, improve public safety and the image of the city, and brings a win-win proposition to all stakeholders[4].

In order to provide a useful reference for further theoretical research and practical exploration of the old industrial buildings reuse, this research quantitatively and systematically sorts out related research papers and reviews. It is of great academic significance to couple the reuse of old industrial buildings with big data and informatization, and then extract the research hotspots related to the reuse of old industrial buildings, and analyse the development trend from multiple perspectives. Formatting the title, authors and affiliations.
2. Formatting the text

2.1. Data collection
This research uses WOS (Web of Science) core collection for data collection and uses the "oldindust* build*" or "oldindust* architect*" or "indust* heritage" as retrieve terms [5], and the search information is shown in Table 1. It should be noted that the search time was March 20, 2020, and the total number of retrieved documents was 386.

| Search Item     | Search Content            |
|-----------------|---------------------------|
| Search Topic    | old indust* build*        |
|                 | old indust* architect*    |
|                 | indust* heritage          |
| source          | Web of Science; IEEE; ACM; Scopus |
| Document Type   | Article&Review            |
| Language        | English                   |
| Search Timespan | 2000-2019 years           |
| Search Results  | 386 records               |
| Data Acquisition Time | Mar.20,2020            |

2.2. Methods description
Scientometrics and Bibliometrics are now at least half a century old [6]. In recent years, the emergence of software such as CiteSpace has greatly increased the application of new technologies for document analysis in the field of knowledge visualization [7]. In early 2004, C.M. Chen created CiteSpace software as a readily available Java application [8]. CiteSpace has conducted a structured and time-critical analysis of various networks generated by scientific publications [9]. It can identify key words in a scientific field, and perform co-occurrence analysis, cluster analysis, and emergence analysis to reveal the scientific fields. Research hotspots, development trajectories and predicted trends objectively reflect the development of the scientific field. The software excels at visual analysis of specific research subjects [10-11].

Based on the data in 386 documents obtained from the WOS core collection, this research uses two softwares, Histcite and citespace, to perform a two-part scientometric analysis. In view of the simple and clear characteristics of Histcite analysis results, the first part uses HistCite software to carry out general statistical analysis in the field of old industrial buildings. It mainly focuses on analysis of the country in which the document was published, the year of publication, major journals, and well-known authors. The second part uses citespace software to perform keyword clustering analysis and emergence analysis on the literature, aiming to clearly and intuitively show the theme evolution, research status and development trends of the old industrial building reuse research field.

3. Results and Discussion

3.1. Year and country distribution analysis
Changes in the time and space of published literature reflect the evolution of research related to old industrial buildings [12-13]. As shown in Figure 1, the annual distribution of related literature on reuse of old industrial buildings. Since 2000, the overall number of published documents has shown a rapid growth trend, mainly divided into three stages. Above all, the first stage is 2000-2011 year, and it is in a stable fluctuation period, the total number of publications in this decade is relatively stable. Secondly, the second period is 2011-2017 year, this period of rapid growth with a maximum growth rate of 46%. Finally, the third stage is 2017-2019, this period with a smooth curve and the number of fluctuations is not obvious.
As shown in Figure 2, from the perspective of the countries distribution, the top three countries for publications are the United Kingdom, the United States, and China. Among them, United Kingdom tops list with 40 publications, and it is followed by the United States and China, which publish 39 and 38 publications, ranking second and third respectively. The contribution of the above three countries in the global publications of old industrial buildings is 30%, indicating that the three countries have strong research capabilities in the field of old industrial building research. Some European countries (e.g. Germany, Italy, Sweden, Netherlands) have 26 to 30 publications, which reflects the increasing concentration of old industrial building research in these regions. Overall, North America, Southeast Asia, and some Western European countries have concentrated their research on old industrial buildings. Africa, the Middle East, and western South American coastal countries have fewer than 10 publications, which means that these regions have less focus on old industrial buildings research.

In the Knowledge mapping, the nodes represent the research objects, and their sizes and colors correspond respectively to the number and the years. The links represent the relationships between the research objects, and the thickness and color thereof represent the closeness and occurrence time of the relationships. From the Knowledge mapping of the national cooperation network for the old industrial buildings research, we can see that Cooperation between research institutes has obvious regional characteristics, with most cooperation between countries on the same continent and less intercontinental cooperation. And in recent years, cooperation between European countries (UK, Italy, Spain, Switzerland, etc.) has been closer.

### 3.2. Citation journals analysis

The total publications in the field of old industrial buildings reuse involves 132 journals around the world. Table 2 shows the 5 journals with the most publications. Among them, RENEWABLE & SUSTAINABLE ENERGY REVIEWS has 22 publications, which ranks first. This is followed by the Journal of Systems and Software, which has 19 publications, ranking second. IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS has published 15 publications, JOURNAL OF PERFORMANCE OF CONSTRUCTED FACILITIES has 14 publications, and INDOOR AND BUILT ENVIRONMENT has 11 publications. Impact factor (IF) was proposed by Eugene Garfield, which is
one of the important indicators for objectively measuring the quality of journals. The H-Index is used to describe the highest citations of a publication[14-15].

Generally speaking, the size of h index is positively correlated with the impact of publications. The RENEWABLE & SUSTAINABLE ENERGY REVIEWS magazine with the largest number of old industrial building publications, and the IF index is 10.556, the H Index is 222. The top three magazines with the most publications have the IF index of the publications are all above 7, and the H index is above 90, the INDOOR AND BUILT ENVIRONMENT is lowest with an IF of 1.367, which reveals that old industrial buildings publications are generally of high quality. Four of the top five magazines by number of publications are published in the UK, and the publishers of the top two magazines belong to Elsevier, indicating that the UK attaches great importance to the research on the reuse of old industrial buildings.

Table 2: Top 5 research journals in the field of old industrial buildings

| Journals | Publications | Citations | IF (2018) | Publisher | Country or region |
|----------|--------------|-----------|-----------|-----------|------------------|
| RENEWABLE & SUSTAINABLE ENERGY REVIEWS | 22 | 203 | 10.556 | Elsevier Ltd | UNITED STATES |
| JOURNAL OF SYSTEMS AND SOFTWARE | 19 | 214 | 2.559 | Elsevier Inc. | UNITED STATES |
| IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS | 15 | 255 | 7.377 | IEEE Computer Society | UNITED STATES |
| JOURNAL OF PERFORMANCE OF CONSTRUCTED FACILITIES | 14 | 175 | 1.542 | American Society of Civil Engineers (ASCE) | UNITED STATES |
| INDOOR AND BUILT ENVIRONMENT | 11 | 198 | 1.367 | SAGE Publications Ltd | ENGLAND |
| RENEWABLE & SUSTAINABLE ENERGY REVIEWS | 22 | 203 | 10.556 | Elsevier Ltd | UNITED STATES |
| JOURNAL OF SYSTEMS AND SOFTWARE | 19 | 214 | 2.559 | Elsevier Inc. | UNITED STATES |
| IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS | 15 | 255 | 7.377 | IEEE Computer Society | UNITED STATES |

3.3. Influential authors and institutions analysis

Old Industrial Building Publications are distributed in 264 institutions worldwide. Table 3 lists the top 10 institutions with the highest productivity in the number of old industrial building publications. Among them, five of the top ten research institutions are from developed countries in Europe. Univ Groningen in the Netherlands ranks first, and Chalmers UnivTechnol is in the second. From the above, we can see that scholars from developed countries in Europe have rich research on old industrial architecture. According to the citations, Stanford Univ published three publications with a citation of 423, ranking first, and Chalmers UnivTechnol ranked second, it can be seen that the publications published by these two institutions have a greater impact Overall, the ten organizational types are all colleges and universities, indicating that the research strength of colleges and universities in the field of old industrial building research is relatively concentrated.

Table 3: Productive organizations of old industrial buildings research

| Institution | Publications | Country | Total global citation score |
|-------------|--------------|---------|----------------------------|
| 1 | Univ Groningen | 6 | Netherlands | 44 |
| 2 | Chalmers UnivTechnol | 5 | Sweden | 141 |
| 3 | Hong Kong Polytech Univ | 4 | China | 24 |
| 4 | Univ Aquila | 4 | Italy | 117 |
| 5 | Univ British Columbia | 4 | Canada | 116 |
| 6 | Stanford Univ | 3 | United States | 423 |
| 1 | Univ Groningen | 6 | Netherlands | 44 |
| 2 | Chalmers UnivTechnol | 5 | Sweden | 141 |
As shown in Figure 3, this research uses the CiteSpace to draw a cooperation network between institutions in the field of old industrial buildings research, from which 3 or more publication institutions were selected. It shows the cooperation between the two most productive institutions (Univ Groningen and Chalmers Univ Technol) did not cooperate with other productivity ones. Similarly, Hong Kong Polytech Univ and Univ British Columbia also collaborated, but did not collaborate with others. On the whole, the current research in the field of old industrial construction is still relatively decentralized, the cooperation network has fewer components, and the core institutions have sparse communication.

![Figure 3. Cooperation network of institutions](image)

As shown in Table 4, the top 5 productive authors are listed. Each author has an H-index of more than 7. Among them, Rojas-Sola, Ignacio of the Universidad de Jaen ranked first in the number of publications. Professor Avgeriou, Paris at the University of Groningen and Professor Bottero, Marta Carla from Polytechnic University of Turin rank first and second respectively in the H Index. Therefore, these three authors are authoritative scholars with strong influence in this field.

| Publications | Author         | H index | Institution                  |
|--------------|---------------|---------|------------------------------|
| 6            | Rojas-Sola, JI| 9       | Universidad de Jaen          |
| 3            | Avgeriou P    | 20      | University of Groningen      |
| 3            | Sansoni G     | 13      | University of Brescia        |
| 3            | Soyez D       | 7       | University of Cologne        |
| 2            | Bottero MC    | 16      | Polytechnic University of Turin|
| 6            | Rojas-Sola, JI| 9       | Universidad de Jaen          |
| 3            | Avgeriou P    | 20      | University of Groningen      |

3.4. Co-occurrence analysis
Use CiteSpace to draw a co-occurrence network. Set the software analysis time as 2000-2019, the time slice is set as 1, node types to Keywords, and select top 50 levels of most cited or occurred items from each slice, and point threshold to 25.0%. Then run the software after setting. Cluster analysis should be performed after running the software. First, click the cluster analysis button. Then select keywords as the cluster label, and LLR log-likelihood ratio as the algorithm. Finally, select the node and line color, and adjust to the appropriate threshold, the knowledge graph is shown in Figure 4. It contains a total of 86 nodes and 120 connections, and the cluster's modularity level is 0.7265, indicating that the same-cited network structure has high reliability.

![Figure 3. Cooperation network of institutions](image)
industrial buildings can be realized more with the help of building information models, so as to carry out technical simulations and reduce the risk of old industrial building reconstruction. Cluster 1 is industrial heritage. The main research object is the buildings classified as industrial heritage in old industrial buildings. This cluster mainly discusses the theme of protective development of industrial buildings, including the classification standards of industrial heritage, Protective strategies, etc. Cluster 2 is Industry 4.0. With the boom of Industry 4.0, more and more researchers tend to explore how to use the opportunities brought by Industry 4.0, and try to find new technologies to protect the reuse of old industrial buildings in this context. Throughout the life cycle of a building, building information standardization and information exchange can be achieved with the help of BIM. Thereby, promoting the collaboration and overall utilization efficiency of industrial Informationization and old industrial building reuse.

Through the citation bursts map, we can see the degree of scholars' interest in these research issues. This article uses CiteSpace software to visually analyze the articles retrieved from the core database, so that keywords with strong burst can be identified. As shown in Figure 5, this article selects the keywords by time to display the top 10 keywords with the strongest citation bursts. As can be seen from Figure 5, the most strength burst keywords is the software architecture, which first appeared in 2011 and before that there were emergent words such as modularity, innovation, etc., which promoted the development of software architecture in the construction field. Industry 4.0 is an emerging keyword that has appeared in the past year, and an intensity of 5.02 indicates that it is more important. Industry 4.0 changes the construction industry and its connected supply chains (CSCs), and designs complex construction processes on a collaborative digital platform (etc. Building Information Model-BIM), which is used as a building Collaborative methods and tools to improve the "predictability" of design during the transformation and construction process.

The distribution of bursts in different stages is shown in Figure 5. The first occurrence of keywords is relatively concentrated in two stages, the first stage start 2003 to 2006, and the second stage start 2013 to 2019. The first phase of the main research focused on industrial heritage and reuse model innovation. Moreover, initially started the construction software development. At this stage, industrial heritage research lasted a relatively long time and was relatively mature. The keywords that appeared for the first time in the second phase mainly included big data, the Internet, and information management. It can be seen that the research in this phase has been clearly given the characteristics of the Internet era, and most of them use the means of computers to construct and manage the reuse of old industrial buildings. It can be predicted that the research on the reuse of old industrial buildings in the context of Industry 4.0 will remain a hot issue in the next few years.
4. Discussion of gas in research

First of all, the preservation and continuation of industrial historical and cultural values should not only remain at the level of retaining material materials and original skins, but should also resonate in terms of the creation of functional spaces and the reproduction of place spirit. Not only must it meet the needs of contemporary architectural reuse in terms of function and aesthetics, but it should also arouse the public's memory of industrial history and culture in terms of place spirit. Secondly, the old industrial building reuse practice, try various types of reuse models. Among them, the development of industrial tourism is one of the more prominent trends, and its important role in tourism development, urban renewal, and the establishment of urban image and sense of place is becoming increasingly obvious. Industrial culture should be integrated into the tourism development process, with more emphasis on creative design and development. However, there is currently a lack of research in this area. Finally, the recycling of old industrial buildings is an attempt to update the function, space and form in the context of low-carbon sustainable development. In the process of building renovation, attention should be paid to the use of low-carbon and environmentally friendly building materials; at the same time, on the basis of ensuring that the building is beautiful and functional in the process of building renovation, ergonomics, fluid mechanics, and aerodynamics should be integrated. Knowledge in the design of building renovation plans should strengthen the low-carbon environmental protection design concept of building renovation.

5. Conclusions

This article refers to the 386 kinds of publications retrieved from the core collection of Web of Science. Based on the perspective of scientometric analysis, HistCite and CiteSpace software are used to systematically sort and visualize the field. Conclusions as below:

(1) The number of research documents related to the reuse of old industrial buildings has greatly increased. The United States, the United Kingdom and China are the countries with the largest number of publications, and research on the reuse of old industrial buildings is relatively mature in parts of Europe and countries. RENEWABLE & SUSTAINABLE ENERGY REVIEWS, JOURNAL OF SYSTEMS AND SOFTWARE are the main journals. Univ Groningen and Chalmers UnivTechnol are the organization with the largest number of publications in the field of old industrial building recycling, while Stanford Univ's publications are relatively more influential. Professor Rojas-Sola, Professor JI and Professor Aygeriou P are leading experts in this field.

(2) According to the analysis of keyword cluster analysis, scholars prefer the "application of BIM technology in the recycling of old industrial buildings", "protection and development of industrial heritage" and "the opportunities and challenges of old industrial buildings in the context of Industry 4.0" research in three directions. Through keyword strongest citation bursts analysis and time-zone analysis, we can see that research on old industrial building regeneration and construction technology in the context of Industry 4.0 is relatively active, which is an academic hot issue in recent years and will remain a research trend for a period of time in the future.
(3) The research on the reuse of old industrial buildings in this research has the following limitations. For the purpose of improving the quality of search documents, the search scope is focused on the Web of Science core collection database, so it may not be able to fully display the old industrial building recycling field development of. Subsequent scholars' research can try to expand the scope of search methods through other databases; the current development of the Internet has brought more new perspectives to the research of the topic. There is a relatively broad research space, and we can carry out scientometric research on more literature and actual projects in the field of old industrial building reuse in future research.

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