An overall review of research on prefabricated construction supply chain management

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Abstract:	

Dear Reviewer and Editors,

We would like to express our sincere gratitude for your constructive comments on our manuscript. We have made every attempt to fully address these comments in the revised manuscript, and we believe these revisions have led to significant improvements and enhancements to the manuscript. Your original comments are listed below followed by our response to each comment (in red).

We look forward to hearing from you regarding our submission. We would be glad to respond to any further questions and comments that you may have.

Best Regards.

Referee: 1

Comments:

More depth is required in the discussion and conclusion section. Some discussions about lean supply-chain management processes/techniques (like Just-in-time delivery) or Industry 4.0 tools and technologies (IoT-based tracking tools) should be added to the paper. A separate section about the implications for the industry and academy is required.

We truly appreciate all your insightful suggestions and constructive comments. We have added a discussion of articles related to project delivery and lean supply chain management, please see section 5.1.4 in red, lines 474 to 486. Because the original section 5.1.6 is an information technology-related study, which overlaps with the topic of Industry 4.0, it is combined into one section for discussion. Other articles related to Industry 4.0 technologies (such as IOT) are added in section 5.1.6, please see lines 519 to 559 in red. The implications for the industry and academy is added in section 6.1 implications, please see line 685-694.

Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes, the revised paper is improved, and currently it contains contributions to the supply chain management in prefabricated construction research domain. However, there are still some rooms for improvement.

Thank you for your comments, we have made some modifications.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: There is still room for improvement. For instance, in section 5.1.4 line 469 about research on project delivery and schedule, There should some reference to and discussion about

just-in-time delivery for prefabricated projects and how scholars investigated this topic in the Lean+prefabrication supply-chain literature.

Thank you for your comments, we have added a discussion of articles related to project delivery and lean supply chain management, please see section 5.1.4 in red, lines 474 to 486. Changes have also been made to the corresponding table. Please see Table 9 in the document titled "Table" for details.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The paper methodology is improved, particularly in the qualitative analysis section.

Thank you for your confirmation of the modification we have made.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: The result section is improved, however there is still room for improvement. For instance, the overall outcomes of this study for the industry practitioners and academic researchers should be provided in the conclusion or discussion section.

Thank you for your comments. We have added relevant content, please see the conclusion, lines 685to 694.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: This part needs to be provided, as I could not find a specific section which provides implications for research, practice and/or society.

Thank you for your comments. We have added relevant content, please see the conclusion, lines 685 to 694.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: The readability of the paper is improved in the revised version.

Thank you for your confirmation of the modification we have made, this revision we further improved the readability of the article.

An overall review of research on prefabricated construction supply chain management

Abstract

Purpose

As a strand in industrialization movement in Architecture, Engineering and Construction (AEC) industry, prefabricated construction (PC) has gained widespread popularity due to it high efficiency, energy saving, low environmental impacts, safety and other advantages. Well managed supply chain can further leverage the advantages of PC. However, there is a lack of more systematically overview of the prefabricated construction supply chain (PCSC). This paper aims to comb the current status and look into the future direction of PCSC by reviewing the existing research.

Design/methodology/approach

131 articles related to prefabricated construction supply chain management (PCSCM) from 2000 to 2022 have been collated to i) conduct a bibliometric analysis by using VOSviewer, including the following: literature sources, keywords co-occurrence, co-authorships, authorship citation and country active in the field of PCSCM, ii) classify and summarize the status of research in PCSCM through qualitative discussion, and iii) point out the future research directions.

Findings

131 articles are carried out for bibliometric analysis and in-depth qualitative discussion, the visualization maps and the main research themes in the field of PCSCM are obtained. The results show that supply chain intelligentization and informatization are hot topics. Finally, future research directions that should be paid attention to in the field of PCSCM are pointed out.

Practical implications

This study can help project managers understand the current status and problems of PCSC operations and provide a basis for future management decisions.

Originality/value

Compared with previous studies, this study adds the dimension of "article authorship" to the quantitative analysis and discusses the research themes in the field of PCSCM in a comprehensive manner. In addition, this paper deeply discusses the the main research topics from both the specific contents and research methods adopted.

Keywords

Prefabricated construction, supply chain management, Bibliometric analysis, qualitative discussion, literature review

1. Introduction

PC as an alternative and novel construction technology is a construction method. Using this method, most on-site activities are performed off-site, usually in a safe and controlled factory environment away from the construction site (Jaillon and Poon, 2014), and the prefabricated components manufactured in a factory are then transported to the site for assembly. Compared to conventional construction methods which normally are labor-intensive, produce high volumes of construction waste and have lower efficiency (Wang et al., 2018a), PC has attracted remarkable attention from both scholars and practitioners due to its advantages, e.g. green building features, controllable environmental impacts, reduced energy consumption, high production efficiency, lower costs, enhanced safety and sustainability (Liu et al., 2020a; Wang et al., 2019b; Zhong et al., 2015).

The PCSC plays a key role in connecting construction sites and off-site factories (Wang et al., 2019b). As early as 1999, Jardim et al. (1999) suggested that the effective exchange of resources, materials and cash flow among all stakeholders in construction projects was the key factor to avoid project delays, cost overruns and to ensure the success of the project. Later in 2003, Kahkonen et al. (2003) made it clear that standardization of supply chain processes in the delivery of high-level prefabricated components was likely to reduce performance differences and improve quality. It was not until recent years that the PCSCM received further attention (Liu et al., 2020a). However, due to the characteristics of large investments, long construction period, groups of suppliers and subcontractors involved, and more complex processes, the PCSC tends to be more complex, inefficient and costly (Xun et al., 2019). Supply chain operation problems, such as ineffective supply of prefabricated components and poor cooperation among participants, are the main bottlenecks that hinder the development of PC. Poor PCSCM can increase transportation cost, affect production efficiency and make later maintenance more complicated (Maas and Eekelen, 2004). The literature review can help to quickly understand the current state of research in a particular research area and highlight research gaps. Unfortunately, there are few review articles in PCSC, and the current study does not provide a comprehensive view of the latest developments in PCSC, although the PCSC has received more and more attention in recent years and the number of publications has also increased greatly. Therefore, the literature since the year of 2000 was reviewed combining bibliometric analysis with qualitative discussion to show latest research progress and future direction in PCSC.

The remainder of this paper is structured as follows. The related research background is described in Section 2. The methodologies adopted in this research are explained in Section 3. The results via visual data analysis are presented in Section 4. The qualitative discussion on stratified review results from varied aspects is showed in Section 5. Concluding remarks, contribution and future research directions are summarized in Section 6.

2. Background

2.1 General supply chain management

PC is a new technology integrating construction with manufacturing, and PCSC belongs to both the construction supply chain and the manufacturing supply chain. On the one hand, modern manufacturing supply chain, which is vulnerable to various risks, is a complex network spanning different geographical locations. On the other hand, the operational efficiency of the supply chain is further affected by the weak technical foundation, low management level, lack of effective information communication and inefficient cooperation in the traditional construction supply chain. In summary, as far as the PCSC is concerned, it involves a variety of stakeholders, such as contractors, designers, manufacturers, transporters, assembly subcontractors, etc., and requires various technical and information exchanges in design, manufacturing, transport and assembly. The frequent information exchange between independent companies increases the vulnerability and complexity of PCSCM. Therefore, the PCSCM should be based on the existing manufacturing supply chain management and traditional construction supply chain management. Subsection 2.1.1 and 2.1.2 respectively summarize the mainstream research on supply chain management in manufacturing and construction industries in recent years.

2.1.1 Manufacturing supply chain management

Esfahbodi et al. (2016) developed and empirically evaluated a comprehensive sustainable supply chain management (SSCM) performance framework based on resource dependence theory (RDT), which linked SSCM practice with organizational performance. Ahmadi et al. (2017) proposed a framework to study the social sustainability of supply chain. Feng et al. (2018) studied the mediating effects of environmental and operational performance on green supply chain management (GSCM) and financial performance. Based on the manufacturing supply chain in developing countries, Mangla et al. (2018) identified 16 important obstacles to the adoption of circular supply chain in India through literature review and expert interviews, and analyzed these obstacles by using the comprehensive explanation structure model. Mani et al.

(2018) used co-variance-based structural equation modeling to investigate the social sustainability of suppliers in Indian manufacturing industry. Kusi-Sarpong et al. (2019) put forward a framework of sustainable innovation standards to study the sustainable supply chain consisted of manufacturing enterprises. Qaiser et al. (2019) proposed the road map of sustainable reverse supply chain operation, and revealed the relationship between Industry 4.0 and circular economy by solving the case-based model that affected economic and environmental performance. Wang et al. (2020a) analyzed 260 samples based on three measurement periods of Chinese manufacturing industry by hierarchical multiple regression method, and revealed the influence of corporate social responsibility on green supply chain management. Sarkar et al. (2021) studied waste management in manufacturing sustainable supply chain based on a three-level sustainable supply chain model, which consisted of a single supplier, a single manufacturer and multiple retailers.

2.1.2 Construction supply chain management

The one-off nature of the project, the arduousness of the project scale and life cycle make the supply chain management within the construction industry extremely complicated (AlMaian et al., 2015). Isatto et al. (2015) discussed the ways of supply chain members fulfilling their commitments from the perspective of language-action (LAP) and how these ways affected the integration and coordination of the make-to-order supply chain. Woo et al. (2016) empirically tested the communicational ability of green supply chain management in construction industry and the relationship among external green integration, green cost reduction and enterprise competitiveness from the perspective of suppliers. Kim and Nguyen (2018) used factor analysis technique and two-step Structural Equation Modeling (SEM) model to reveal the characteristics of construction supply chain relationship and its influence on project performance. Rudolf and Stefan (2018) provided a systematic and structured view for the key supply chain risks in large-scale general contracting projects. Zeng et al. (2018) verified that supply chain integration contributed to the sustainable utilization of building materials by using the partial least squares structural equation model. Meng (2019) discussed the implementation of the lean principle in the project-based construction supply chain. Ps and Sash (2019) put forward a comprehensive risk management method for construction project supply chain by using grounded theory, fuzzy cognitive map and grey relational analysis. Shahbaz et al. (2020) identified three types of risks in the supply chain of construction industry through empirical investigation, which were supply-side risk, process-side risk and demand-side risk. Mojumder and Singh (2021) discussed various driving factors, contributing factors and obstacles of green supply chain in Indian construction industry.

2.2 PCSCM

Poorang and Farts (2013) suggested that there were many technical terms associated with modern methods of construction including but not limited to prefabrication and draw up on their similarities and differences in detail. They provided a specific definition of prefabrication after Klotz (1986) in *Vision der Moderne: das Prinzip Konstruktion*, where he described the term prefabrication as: "...manufacture of parts of a building in a factory before they are brought to the site for incorporation in the finished structure". Although some might anecdotally believe that the relationship between architecture and prefabrication has always been problematic, to a greater or lesser extent, the building construction process has always been associated with prefabrication in its entire documented history (Poorang and Farts, 2013).

The construction industry has been under tremendous pressure since the beginning of the 20th century, due to the population growth around the world, so the demand for construction continues growing. It is suggested that to alleviate the pressure, one of the solutions is to integrate and utilize the benefits of manufacturing industries in the building and construction industry (Ricardo, 2019). Under such circumstances, PC came into being and vigorously promoted the industrial development of the construction industry. Compared to traditional construction methods, prefabricated methods have the several advantages including green and sustainability, better environmental impacts, (including energy saving), higher and better efficiency (throughout the production process and of the final product), arguably lower costs, lower incident rates and better health and safety features (Liu et al., 2020a; Wang et al., 2019b; Zhong et al., 2015). However, the biggest difference between PC and traditional construction is that in PC prefabricated components are produced in a controlled factory environment and transported to the construction site for installation or assembly (Razkenari et al., 2018). This extends the PCSC and holds it responsible for the whole process of manufacturing, transportation, delivery and installation of prefabricated products (Hasim et al., 2018). Therefore, the PCSC is very complex and involves multiple processes and stakeholders (Luo et al., 2020). It is precisely because the PCSC is different from the traditional construction supply chain that the PCSC must be focused on exclusively. Good supply chain management can promote PC to give full play to its advantages and maximize the benefits of construction projects.

Figure.1. reflects the development trend of related research on PCSCM from 2011 to 2022 (data is from the sample in this paper). Before 2010, PCSCM has not received enough attention, and this field has attracted significant attention only in the past ten years or so. This is also mentioned in the research of Wang et al. (2019b). Therefore, the literature published from 2011 to 2022 are selected to show the research and development trend of PCSC.

It can be seen from Figure 1 that the related research began to increase significantly from 2014. The overall upward trend shows that the development speed of PCSCM is accelerating, and people increasingly realize the importance of PCSCM. However, even with the rapid development of related research on PCSCM, the operation of PCSC in practice has not made perfect progress. One of the reasons is the lack of understanding on PCSC (Li and Mao, 2017). Literature review is considered to be a convenient and viable method for gaining insight into a particular area of research (He et al., 2017), and therefore is promising to help lay the groundwork, systematically provide information to navigate research and address issues related to PCSCM. Liu et al. (2020b) discussed four topics, mainly focusing on strategic research and project evaluation, design and optimization for PCSC process, supply chain integration and management, and the application of advanced technologies. Wang et al. (2019b) classified the existing research in PCSCM, in order to reveal the research gaps and put forward future research opportunities. However, the existing studies do not provide a holistic overview of PCSCM research. Compared with previous studies, the perspective involved in the bibliometric analysis in this article is more complete, involving five aspects: literature sources, co-occurrence of keywords, co-authorships, authorship citation and country active. Furthermore, this study discusses the existing articles in a more comprehensive classification, which can help readers to grasp the current status, the research hotspots and the research gaps of PCSCM more effectively.

Figure.1 Trends of publications in PCSCM

3. Methodology

This paper makes a bibliometric analysis and categorization summary of the literature related to PCSCM through the following three steps: (1) "Web of Science" is selected as the database resource to collect relevant literature, (2) VOSviewer, a visual analysis tool, is used to conduct quantitative bibliometric analysis, (3) the qualitative discussion in depth is adopted to comprehensively stratify the PCSCM from different perspectives. The technical route for this study is shown in Figure 2.

Figure 2. Technical route for this study

3.1 Data collection

Web of Science (WoS) is chosen as a database because it is one of the world's leading citation databases (Zhu and Liu, 2020). WoS, where high-quality scientific papers are stored (Blanco-Mesa et al., 2017), is considered as one of the most important databases in terms of academic research and practice, hence it is widely used in literature review in various fields, including medical related fields (Zhu et al., 2020), sports entrepreneurship (María et al., 2019), as well as internet research and analysis (Moreno-Guerrero et al., 2020).

This study conducted a preliminary search for articles published between 2000 and 2022. As initially mentioned by Poorang and Farts (2013) and then reiterated by others such as Zakaria et al. (2018), other alternatives have been used with different degrees of overlap with the concept of prefabrication in the building and construction industry, such as "industrialized buildings", "off-site construction", "modular building", etc. Finally, the retrieval formula is determined as follows: "prefabricated and (construct* or building or house) supply chain" OR "precast construct* supply chain" OR "modular* and (construct* or building) supply chain" OR "off-site construct* supply chain" OR " industrialized and (construct* or building) supply chain" (wildcard character "*" can represent single or multiple characters). The initial number of retrieved literature is 308. As WoS core is considered to be a more authoritative database (Liu et al., 2020b; Blanco-Mesa et al., 2017), firstly, the WoS core is selected as the filter, and articles belonging to the WoS core are retained after filtering. At the next stage, 9 review articles and other irrelevant literature is excluded, which brings down the final number of papers to 131 to be analyzed in the next stage.

3.2 Bibliometric analysis

The use of bibliometrics is becoming more and more prevalent in different disciplines (Aria and Cuccurullo, 2018). Bibliometrics belongs to the research field of library and information, and it is a statistical method, but it is not exclusively limited to just quantitative analysis, strictly speaking, the measurement of physical units of publications, bibliographic citations and their substitutes are called "bibliometrics" (Broadus, 1987), which is then enriched by an in-depth qualitative review of the results to provide enough ground for discussion and further research in the area of the study focus. Another explanation is that bibliometric analysis refers to visual analysis of specific large-scale scientific data sets(Liu et al., 2020b).

Bibliometrics, which can be described as a science, is used to build bibliometric maps (Blanco-Mesa et al., 2017). There are several visualized and analytical tools which can be used to produce bibliometric maps with different features, capabilities and limitations. VOSviewer was designed by van Eck and Waltman and first introduced in a paper in *Journal of Scientometrics* in 2010 (Eck and Waltman, 2010). It is an open source application that can be used to review and analyze literature data retrieved from different databases, including WoS. It is favored by scholars because of its extensive search options, high interoperability with different scientific databases, as well as ease of learning and use. Unlike some other applications used for bibliometric mapping, VOSviewer is a professional software, which illustrates scientific maps of various knowledge fields based on the principle of literature co-citation and coupling (Eck and Waltman, 2010; Hu et al., 2019). It can overcome the serious problems such as rather simple graphic representation and overlapping labels of SPSS and Pajek bibliometrics maps (Eck and Waltman, 2010), and clearly and intuitively reflect the current situation of research fields from all aspects. In this paper, VOSviewer is used for visual analysis of existing literature because of its advantages and capabilities. There are five main categories in visual analysis: 1) journal sources, 2) keywords co-occurrence, 3) co-author analysis, 4) authorship citation, and 5) country active. This paper presents a bibliometric analysis of the existing literature on PCSCM from the five above-mentioned aspects.

3.3 Qualitative discussion

Quantitative visual analysis of existing literature by itself cannot provide a complete and comprehensive understanding of the existing research status. A detailed qualitative discussion on the existing literature is necessary to further capture the research state on PCSCM. Taxonomy is a viable way to categorize and summarize the existing literature. In addition, taxonomy has been used to discuss the performance of modular buildings in terms of cost, schedule, environmental, health and safety (Kamali and Hewage, 2016). Wang et al. (2019b) used taxonomy to create a classification system to reveal research gaps and opportunities in prefabricated supply chain management. The classified discussion method adopted in this study can help understand research results by spliting the complex PCSC into different aspects.

4. Results of visual analysis

4.1 Analysis of publication sources

In this study, VOSviewer is used to analyze the journal sources of literature related to PCSCM. Cluster analysis of journal sources can reflect the contribution of journals to the entire research field to some extent (Liu et al., 2020b). Figure 3 shows the clustering of journal sources and their relationship. In the past research on scientific cartography, different thresholds were tested using text mining tools, and it was finally concluded that the minimum number of articles and citations to help achieve ideal and meaningful results were 3 and 20 respectively (Oraee et al., 2017; Jin et al., 2018). However, some other studies had set the minimum number of articles to 3 and the minimum number of citations to 10 (Liu et al., 2020b). In this study, the minimum number of articles is set to 3 and the minimum number of citations is set to 20 through several tests. In Figure 3, larger nodes and font sizes represent journals with a larger number of published articles, and the link between nodes indicates the mutual citation among journals. For example, *Automation in Construction* has a strong correlation with *Journal of Cleaner Production*. Nodes of the same color can be classified into one category. Therefore, as shown in Figure 3, *Journal of Management in Engineering*, *Automation in Construction* and *Journal of Cleaner Production* can be classified into the same cluster, and journals belonging to the same cluster generally have higher relevance, that is, they are considered to have higher mutual citation rating.

Table 1 shows the number of articles published in each journal, total link strength, total citations, average citations and average published years. The first three indices are highly correlated, which can be used to quantitatively analyze the influence of journals in this research field. As shown in Table 1, the journals with the highest total number of articles are *Journal of Cleaner Production* and *Journal of Construction Engineering and Management*, and the journal with the highest total citations is *Automation in Construction*. However, according to the average citations, although the numbers of articles of *Journal of Management in Engineering* and *International Journal of Production Economics* are not among the best, they still have higher influence. In addition, according to the average published year, it can be seen that *Sustainability*, *Journal of Cleaner Production* and *Journal of Management in Engineering* are active in recent years and are expected to have great development potential.

Figure 3: Analysis of Publication Sources (Scientific Journal Outlets)

Table 1: Publication Sources (Scientific Journal Outlets): Total link strength, Number of articles, Total citations, Average citations, Average published year, Average normalization citations

4.2 Analysis of keywords co-occurrence

Keywords can reflect the research topic of literature (Jin et al., 2018; Su and Lee, 2010) and the research concentration in a particular study area (Liu et al., 2020b). The visual analysis of keyword co-occurrence gives us a preliminary understanding of the current research hotspots. There are three types of keyword analysis in VOSviewer, which are author keyword, keyword plus and all keywords. "Author keywords" (Jin et al., 2018) or "all keywords" (Liu et al., 2020b) can be used for clustering analysis of keywords. The co-occurrence frequency indicates the strength of the connection between two keywords (Wang et al., 2019a). The minimum co-occurrence times of keywords is set to 3 (Liu et al., 2020b;Jin et al., 2018). Therefore, 102 of all the 1150 keywords meeting the preset minimum threshold were screened. First, keywords with no significance were removed, such as "supply chain", "prefabricated construction", and "supply chain management". The second step was to remove irrelevant keywords, such as "social responsibility", "selection" and "project management". Finally, synonymous keywords, for example, "supply chain integration" and "integration", "RFID" and "radio frequency identification technology", "BIM" and "building information model", etc., were merged, As a result, 30 valid keywords are retained, and the scientific map for visual analysis is obtained and shown in Figure 4. Node size indicates the number of keywords co-occurrence, and 30 keywords are roughly classified into four categories according to different node colors. Red nodes reflect that Asian countries and regions have made more contributions to the innovation and sustainable development research on PCSC. Yellow nodes reflect that advanced information technologies, such as BIM, RFID, genetic algorithms, etc., are used to optimize the PCSC. Blue nodes indicate that the simulation is often used to study how to improve the flexibility of PCSC and how to facilitate the integration of the supply chain. Green nodes reflect that the game theory is often used to study the inventory, cost and risk in the PCSC.

Table 2 shows the total link strength, co-occurrence times and average published year of each keyword. It can be concluded that keywords such as "innovation", "optimization",

314 "integration" and "logistics" are mentioned more frequently. According to the average
315 published year, "genetic algorithm", "sustainability", "risk" and "lean" are popular topics.

316 Figure 4: Analysis of Keyword Co-occurrence

317 Table 2: Analysis of Keyword Co-occurrence: including Total link strength, Occurrence, Average
318 citations, Average published year, Average normalization citations

4.3 Analysis of co-authorship

Understanding the authorship partnerships in a certain research field not only increases the possibility of obtaining professional knowledge and funds, but also improves the research efficiency and prevents an author from being isolated (Jin et al., 2018; Hosseini et al., 2018). In order to study authorship partnerships, the threshold usually set for the minimum number of articles published by an author is 3, and the minimum number of articles cited by scholars is 20 when using VOSviewer (Jin et al., 2018). However, since the number of existing articles in the field of PCSCM is not large enough, the minimum number of articles published by authors in this study is set to 2 after several tests with the purpose of avoiding missing authors with few articles but great influence. Therefore, 12 out of the 642 authors who meet the threshold requirements are retained. The visualization analysis results of co-authorship is shown in Figure 5. According to the color of nodes in the figure, author clusters can be roughly divided into five categories. There are two notable research groups. One is composed of Zhai, Zhong and Xu, and the other is composed of Xue, Shen, Li and Xu. As shown in the Figure 5, these two research groups have contributed many papers in the field of PCSCM.

Figure 5: Analysis of Co-authorship

Table 3 shows the results of quantitative analysis on co-authorship, including total link strength, number of articles, total citations, average citations, average published year and average normalization citations. According to number of articles published in the past decade, the top 3 authors who have published in the field of PCSCM are Shen, Hu, and Wang. According to the average citations, some authors have great influence, such as Xue, Xu, Mao and Pan, although they have published a small number of articles. In recent years, the more active authors are Shen, Li, et al., which means that these authors will be the potential force for further development in the field of PSCSM.

Table 3: Analysis of Co-authorship, including: Total link strength, Number of articles, Total citations, Average citations, Average published years, Average normalization citations

4.4 Analysis of authorship citation

In order to find the authoritative publications in the field of PCSCM, this paper analyzes the citations of existing documents. After many tests, the desirable results can be obtained by setting the minimum citations of articles to 10. 15 out of the 117 articles meet the threshold requirements. Figure 6 shows the most frequently cited articles in the field of PCSCM and the links among the articles, which can measure the influence of the articles in the research community.

Table 4 shows a quantitative analysis of authorship citation, including title, links, citations and normalization citations. According to Table 4, The article titled Stakeholder-Associated Supply Chain Risks and Their Interactions in a Prefabricated Building Project in Hong Kong (Luo et al., 2019) has the strongest links. Cheng et al. (2010) and Pan et al. (2012) entered the field of PCSCM earlier and studied the integration of PCSC. Li et al.(2016) achieved high-level achievements in the study on schedule risk in prefabricated housing in Hong Kong. In addition, the research conducted by Demiralp et al. (2012) and Wang et al. (2017) on the combination of RFID technology with PCSC also have high influence.

Figure 6: Analysis of Authorship Citation

Table 4: Analysis of Authorship Citation: Title, Links, Citations, Normalization citations

4.5 Analysis of country active

The contribution and relationship of each country to the field of PCSCM are discussed in this section. Setting the minimum number of articles published in one country as 3 and the minimum number of citations as 20 (Jin et al., 2018), 14 out of the 47 countries meet the threshold standard and are retained. The countries and regions active in the research field of PCSCM are shown in Figure 7 and Table 5. It can be seen from Figure 7 that the United States and China are respectively the core developed and developing countries in this research field, with the largest number of publications widely cited by other countries. Other active countries are Britain, Germany and Australia, while Japan and France with only some publications interact less with other countries. Table 5 shows the quantitative analysis results of country active. According to the Figure 7, Sweden enters the field of PCSCM earlier, and its publications are more influential. Although China has the largest number of publications, its international influence is not significant. The United States and Australia are the mainstays of the current development in PCSCM.

Figure 7: Analysis of Country Active

Table 5: Analysis of Country Active : Total link strength, Number of articles, Total citations, Average citations, Average published year, Average normalization citations

5. Qualitative discussion

5.1 Stratified Review

At present, researchers and practitioners have paid more and more attention to PCSCM (Zhang et al., 2019). In the previous sections, the relevant literature in the field of PCSCM has been quantitatively analyzed by using VOSviewer. This section categorizes and qualitatively discusses the existing research on PCSCM from seven aspects to more clearly grasp the current research progress in the field of PCSCM: logistics and transportation, inventory planning, supply chain costs, delivery and schedule, risks and resiliency, supply chain intelligentization and informatization, .

5.1.1 Research on logistics and transportation

The research on logistics of PCSC is shown in Table 6. Logistics plays an important role in the successful completion of PC (Gosling et al., 2016). The transportation process also serves as a link between the construction site and the prefabricated plants (Shukor et al., 2016). As a result of the transformation from on-site construction to off-site construction, the traditional construction supply chain needs to be updated. The most remarkable change in the PCSC is that the supply chain should focus on the transportation of prefabricated components. The logistics optimization is the key to the new time-sensitive PCSC and can reduce the uncertainty in the transportation process of prefabricated components (Liu and Lu, 2018; Hsu et al., 2018). Ahmadian et al. (2016) used the results of case studies to emphasize the importance of considering the transportation time of off-site materials in the planning of large-scale industrialized projects and proposed a framework for estimating the duration of off-site transportation. Fang and Ng (2019) examined the potential for deriving logistics plans for materials production, supply and consumption using genetic algorithms (GAs). Hsu et al. (2018) established a mathematical model to optimize the logistics process of modular structure, which included three processes: manufacturing, storage and assembly. In order to emphasize logistics and supply chain management, a special simulation template was developed to facilitate the simulation modeling of the manufacturing, transportation, assembly and installation process of preforms (Liu et al., 2017). Zhang and Yu (2020) considered the interdependence, dynamic interaction and coordination among stakeholders in different stages and solved the dynamic traffic planning problem of PCSC.

5.1.2 Research on inventory planning

The research on inventory planning involved in PCSC is shown in Table 7. Prefabricated components need to be stored in a factory, warehouse or construction site before being transported or assembled. The layout and inventory arrangement of warehouses can both affect the production efficiency of PC (Wang et al., 2019b). Hsu et al. (2017) determined the most suitable production plan and the best outsourcing quantity of prefabricated components in the manufacturing environment with uncertain productivity, and established a two-stage stochastic programming model and a mixed programming model to confirm the most favorable plan to deal with inventory changes. In order to optimize the inventory arrangement and reduce related costs, the optimal order batch and delivery batch could be obtained through the master-slave decision-making model with centralized distribution centers (Zhang et al., 2017). Based on the traditional EOQ (economic order quantity) model and the construction supply chain theory, the inventory cost model and ordering strategy were obtained and optimized by combining with sequential decision-making, which was proved to be effective (Yang et al., 2018). Furthermore, in order to avoid the adverse effects caused by improper delivery of prefabricated components, transportation companies needed to reserve some buffer space in their intermediate warehouses. Nash model had been proved to be effective in alleviating the pressure on logistics providers, reducing buffer space and related inventory costs (Zhai et al., 2019; Yue et al., 2019; Zhai et al., 2018).

5.1.3 Research on supply chain costs

The research on the costs of PCSC. is shown in Table 8. In order to decrease the total cost of PCSC, it is necessary to establish a supply chain cost model to identify the sources of various costs and how they affect the total cost of the supply chain, so as to find countermeasures to reduce the total cost (Kim et al., 2016). Demiralp et al. (2012) used simulation-based decision support tools to simulate cost savings by using RFID for various participants in PCSC and calculated the cost of technology investment that should be shared among all parties through the cost-share ratio. To reduce the total material management cost in PCSC, Ko (2013) proposed a material supply chain framework that allowed finding the most profitable transshipment strategy by simulating different order lead time, demand, transportation cost and shortage cost. Estimating the total cost of the supply chain by using activity-based costing is also helpful to find out the key areas to reduce the total cost (Wang et al., 2018c). Feng et al. (2017) used evolutionary game theory to deduce the cooperative relationship between producers and promoted participants and stabilized this relationship by establishing an effective reward and punishment mechanism, which could reduce the initial cost of PCSC. Zhang and Yu (2021) proposed a multi-objective optimization model to study the resilience of construction schedule dependence of PCSC plan by considering transportation cost. Zhang et al. (2021a) put forward an evaluation model to guide the cost-controllable supply chain of PC and quantified and distinguished the influence degree of direct or indirect factors related to cost performance in the supply chain.

5.1.4 Research on project delivery and scheduling

Timely delivery of prefabricated components is very important for the successful completion of PC (Kim et al., 2020), while production scheduling plays an important role in timely delivery of prefabricated components. Reasonable schedule can promote the timely delivery of prefabricated components and projects (Wang and Hu, 2018). Production scheduling of components should require consideration on economic and environmental impacts (Kong et al., 2018) and should focus on each stage before and after the production of components. Wang and Hu (2017) integrated the process of mold manufacturing, components storage and transportation from the perspective of the whole PCSC and considered the three situations of day, night and all day, so as to revise the traditional production scheduling model. Liu and Lu (2018) established a schedule optimization model based on constrained programming to deduce the project schedule meeting the variable material delivery time and limited human resource availability. Lee et al. (2019) presented the classification of PC projects as manufacturing driven, on-site driven or a combination to improve scheduling strategies based on a schedule-driven approach. Si et al. (2021) proposed a dynamic compensation mechanism to realize timely component delivery, through which the factory could share the possible changes of the delivery date of each component with its customers. Aiming to achieve lean PCSC, Chen et al. (2020a) started from the concept of lean management and constructed an integrated BIM-RFID database system that links information on material demands with look-ahead plans to better manage material flow processes. Wang et al. (2020d) investigate the process optimization of a precast concrete component production line by using value stream mapping, which is an innovative application of lean production theory and value stream mapping in complex precast concrete component production lines. Based on Lean Construction Principles, Goh and Goh (2020) developed baseline (As-Is) simulation model of an ongoing precast prefabricated volumetric construction (PPVC) project case study, which can reduce project delivery time by applying lean concepts. Du et al. (2022) characterized the production scheduling of the prefabricated components problem into a permutation flow shop scheduling problem (PFSSP) with multi-optimization objectives based on the principles of value-based management (VBM) and just-in-time (JIT) lean construction. Table 9 shows the related research on the delivery of prefabricated construction and the progress of supply chain up to now.

5.1.5 Research on supply chain risk and resiliency

The research on supply chain risk and resilience of PC is summarized in Table 10. The structure of PCSC is becoming more complex, which makes the related risks more prominent (Wang, 2019). The risks of PCSC are inevitable, so they must be anticipated to ensure the success of the project (Hatmoko et al., 2018). Li et al. (2016) paid attention to the schedule risks in the PCSC earlier, and BIM as the central strategy could effectively reduce the key schedule risks. On this basis, Vensim software package was applied to discuss the possible impacts of various risks on the progress (Li et al. 2017), and then a hybrid dynamic model was developed to analyze the relationships among schedule risks by further evaluating the schedule risks using the Anylogic (Li et al., 2018a). In addition, the overall management risks of PCSC (Wang et al., 2018b; Hatmoko et al., 2018; Wang, 2019) and stakeholder risks (Luo et al., 2019) have also been studied recently. Wang et al.(2018b) proposed a global disturbance evaluation model to evaluate the uncertainty of prefabricated supply chain. Hatmoko et al.(2018) identified risk factors in PCSC and finded out the key risk factors according to five dimensions of supply chain operation reference (SCOR) model. Wang (2019) explored the similarity between the risk management in PCSC and discussed the biological immune system. From a stakeholder perspective, Luo et al. (2019) established a risk network for the PCSC in Hong Kong by using social network analysis (SNA) and ranked the risks in PCSC by severity. Hsu et al.(2019) put forward a mathematical model to design and optimize risk-average logistics configurations for PC projects under operational uncertainty. Zhang et al. (2021b) constructed a conceptual model of factors influencing the resilience of PCSC and further conducted empirical study showing that the production and on-site assembly of components have a significant impact on the resilience of the PCSC. Ekanayake et al. carried out a series of studies on resilience in PCSC and developed a multilevel-multicriteria mathematical model to analyze the PCSC in Hong Kong (Ekanayake et al. 2021a). In addition, they also simulated the dynamic influence of supply chain vulnerabilities and supply chain capabilities in PCSC indicating that on-site assembly was considered as the most vulnerable stage, while anticipation as the most influential capability (Ekanayake et al. 2021b). In view of the urgency of improving supply chain resilience in PC, Ekanayake et al.(2021c) explored the relationship between supply chain vulnerability and supply chain capability and they also developed a model to evaluate supply chain capability to improve the resilience of industrialized construction in high-density cities (Ekanayake et al., 2021d).

5.1.6 Research on supply chain intelligentization and informatization

With the advent of the era of Industry 4.0, a new generation of revolutionary technologies in the industrial field promotes the transformation of the construction industry to intelligentization. In this context, many research results have been achieved in the field of PCSC. See Table 11 for research on informatization in PCSC. The research on intelligentization in PCSC focuses on real-time information and prefabricated component tracking. Zhong et al. (2017) and Li et al. (2018b) combined Internet of Things (IoT) and BIM to design an information platform to achieve real-time visibility and traceability in PCSC. Xu et al. (2019) proposed a cloud-based fleet management platform through integrating the advantages of IoT and cloud technology to address the scarcity of real-time data and ineffective information sharing mechanisms. Zhao et al. (2019) introduced an innovative method that incorporated Radio Frequency Identification (RFID) and Long Range (LoRa) technologies, sensor networks, the BIM model and cloud computing to automatically collect, analyze and display real-time information about PC components. Wang et al. (2020c) developed a novel blockchain-based information management framework for the PCSC and proposed a visualization system to achieve (1) information sharing management, (2) real-time control of scheduling, and (3) information traceability. Luo et al. (2020) used automated data collection techniques to obtain real-time information on prefabricated components in each operational phase of the PCSC and identify the factors that hinder the efficiency of the PCSC. Jiang et al. (2022) and Zhao et al. (2022) developed a system based on digital twin technology for real-time monitoring of assembly stages on-site. In addition, Li et al. (2014) developed a software platform system and integrated all members of the PC project into this platform. On this unified platform, the whole PC project is under the control of supply chain management. Zhong et al. (2015) proposed the architecture of an Physical Internet (PI)-enabled prefabricated housing construction which upgrades and transforms the PC so that the logistics echelons could be integrated and synchronized. In order to improve communication efficiency. Abedi et al. (2016) developed a system architecture and prototype of context-aware cloud computing building information modeling (CACCBIM) for PCSCM. Based on RFID application and multi-agent simulation, an information tracking and supply mechanism of PCSC is proposed (Du et al., 2017). Wang et al. (2017) investigated the data-driven mechanisms and benefits of utilizing RFID in knowledge-based PCSC. Bian and He (2017) took the information flow as the breakthrough point, analyzed the whole life cycle information flow of the prefabricated construction. Xu et al. (2018) proposed a cloud-based integrated IoT platform through exploiting the concept of cloud asset. Wang et al. (2020e) proposed a conceptual framework of an Intelligent Construction System for Prefabricated Buildings based on the Internet of Things (ICSPB-IoT) to break the bottleneck of information integration and interaction in the PCSC. Li et al. (2021) developed an intelligent platform based on service-oriented manners with blockchain- and IoT to promote the sustainability of the PCSC. Lee and Lee (2021) developed a digital twin framework for real-time logistics simulation by using IoT sensors, BIM, and GIS, which could predict potential logistics risks and accurate arrival time of modules, effective supply chain coordination can be achieved through reliable prediction. Aiming for environmental friendliness, Tao et al. (2018)

proposed a greenhouse gas emission monitoring system based on IoT technology to real-time monitor emissions during the production of components.

5.1.7 Research on modern construction technology

A significant feature that distinguishes PC from traditional construction is that prefabricated components are transferred to the construction site for assembly. The design and on-site assembly of prefabricated components make the PCSC needs to pay more attention to the design stage and assembly stage, which is different from the traditional construction supply chain (Mohamed et al., 2021). The application of modern design and assembly technology is conducive to promoting the development of PC and improving their supply chain management. This section provides a review of research related to design and assembly technology for further study of the application of modern technology in the PC.

Isaac et al. (2016) put forward a graph-based method, which decomposes the design into non-repetitive modules, so that these modules can be easily replaced in case of any damage, and optimizes the modules by applying clustering algorithm to the data of BIM tools. Said et al. (2017) put forward a new model of platform optimization for exterior wall panels (EPWPO), which is solved by non-dominated sorting genetic algorithm (NSGA). This model can not only find the near optimal geometric and structural design of wallboard, but also minimize the production cost. Alwisy et al. (2019) developed a systematic method, It utilized 2D computer-aided design (CAD) drawings to automatically generate BIM and construction manufacturing BIM. Navarro-Rubio et al. (2020) combined artificial neural network with finite element model to improve the design efficiency of prefabricated components and found the best structural design. Chen et al. (2020b) developed an optimization design program using genetic algorithm. Compared with the results of existing methods, the optimization design program can find the best structural design more quickly and accurately.

Taghaddos et al. (2018) proposed a more comprehensive method to help plan multiple mobile crane operations, such as crane selection, crane location and path planning. In order to solve the assembly sequence planning and optimization (ASPO) problem in PC, Building Information Modelling (BIM) and Improved Genetic Algorithm (IGA) were organically combined to propose a new method called BIM-IGA-based ASPO method. This method used BIM for parametric modelling, used IGA to search for an optimal assembly sequence, and then used BIM again for visual simulation to further test the assembly sequence. Besides, IGA, which was improved in coding mode, crossover operation and mutation operation, was also used to achieve the dynamic adjustment of assembly sequence in

587 construction process (Wang et al., 2018d). Zheng et al. (2020) developed a module-detection model based on mask regions with volatile neural network (mask r-CNN), which could automatically monitor modules in the process of site construction. Li et al. (2020) developed the smart work packaging (SWP)-enabled constraints optimization service, to achieve autonomous initial path planning of crane, networked constraints classification, and adaptive decisions on path re-planning. Wang et al. (2021b) proposed a novel framework that integrates the latest computer vision methods to realize automatically monitoring construction progress of precast walls, status information identified and collected was stored as a JavaScript object notation (JSON) format and then sent into a corresponding building information model (BIM) to timestamp the wall components.Table 12 shows the related research on the modern construction technology of PCSC in recent years.

5.1.8 Research on other topics

The research in PCSCM also involves other aspects. For instance, Rocha et al. (2019), Kahkonen et al.(2003), Xun et al. (2019) had contributed to providing standardized PCSC processes. Arashpour et al. (2017), Daget and Zhang (2019), Han et al.(2017) and others had devoted themselves to studying how to make optimal decisions in different stages of the PCSC to improve the efficiency of PC projects. Green et al. (2017), Zeng et al. (2018) and others contributed to the integration of PCSC. Considering the impact of construction projects on the environment, Du et al. (2021) discussed the key factors affecting carbon emissions and their relationship from the perspective of PCSC in order to realize the carbon reduction potential of prefabricated construction. In addition, Wuni and Shen (2021) studied the key determinants of PCSCM success, and the results showed that design for SCM, effective communication and information sharing, organizational readiness, seamless integration and coordination of PCSC, early involvement of critical supply chain stakeholders and extensive supply chain planning are the top five critical success determinants of effective PCSCM.

5.2 Summary of the discussion

5.2.1 Top ten articles with cited frequency

This section summarizes the ten most frequently cited articles in the existing research on PCSC, as shown in Table 13. The research contents of these articles mainly involve risk management (Li et al., 2016; Luo et al., 2019; Wang et al., 2020c), investment cost (Demiralp et al., 2012; Arashpour et al., 2017) and component delivery (Zhai et al., 2016; Wang and Hu, 2017;

Hsu et al., 2018).

Li et al. (2016) and Luo et al. (2019) applied social network analysis (SNA) to identify and investigate the potential network of risk factors related to stakeholders in PCSC. Wang et al. (2020c) constructed a information management framework in PCSC based on blockchain to cope with the risks, such as fragmentation, poor traceability, lack of real-time information and so on. In order to reduce the cost of PCSC operations, Arashpour et al. (2017) proposed an optimization model to improve the performance of the supply network with less investment, and consideration should also be given to how the related investment costs were allocated among the stakeholders (Demiralp et al., 2012). Zhai et al. (2016) presented the coordination scheme to solve the problem of production lead-time value preservation in the PCSCM. To further optimize the component production scheduling, Wang and Hu (2017), Hsu et al. (2018) considered various stages including component manufacturing and storage in a comprehensive manner, while Wang and Hu (2017) only focused on the component transportation stage and Hsu et al. (2018) only focused on the assembly stage. From the materials management perspective, Cus-Babic et al. (2014) discussed the information flow integration related to material management in PCSC. Starting from the concept of modularity, Margherita et al. (2015) investigated the concept of modularity within the Engineer-to-Order (ETO) industries (such as construction and shipbuilding) by means of an explorative case study approach .

5.2.2 The main research methods adopted

This part summarizes the commonly used research methods in the field of PCSC, shown in Table 14. It can be seen that mathematical modeling is widely used and generally applicable to a variety of research topics. In addition, there are also definite preference on the research methods used for different topics. For example, genetic algorithm is mostly used in the study on scheduling and delivery in PCSC, while system dynamics and social network analysis can be considered only in the research on the risk and resilience in PCSC. More obviously, RFID is almost one of the most effective research methods for scholars to study the real-time state of prefabricated components in PCSC.

5.2.3 Research trends in terms of different topics

As can be seen from Table 15, there are more and more publications about the topics of risk, resilience and real-time information in PCSC compared to other research topics. There has been a significant increase on the number of articles about risk and resilience in PCSC in the latest years, which indicates that PCSC is facing severe challenges brought by uncertainty, hence the risk management and resilience control of PCSC has received wide attention from scholars. In addition, PCSC operates around various stakeholders and prefabricated components, which need to go through multiple stages from design, manufacturing, transportation to on-site assembly. This process involves complex information exchange. It can be seen from Table 15 that scholars have recognized this problem and have started to study it in early years, but the research on informatization in PCSC has not been further expanded in recent years. However, the efficiency of PCSC is heavily influenced by the efficiency of information sharing among all participants, and therefore it is necessary to pay close attention to intelligentization and informatization in PCSC continuously.

Table 6: Research on Logistics and Transportation

Table 7: Research on Inventory Planning

Table 8: Research on Supply Chain Costs

Table 9: Research on Project Delivery and Scheduling

Table 10: Research on Supply Chain Risk and Resiliency

Table 11: Research on Supply Chain Intelligentization and Informatization

Table 12: Research on Modern Construction Technology

Table 13: Top ten articles with cited frequency

Table 14: The main research methods adopted

Table 15: Research trends in terms of different topics

6. Conclusion

6.1 Summary

Based on the WoS core, 131 documents that meet the requirements are reviewed and summarized in the field of PCSCM .The two main tasks of this review are (1) to conduct a visual analysis on the existing literature in PCSCM to capture the overall picture of this research area, and (2) to summarize the existing literature into different modules and areas of PCSCM through qualitative discussion The quantitative analysis is conducted from five aspects: journal sources, keywords co-occurrence, co-author analysis, authorship citation andcountry active. The qualitative analysis discusses existing studies from seven themes: logistics and transportation, inventory planning, supply chain costs, delivery and scheduling, risk and resiliency, supply chain intelligentization and informatization and modern construction technology. Through above analysis, this literature review comprehensively and systematically reveals the fundamental venation, current research progress, trends and future directions in the field of PCSCM.

6.2 Implications

Compared to previous studies, this study is more comprehensive and integrated, as reflected by the addition of the dimension related to "article authorship" in the quantitative analysis and by covering all main themes in the qualitative discussion in the field of PCSCM (including the most recent articles published in 2022). In addition, this paper deeply discusses the the main research topics from both the specific contents and research methods adopted. The findings received in this review can help scholars acquire academic knowledge, research frontiers and emerging trends and explore future research directions in the field of PCSC from different research perspectives . what's more, this study can help project participants to understand the current operation status and existing problems of PCSC in practice and provide a basis for future solutions to the difficulties faced in PCSC.

6.3 Future direction

- The unqualified or defective prefabricated components will not only cause waste in materials and the invested funds, delay on construction progress and even cause long-term problems associated with project performance and quality, so the quality inspection of precast components is the one of future research topics.
- The logistics and transportation management in PCSC mainly focused on prefabricated components in previous publications. The logistics management of construction waste needs to be paid more attention to in the future research on PCSCM. Effective recovery on

construction waste can achieve a win-win situation warranting both economic and environmental benefits.

- Previous studies could not grasp the comprehensive supply chain risk situation and the impacts of all uncertainties. Future research should identify and control the risk factors in all phases of PCSC.
- Advancing the informatization level in PCSC is one of the keys to improve the PC efficiency. How to combine modern construction technologies with information technologies and intelligent tools will be an interesting research direction.

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Table 1: Analysis of Publication Sources (Scientific Journal Outlets): Total link strength, Number of articles, Total citations, Avg. citations, Avg. pub. Year, Avg. norm. Citations

Source	Total link strength	Number of articles	Total citations	Avg. citations	Avg. pub. year	Avg. norm. citations
J of Management in Engineering	23	3	106	36	2018	3.56
Sustainability	20	6	20	4	2018	0.62
J of Cleaner Production	19	12	161	15	2019	2.07
Automation in Construction	14	7	166	28	2017	1.93
International J of Production Economics	4	8	175	22	2016	2.31
J of Construction Engineering and Management	10	12	93	9	2018	0.95

Table 2: Analysis of Keyword Co-occurrence: including Total link strength, Occurrence, Avg. Citations, Avg. pub. Year, Avg. norm. citations

Keyword	Total link strength	Occurrence	Avg. citations	Avg. pub. year	Avg. norm. citations
Model	92	19	16	2017	1.65
Framework	84	14	9	2017	1.55
Innovation	80	14	15	2016	1.32
Integration	70	12	6	2016	0.79
Hong Kong	68	11	13	2016	1.31
Optimization	67	15	5	2017	0.80
Flexibility	62	8	3	2018	0.54
Strategy	59	9	5	2018	0.90
Uncertainty	58	9	4	2019	0.73
Technology	49	8	10	2017	1.25
Logistics	46	10	10	2016	1.40
Inventory	40	5	13	2017	2.54
Simulation	33	8	14	2016	0.95
China	32	6	37	2016	3.31
Game Theory	30	4	7	2018	0.99
Supply Chain Coordination	30	4	7	2018	0.99
Genetic Algorithm	28	4	14	2019	2.42
Japan	27	4	20	2016	1.00
Reduction	26	4	12	2018	1.52
Barriers	25	5	25	2018	2.55
Cost	23	4	3	2017	0.40
Lean Construction	23	3	2	2019	0.69
RFID	20	4	18	2017	1.45

BIM	18	4	23	2017	2.40
Dynamic Capability	18	3	4	2018	0.57
Sustainability	18	3	2	2018	0.46
Risk	17	3	2	2018	0.39
Critical Success Factors	15	3	2	2019	0.23
Information	14	3	6	2016	0.72
Interoperability	13	4	10	2016	1.76

Table 3:Analysis of Co-authorship, including total link strength, number of articles, total citations, average citations, average published years and average normalization citations

Author	Total link strength	Number of articles	Total citations	Avg. citations	Avg. pub. Year	Avg. norm. citations
Shen, Geoffrey Qiping	11	5	104	21	2018	2.75
Li, Clyde Zhengdao	9	3	84	28	2017	3.37
Xue, Fan	9	3	91	31	2016	3.19
Luo, Lizi	8	3	33	11	2018	2.25
Xu, Xiaoxiao	7	2	84	41	2016	4.56
Hu, Hao	6	6	88	15	2018	2.31
Wang, Zhaojing	6	6	88	15	2018	2.31
Xu, Gangyan	6	4	25	6	2018	1.14
Zhai, Yue	4	4	28	7	2018	0.99
Zhong, Ray Y.	4	3	33	11	2016	1.33
Arashpour, Mehrdad	2	2	24	12	2018	1.65
Bai, Yu	2	2	24	12	2018	1.65
Mao, Chao	1	2	93	47	2016	3.26
Pan, Wei	1	2	162	81	2013	4.55

Table 4: Analysis of Authorship Citation: including Title, Links, Citations, Norm. citations

Document	Title	Links	Citations	Norm. citations
Luo, Shen, Xu, Liu and Wang	Stakeholder-Associated Supply Chain Risks and Their Interactions in a Prefabricated Building Project in Hong Kong.	9	16	3.64
Li, Shen, Xu, Xue, Sommer and Luo	Schedule risk modeling in prefabrication housing production	5	17	2.12
Pan, Gibb and Dainty	Strategies for Integrating the Use of Off-Site Production Technologies in House Building	5	72	3.05
Arashpour, Bai, Aranda-mena, Bab-Hadiashar,	Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction	4	21	1.82

Hosseini and Kalutara				
Demiralp, Guven and Ergen	Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated prefabricated components	4	43	2.62
Wang and Hu	Dynamic response to demand variability for precast production rescheduling with multiple lines	3	33	5.08
Wang, Hu and Zhou	RFID Enabled Knowledge-Based Precast Construction Supply Chain	3	21	2.62
Zhai, Zhong, Li and Huang	Production lead-time hedging and coordination in prefabricated construction supply chain management	3	17	2.12
Li, Hong, Xue, Shen, Xu and Mok	Schedule risks in prefabrication housing production in Hong Kong: a social network analysis	3	67	6.99
Cus-Babic, Rebolj, Nekrep-Perc and Podbreznik	Supply-chain transparency within industrialized construction projects	3	22	2.40
Wang, Hu and Gong	Simulation based multiple disturbances evaluation in the prefabricated supply chain for improved disturbance prevention	2	10	1.54
Han, Skibniewski and Wang	A Market Equilibrium Supply Chain Model for Supporting Self-Manufacturing or Outsourcing Decisions in Prefabricated Construction	2	12	1.50
Wang and Hu	Improved Precast Production–Scheduling Model Considering the Whole Supply Chain	1	18	2.25
Kim, Han, Yi and Chang	Supply chain cost model for prefabricated building material based on time-driven activity-based costing	1	13	1.36
Cheng, Law, Bjornsson, Jones and Sriram	A service oriented framework for construction supply chain integration	1	86	3.62

Table 5: Analysis of Country Active: Total link strength, Number of articles, Total citations, Avg. citations, Avg. pub. Year, and Avg. norm. citations

Country	Total link strength	Number of articles	Total citations	Avg. citations	Avg. pub. year	Avg. norm. citations
China	124	44	349	9	2015	1.13
USA	56	25	356	15	2015	1.22
Australia	27	6	78	13	2016	1.02
England	20	13	191	15	2014	1.53
New Zealand	18	3	27	9	2016	1.21
Germany	13	8	103	13	2013	1.25
Italy	13	7	42	6	2013	0.54

Brazil	11	6	34	6	2018	1.00
Wales	10	4	47	12	2014	2.24
France	9	6	66	11	2013	1.69
Netherlands	8	5	28	4	2015	0.67
Sweden	6	6	122	20	2012	1.10
Canada	5	6	39	7	2016	0.71
Japan	3	5	35	7	2015	0.70

Table 6: Research on Logistics and Transportation

Title	Author	Year	Research topics	Research methods or tools
Modular Construction System Simulation Incorporating Off-Shore Fabrication and Multi-Mode Transportation	Liu, J. Y., et al.	2016	logistics management	modeling based on Simphony
Accounting for Transport Times in Planning Off-Site Shipment of Construction Materials	Ahmadian, F. F. A., et al.	2016	off-site material transport time and influence factor	case study
Optimal logistics planning for modular construction using two-stage stochastic programming	Hsu, P. Y., et al.	2018	optimizing the logistics system	two-stage stochastic programming model, case study
Sustainable multi-period reverse logistics network design and planning under uncertainty utilizing conditional value at risk (CVaR) for recycling construction and demolition waste	Rahimi, M., et al.	2018	reverse logistics network, recovery of construction waste	Two-stage stochastic programming, off-site and on-site separation
Genetic algorithm for determining the construction logistics of prefabricated components	Fang, Y., et al.	2019	logistics planning	genetic algorithms (Gas), Activity-Based Costing (ABC) method
Dynamic transportation planning for prefabricated component supply chain	Zhang, H., et al.	2020	dynamic transport planning	just-in-time (JIT), particle swarm optimization (PSO) algorithm

Table 7: Research on Inventory Planning

Title	Author	Year	Research topics	Research methods or tools
Establishing Outsourcing and Supply Chain Plans for Prefabricated Construction Projects Under Uncertain Productivity	Pei-Yuan, H., et al.	2017	inventory dispatching, production planning	two-stage stochastic programming model, mixed integer linear programming model

Mechanism of Leader-Follower Distribution Decision of the Suppliers with the Supply Hub	Zhang, L., et al.	2017	supplier collaborative distribution	collaborative main-slave decision-making mechanism (centralized distribution center as main supplier as slave)
Ordering Strategy Analysis of Prefabricated Component Manufacturer in Construction Supply Chain	Yang, H. X., et al.	2018	ordering strategy	EOQ model, construction supply chain theory, order decision, Gas, Matlab
Buffer space hedging and coordination in prefabricated construction supply chain management	Zhai, Y., et al.	2018	buffer space hedging	Stackelberg games, Nash game, mathematical modeling
Optimization of reinforcement steel supply to precast concrete plants	Nical, A.	2019	procurement strategy	mathematical modeling
Multi-period hedging and coordination in a prefabricated construction supply chain	Zhai, Y., et al.	2019	buffer space hedging	cooperative game, Nash game
Buffer space hedging enabled production time variation coordination in prefabricated construction	Zhai, Y., et al.	2019	buffer space hedging	Stackelberg games, Nash game

Table 8: Research on Supply Chain Costs

Title	Author	Year	Research topics	Research methods or tools
Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated prefabricated components	Demiralp, G., et al.	2012	allocation of technology investment cost	cost sharing ratio, simulation
Material Transshipment for Precast Fabrication	Ko, C. H.	2013	transshipment strategies, total material management costs	mathematical modeling, computer simulation
Supply chain cost model for prefabricated building material based on time-driven activity-based costing	Kim, Y. W., et al.	2016	total supply chain costs	supply chain cost model using time-driven activity-based costing, sensitivity analysis
Modularity, Lead time and Return Policy for Supply Chain in Mass Customization System	Li, J. Z., et al.	2016	manufacturing cost	simultaneous-move game, sequential-move game and the cooperative game
Study on Cooperative Mechanism of Prefabricated Producers Based on Evolutionary Game Theory	Feng, T. Y., et al.	2017	initial cost, partnership	evolutionary game theory
Supply Chain Cost Prediction for Prefabricated Building Construction under Uncertainty	Wang, S. L., et al.	2018	total supply chain costs	Activity-Based Costing (ABC) method
Exploring transaction costs in the prefabricated housing supply chain in China	Wu, H. J., et al.	2019	transaction costs	Social Network Analysis (SNA), semi-structured interviews
RESILIENCE-COST TRADEOFF SUPPLY CHAIN PLANNING FOR THE PREFABRICATED CONSTRUCTION PROJECT	Zhang, H. and L. Yu	2021	resilience cost	Multi-objective optimization model
A cost evaluation model for IoT-enabled prefabricated construction supply chain management	Zhang, W. N., et al.	2021	supply chain cost assessment	System Dynamics Model

Table 9: Research on Project Delivery and Scheduling

Title	Author	Year	Research topics	Research methods or tools

Improved Precast Production-Scheduling Model Considering the Whole Supply Chain	Wang, Z. J., et al.	2017	production scheduling	genetic algorithm, case study
Sustainable performance of just-in-time (JIT) management in time-dependent batch delivery scheduling of precast construction	Kong, L. L., et al.	2018	production scheduling , environmental performance	Just-in Time (JIT) strategy, batch-scheduling model
Constraint Programming Approach to Optimizing Project Schedules under Material Logistics and Crew Availability Constraints	Liu, J., et al.	2018	uncertainties in material deliveries	constraint programming-based scheduling optimization model
Dynamic response to demand variability for precast production rescheduling with multiple lines	Wang, Z. J., et al.	2018	dynamic production planning, on-time delivery	genetic algorithm, case study
Classification of Modular Building Construction Projects Based on Schedule-Driven Approach	Lee, J., et al.	2019	scheduling strategies	discrete-event simulation model
Lean production theory-based simulation of modular construction processes	Goh, M. and Goh, Y.	2019	construction efficiency project schedule	baseline (As-Is) simulation model, Lean principles
Dynamic production scheduling model under due date uncertainty in precast concrete construction	Kim, T., et al.	2020	production scheduling	discrete-time simulation method
Dynamic decision support framework for production scheduling using a combined genetic algorithm and multiagent model	Du, J., et al.	2020	dynamic scheduling method	genetic algorithm, multiagent system (MAS)
Using look-ahead plans to improve material flow processes on construction projects when using BIM and RFID technologies	Chen, Q., et al.	2020	lean management material management	RFID, BIM
Research on production process optimization of precast concrete component factory based on value stream mapping	Wang, S. Q., et al.	2020	lean production prefabricated components production	lean production theory, value stream mapping
A Dynamic Just-in-Time Component Delivery Framework for Off-Site Construction	Si, T. G., et al.	2021	delivery of prefabricated components	Genetic Algorithm (GA)
Improved biogeography-based optimization algorithm for lean production scheduling of prefabricated components	Du, J., et al.	2022	production scheduling of prefabricated components	Improved biogeography-based optimization algorithm (BBO)

Table 10: Research on Supply Chain Risk and Resiliency

Title	Author	Year	Research topics	Research methods or tools
Schedule risks in prefabrication housing production in Hong Kong: a social network analysis	Li, C. Z., et al.	2016	schedule risk and stakeholder risk	social network analysis (SNA)
Schedule risk modeling in prefabrication housing production	Li, C. Z., et al.	2017	schedule risks	system dynamics, Vensim software package, system dynamic model
A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong	Li, C. Z., et al.	2018	schedule risks	system dynamics and discrete event simulation, hybrid dynamic model, Anylogic software package

Simulation based multiple disturbances evaluation in the prefabricated supply chain for improved disturbance prevention	Wang, Z. J., et al.	2018	the uncertainty of prefabricated supply chain	ARENA-based discrete event simulation, overall disturbance evaluation model
Managing risks of precast concrete supply chain: a case study	Hatmoko, J. U. D., et al.	2018	the risks of the supply chain	Supply Chain Operation Reference (SCOR), questionnaire survey
Risk-averse supply chain for modular construction projects	Hsu, P. Y., et al.	2019	schedule risks	mathematical modeling
Stakeholder-Associated Supply Chain Risks and Their Interactions in a Prefabricated Building Project in Hong Kong	Luo, L. Z., et al.	2019	stakeholder risk	social network analysis (SNA)
Research on Risk Management of Prefabricated Construction Supply Chain Based on Immune Principle	Wang, Y.	2019	the risks of the supply chain	Immune Principle
Influencing Factors of Resilience of PBSC Based on Empirical Analysis	Zhang, M. J., et al.	2021	supply chain resilience	Structural Equation Modeling (SEM)
Modeling Supply Chain Resilience in Industrialized Construction: A Hong Kong Case	Ekanayake, E., et al.	2021	supply chain resilience	social network analysis (SNA), System Dynamic Modeling (SDM)
A fuzzy synthetic evaluation of capabilities for improving supply chain resilience of industrialised construction: a Hong Kong case study	Ekanayake, E., et al.	2021	supply chain resilience	multi-stage-mathematical models, fuzzy synthetic evaluation
Capabilities to withstand vulnerabilities and boost resilience in industrialized construction supply chains: a Hong Kong study.	Ekanayake, E., et al.	2021	supply chain resilience	Partial Least Squares Structural Equation Modeling
A fuzzy synthetic evaluation of vulnerabilities affecting supply chain resilience of industrialized construction in Hong Kong	Ekanayake, E., et al.	2021	supply chain resilience	multilevel-multicriteria mathematical model, fuzzy synthetic evaluation

Table 11: Research on Supply Chain Intelligentization and Informatization

Title	Author	Year	Research topics	Research methods or tools
Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS	Akinci, B., et al.	2007	tracking prefabricated component	RFID,GPS,case study
Automatically tracking engineered components through shipping and receiving processes with passive identification technologies	Grau, D., et al.	2012	tracking prefabricated component	RFID
Piloting a new information sharing method in a construction supply chain	Jussila, A., et al.	2012	information sharing,real-time information	logistics software, BIM , ERP
Based on RFID prefabricated building component design and monitoring system research	Jing, W.	2014	prefabricated construction supply chain	RFID

Study of digital lean construction platform for prefabricated components	Li, Y., et al.	2014	supply chain optimization management	software platform system(BIM, virtual construction technology, IoT, cloud services technology, remote monitoring technology)
Towards Physical Internet-enabled Prefabricated Housing Construction in Hong Kong	Zhong, R. Y., et al.	2015	real-time tracing, real-time interactions	Internet of Things (IoT), cloud techniques
Integrated collaborative tools for prefabricated supply chain management	Abedi, M., et al.	2016	prefabricated supply chain management	Context-Aware Cloud Computing Building Information Modelling (CACCBIM)
A CASE OF STUDY FOR EMBEDDING RFID TAGS IN PRECAST CONCRETER	Alonso-Calvo, R., et al.	2016	identifying prefabricated component and its location	RFID
Research on Information Flow of prefabricated construction supply chain Based on BIM	Bian, J., et al.	2017	whole life cycle information flow	BIM
RFID and Multi-Agent Based Architecture for Information Sharing in Prefabricated Component Supply Chain	Du, J., et al.	2017	information tracking and supply mechanism	RFID, multi-agent simulation
RFID Enabled Knowledge-Based Precast Construction Supply Chain	Wang, Z. J., et al.	2017	benefits of RFID application in supply chain	RFID, simulation, comparative analysis
Prefabricated construction enabled by the Internet-of-Things	Zhong, R. Y., et al.	2017	real-time information tracking	BIM, internet of thing (IoT)
An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction	Li, C. Z., et al.	2018	real-time information tracking	BIM, internet of thing (IoT)
Greenhouse gas emission monitoring system for manufacturing prefabricated components	Tao, X. Y., et al.	2018	carbon emission monitoring	internet of thing (IoT)
Cloud asset-enabled integrated IoT platform for lean prefabricated construction	Xu, G. Y., et al.	2018	material management	internet of thing (IoT)
Cloud-based fleet management for prefabrication transportation	Xu, G. Y., et al.	2019	real-time information information sharing	cloud model, internet of thing (IoT)
Development of Intelligent Prefabs Using IoT Technology to Improve the Performance of Prefabricated Construction Projects	Zhao, L. L., et al.	2019	tracking prefabricated component	RFID, Long Range (LoRa) technologies, BIM, cloud computing
Design of Tracking System for Prefabricated Building Components using RFID Technology and CAD Model	Naranje, V., et al.	2019	tracking prefabricated component	RFID, BIM, CAD
Blockchain-based framework for improving supply chain traceability and information sharing in precast construction	Wang, Z. J., et al.	2020	supply chain real-time information	blockchain-based information management framework

IoT-Based Intelligent Construction System for Prefabricated Buildings: Study of Operating Mechanism and Implementation in China	Wang, X. T., et al.	2020	information integration and interaction	internet of thing (IoT)
Supply Chain Management for Prefabricated Building Projects in Hong Kong	Luo, L. Z., et al.	2020	supply chain real-time information	automated data collection technologies
Digital Twin for Supply Chain Coordination in Modular Construction	Lee, D. and Lee, S.	2021	Real-time logistics simulation	digital twin, BIM, internet of thing (IoT)
A blockchain- and IoT-based smart product-service system for the sustainability of prefabricated housing construction	Li, C. Z., et al.	2021	supply chain sustainability	blockchain, internet of thing (IoT)
Digital twin-enabled smart modular integrated construction system for on-site assembly	Jiang, Y. S., et al.	2022	assembly phase monitoring	digital twin
A Framework for Prefabricated Component Hoisting Management Systems Based on Digital Twin Technology.	Zhao, Y. H., et al	2022	assembly phase monitoring	digital twin

Table 12 Research on Modern Construction Technology

Title	Author	Year	Research topics	Research methods or tools
A methodology for the optimal modularization of building design	Isaac, S., et al.	2016	prefabricated component design	graph-based methodology, clustering algorithm, BIM
Exterior prefabricated panelized walls platform optimization	Said, H. M., et al.	2017	prefabricated component design	non-dominated sorting genetic algorithm (NSGA)
Automated crane planning and optimization for modular construction	Taghaddos, H., et al.	2018	crane operation	mathematical and numerical algorithms
RESEARCH ON ASSEMBLY SEQUENCE PLANNING AND OPTIMIZATION OF PRECAST CONCRETE BUILDINGS	Wang, Y., et al.	2018	prefabricated component assembly sequence	BIM, Improved Genetic Algorithm (IGA)
A BIM-based automation of design and drafting for manufacturing of wood panels for modular residential buildings	Alwisy, A., et al.	2019	shop drawing design	CAD, BIM
Optimum design for unbonded posttensioned precast concrete frames with damping	Chen, Y., et al.	2020	prefabricated component design	Genetic Algorithm (GA)
Smart work packaging-enabled constraint-free path re-planning for tower crane in prefabricated products assembly process	Li, X., et al.	2020	crane path planning	Smart Work Packaging (SWP)
Efficient structural design of a prefab concrete connection by using artificial neural networks	Navarro-Rubio, J., et al	2020	prefabricated component design	Artificial Neural Networks (ANNs)
Virtual prototyping- and transfer learning-enabled module detection for modular integrated construction	Zheng, Z., et al.	2020	construction monitoring	virtual prototyping, transfer-learning techniques, convolutional neural network
Vision-based framework for automatic progress monitoring of precast walls by using surveillance videos during the construction phase	Wang, Z., et al.	2021	construction monitoring	computer vision methods, BIM

Table 13 Top ten articles with cited frequency

Title	Author	Year	Journal	Cited frequency
Schedule risks in prefabrication housing production in Hong Kong: a social network analysis	Li, C. Z., et al.	2016	*J of Cleaner Production*	113
Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated prefabricated components.	Demiralp, G., et al.	2012	*Automation in Construction*	59
Blockchain-based framework for improving supply chain traceability and information sharing in precast construction	Wang, Z. J., et al.	2020	*Automation in Construction*	55
Stakeholder-Associated Supply Chain Risks and Their Interactions in a Prefabricated Building Project in Hong Kong	Luo, L. Z., et al.	2019	*J of Management in Engineering*	55
Optimal logistics planning for modular construction using two-stage stochastic programming	Hsu, P. Y., et al.	2018	*Automation in Construction*	42
Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction	Arashpour, M., et al.	2017	*Automation in Construction*	39
Supply-chain transparency within industrialized construction projects	Cus-Babic, N., et al.	2014	*Computers in Industry*	39
Linking product modularity to supply chain integration in the construction and shipbuilding industries	Margherita, P., et al.	2015	*International J of Production Economics*	36
Production lead-time hedging and coordination in prefabricated construction supply chain management	Zhai, Y., et al.	2017	*International J of Production Research*	35
Improved Precast Production-Scheduling Model Considering the Whole Supply Chain	Wang, Z. J. and H. Hu	2017	*J of Computing in Civil Engineering*	34

Table 14 The main research methods adopted

Topics / Methods	Logistics and Transportation	Inventory Planning	Supply Chain Costs	Delivery and Scheduling	Risk and Resiliency	Real-time Information	Modern Construction Technology
Mathematical modeling	3	3	4		3		
Genetic algorithm	1			4			3
Optimization	1		1	2			
Game theory		3	2				
System dynamics			1		3		
Social network analysis			1		3		
RFID				1		6	
BIM				1	1	9	4
IoT						10	

Table 15 Research trends in terms of different topics

Topic / Years	Logistics and Transportation	Inventory Planning	Supply Chain Costs	Delivery and Scheduling	Risk and Resiliency	Real-time Information	Modern Construction Technology
2007						1	
2008							
2009							
2010							
2011							
2012			1			2	
2013			1				
2014						2	
2015						1	
2016	2		2		1	2	1
2017		2	1	1	1	4	1
2018	2	2	1	3	3	3	2
2019	1	3	1	2	3	3	1
2020	1			4		2	4
2021			2	1	5	3	1
2022				1		2	
Total	6	7	9	12	13	25	10

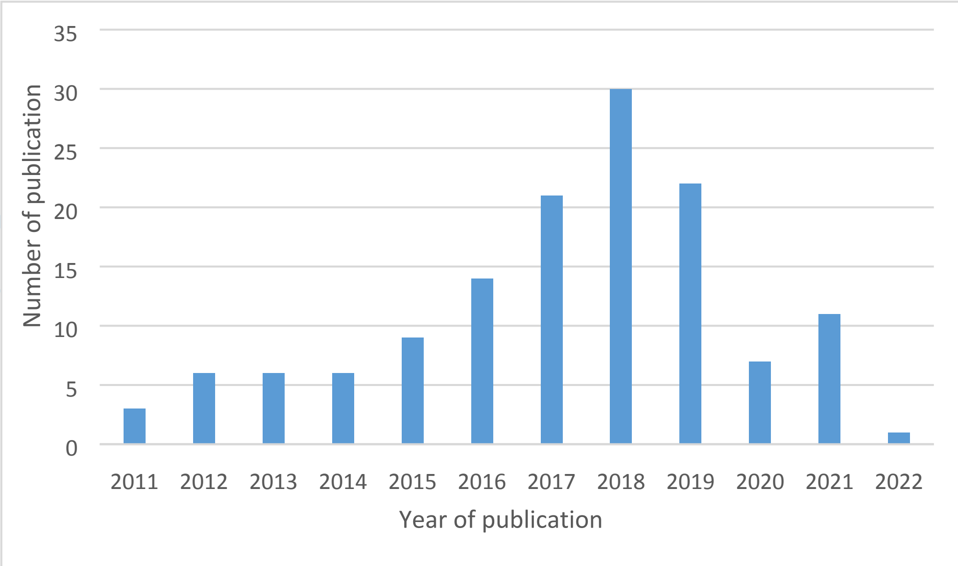

Figure 1 Trends of publications in prefabricated construction supply chain

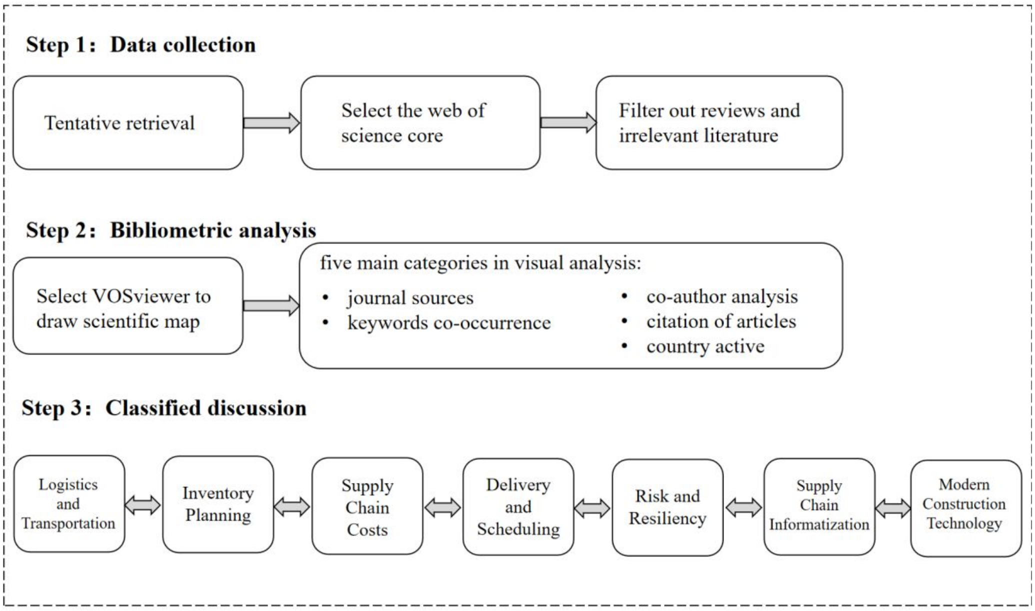

Figure 2 Overall framework and process of this research

Figure 3: Analysis of Publication Sources (Scientific Journal Outlets)

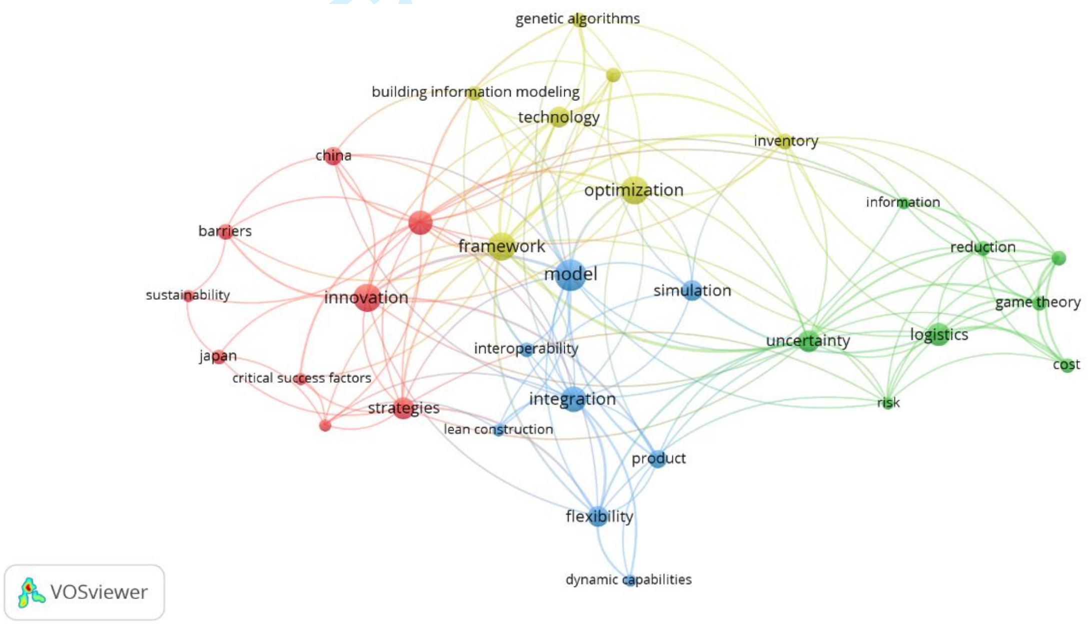

Figure 4: Analysis of Keyword Co-occurrence

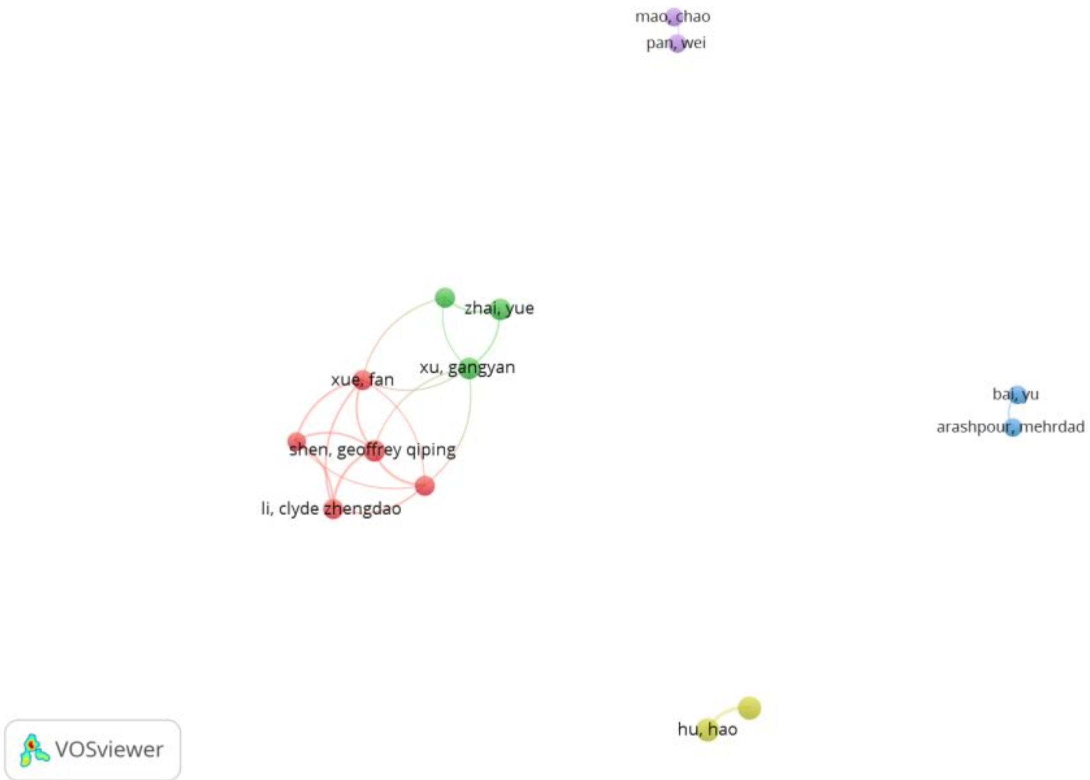

Figure 5: Co-authorship Analysis

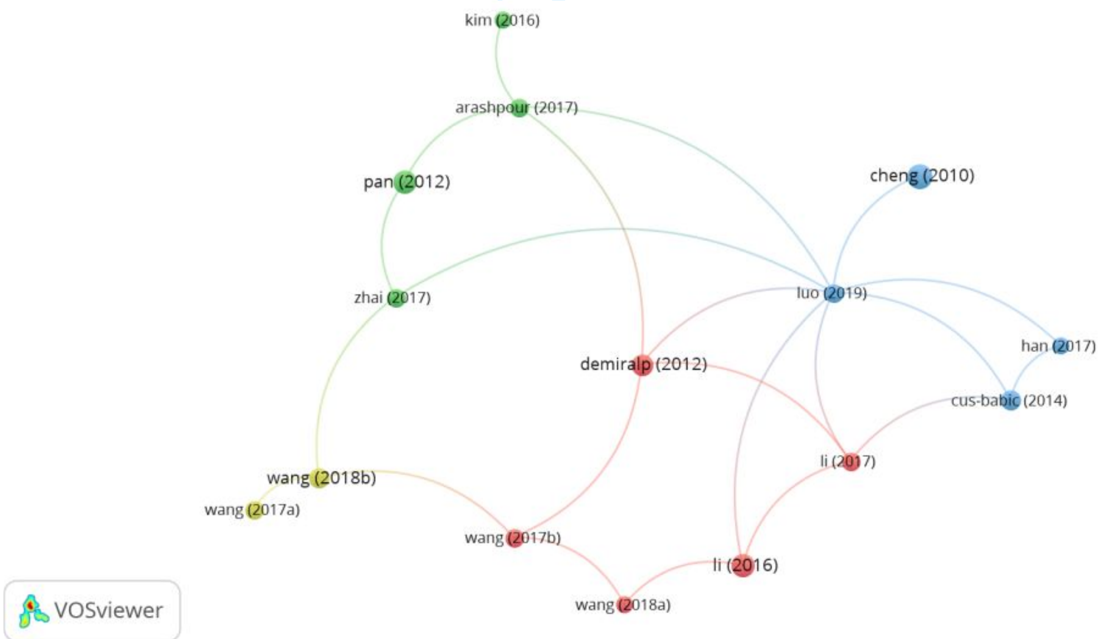

Figure 6: Authorship Citation Analysis

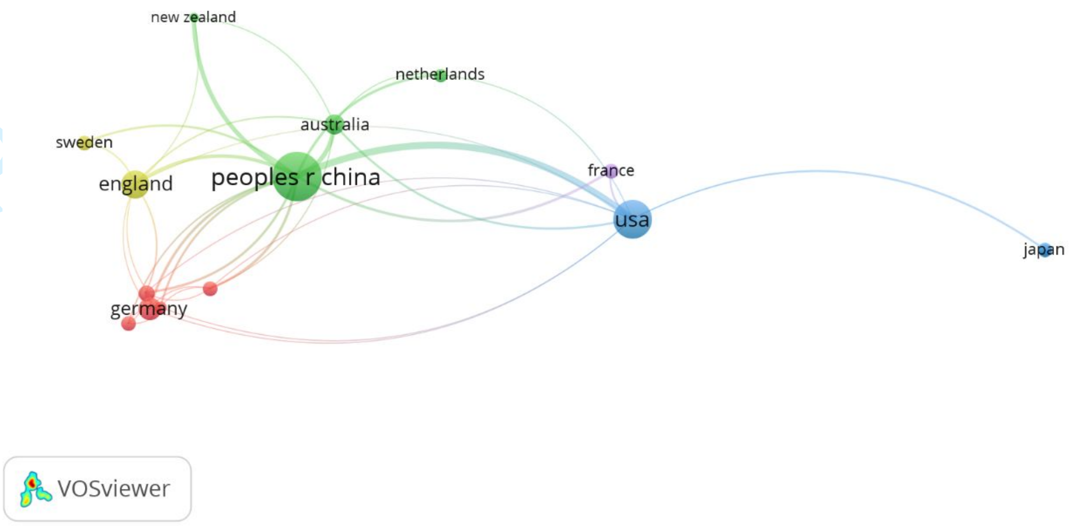

Figure 7: Analysis of Country Active