A Conceptual Development Framework for Prefabricated Construction Supply Chain Management: An Integrated Overview

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Received: 6 January 2020; Accepted: 28 February 2020; Published: 2 March 2020

Abstract: Prefabricated construction (PC), with the characteristics of green, environmentally friendly, energy saving and high production efficiency, is attracting more and more attention from all over the world. Supply chain management is closely related to the application efficiency of PC, but only in the last three years has this interdisciplinary research received due attention. The prefabricated construction supply chain management (PCSCM) have not received enough attention. Especially recently, the related literature shows explosive growth. This paper adopted the method of systematic literature review through the tool of bibliometric statistics. And we reviewed 152 articles from 2001 to 2018, with the goal of understanding the current situation, trends, and gaps in PCSCM research, and a framework is proposed to promote its development. First, the study discussed the four themes of clustering, concentrating mainly on strategic research and project evaluation, PC supply chain process design and optimization, supply chain integration and management, and the application of advanced technology. Then, the research gaps and conceptual development framework to promote PCSCM were reported. Only through the coordinated development of technology, market circumstances, and decision-making level of participants, can the PCSC form an integrated whole, so as to optimize the efficiency and sustainability of prefabricated construction industry and improve its level.

Keywords: Prefabricated construction; supply chain management; literature review; bibliometric analysis; thematic analysis; conceptual framework

1. Introduction

The traditional construction method is slow and inefficient, which brings great burden to the environment (e.g., visual intrusion, air pollution, waste pollution), social welfare (e.g., noise, public health), and sustainable development [1]. More than 40% of solid wastes are construction and demolition waste [2] and dust pollution seriously affects the living quality of residents near the construction site [3]. Obviously, the traditional construction method has brought great troubles to social development and human living quality.

The strong interaction between prefabricated construction (PC) and sustainable development has aroused widespread social concern. PC, a sustainable construction method, has the advantages of green, environmentally friendly, energy saving, and high production efficiency compared with on-site construction [4], and represents a new direction and way for the construction industry to cope with the serious environmental pollution and shortage of social resources [5]. Prefabricated construction supply chain management (PCSCM) is an important way for PC to improve production efficiency and competitiveness, achieve cost and schedule control and energy conservation [6]. PCSCM is a process of planning, organizing, coordinating and controlling the product flow, information flow, capital flow and...
decision flow of prefabricated components, which integrates the whole process of ordering, production, transportation, and assembly with advanced technology [7]. Improper transportation and storage of components, untimely progress control and inconvenient information transmission have made PCSCM the key factors restricting the promotion and development of PC [8].

The development of manufacturing supply chain management has been relatively perfect, while prefabricated construction supply chain management has not received a lot of attention until recent years. They are fundamentally different from each other [9]. For example, in technological coherence, concrete pouring and maintenance during the production of prefabricated components must be completed continuously without interruption [10]; in the transportation process, prefabricated components are of larger size, which have certain requirements for the transportation vehicles [11]; in the assembly process, prefabricated components are installed in accordance with the construction schedule [12]. Moreover, PCSCM has a large number of participants with different demand. Due to the advance of prefabricated construction design and the separation between off-site production and on-site installation, higher requirements are put forward for the coordination and management ability of the participants [13].

From several important literature reviews in PC field, it can be found that PCSCM plays an irreplaceable role in promoting the success of PC project [14]. However, there is no independent complete literature systemically evaluate the nature, influence, contribution and existing problems of PCSCM. To bridge these gaps, the study attempts to conduct a systematic literature review through the tool of bibliometric statistics to determine the status, trends, priorities and gaps of PCSCM. This paper aims to analyze three problems existing in PCSCM: (i) Key research topics of PCSCM; (ii) Research gaps and agendas; and (iii) Further obtain a research framework of promoting PCSCM. Strengthening the practical application of technology and the standardization of the market environment is the basis to promote the implementation of PCSCM. The decision optimization of participants based on the integration of the industrial chain can further optimize the PCSC efficiency. Only through the coordinated development of technology, market circumstances, and decision-making level of participants, can the PCSC form an integrated whole, so as to optimize the efficiency and sustainability of prefabricated construction industry and improve its level. The findings contribute to the acquisition of academic knowledge, research frontiers and emerging trends about PCSCM research, and promote the sustainable development of the PC industry.

2. A Brief Review of PC Research

The whole process of PC, first defined by United Nations Department of Economic and Social Affairs in 1974, includes manufacturing and pre-assembling a certain number of building components, modules and components, and shipping them to the construction site for installation [15]. The biggest difference between PC and traditional site construction is that the process and scope of construction management extend to the production source of components. The supply process which was not so important to the site construction has become the key work of PC. A lot of research has promoted the implementation and promotion of PC. Several literature reviews summarize and analyze the development and research trend of PC, focusing on the construction and production technology, as listed in Table 1.
Table 1. Previous literature reviews.

| Authors                     | Object of Study | Article Number | Topics                                                                 |
|-----------------------------|-----------------|----------------|----------------------------------------------------------------------|
| Li et al. (2014) [1]        | PC Management   | 100            | Industry prospect; environment for technology application; design, production, transportation and assembly strategies; performance evaluation |
| Mostafa et al. (2015) [2]   | Offsite construction | 62            | Offsite barriers and drivers; the integration of lean and agile principles; simulation The performance of modular prefab considering acoustic constrain, thermal behavior, energy consumption; life cycle analysis |
| Boafo et al. (2016) [3]     | Modular prefab   | 146            | The performance of modular prefab considering acoustic constrain, thermal behavior, energy consumption; life cycle analysis |
| Kamali & Hewage (2016) [16] | Modular construction | 104        | Sustainability dimensions assessment (i.e., environmental, economic, and social) |
| Hosseini et al. (2018) [17] | Offsite construction | 501        | The product and technology of off-site construction |
| Jin et al. (2014) [18]      | Offsite construction | 349        | Management practices; process; product; performance; research method; technology |

From Table 1, four main aspects of PC research can be summarized.

1. **Performance and construction technology of prefabricated components.**

   Compared to site construction, PC has the advantages of lower safety hazard, higher production efficiency, lower cost and higher energy saving [19]. The production and installation technology of prefabricated components is quite mature [20]. Modular and standardized component design is basically realized [21]. Bearing capacity, rigidity, ductility, waterproofness, and the construction technology of connection points of prefabricated components are the mainstream of research [22]. The seismic performance of connections still needs to be further studied [23].

2. **Prefabrication buildings and PC development obstacles and drivers.**

   Generally speaking, PC has gained good market acceptance. Policies and regulations, technological innovation, industrial layout and other aspects all show the market potential and driving force of PC. However, the application of PC is still subject to local government policy preferences [24], high upfront investment [1], a lack of highly skilled workers [2], and insufficient transportation supply capacity [25], leading some to argue that PC is not the best choice despite its good performance.

3. **The implementation management of PC.**

   Many researches focus on the life cycle management of prefabricated construction, and systematically study the prefabricated buildings from the aspects of organizational mode [26], contract management [27], and cooperative innovation [28]. Although the PC technology has been developed relatively recently, its actual performance does not have a significant advantage over the traditional building, which is largely related to its weak organizational coordination and management ability in the implementation [29].

4. **Transportation and Supply chain management.**

   Koskela et al. (1990) [30] have long proposed the concept of supply chain management for a long time. Until the last three years, this interdisciplinary research has received its due attention in the PC field. However, in practice, the transportation of PC components still adopts the extensive mode of traditional construction industry [31]. The resulting delays, component damage, and cost overruns have seriously affected PC performance and people’s evaluation [32].

   Research on PCSCM can be divided into three levels: strategic analysis, supply chain optimization, and specific link design, which will be discussed at length in subsequent sections. Nevertheless, the research on PCSCM cannot meet the demand of market implementation on the whole. No article has summarized the research status quo to analyze the gap between theory and practice. Therefore, with
the use of scientometrics technology, this study attempts to systematically review the present situation, trends and gaps of PCSCM, and to build a framework to promote PCSCM.

3. Method

The method of the systematic literature review through the tool of bibliometric statistics is an effective way to identify, examine and evaluate all relevant literature on a particular research topic at an early stage [33]. Bibliometric statistics refers to replacing manually coded articles with bibliometric analysis software (e.g., VOS Viewer and Citespace), which can visually display the statistical results of journals, cited literatures, and keywords, so as to facilitate researchers to understand the research status [34]. Systematic review is a basic and critical method for condensing topics, discovering research gaps, and building knowledge frameworks [35]. The combination of the two can effectively avoid the common subjectivity and unreliability in literature review.

The research framework is shown in Figure 1. In the step 1, a comprehensive literature search and descriptive statistics were made. Based on the statistical results, the four research topics were discussed in the second phase. Finally, a research framework to promote the development of PCSCM is proposed.

The first step is data collection, including the data collection process and descriptive statistics of the literature. Through bibliometric software, the general situation of the research field can be summarized. For example, journal analysis can identify missing areas of research, and keyword analysis can help identify research focus. The bibliometric software used in this paper is VOS Viewer. VOS Viewer is more suitable for visualization of large networks than other text mining tools [36]. The data can be imported directly into it to generate the literature network [37] and create a network map, with the distance between nodes indicating how close they are [38].

The second step is thematic discussion. Based on the clustering results of bibliometric software, the author browsed the whole literature to ensure the accuracy and reliability of the clustering, four
topics in the current research field of PCSCM were summarized, including (1) strategic research and overall design, (2) PC supply chain process design and optimization, (3) supply chain integration and management, and (4) the application of advanced technology.

Finally, a conceptual development framework for PCSCM is proposed. Combined with the systematic review, the framework consists of three parts: technology base, market circumstances and decisions of main participants. The coordinated development of technology, market circumstances and decisions of main participants can promote the integration of supply chain to optimize the efficiency and sustainability of PC industry.

4. Data Collection

4.1. Data collection Process

There are three steps in data collection process, which follows Meho (2008) [39], as shown in Figure 2.

Step1: Select the database. Scopus was chosen as the primary retrieval database for this review. Scopus is the world’s largest database of abstracts and citations of peer-reviewed research literature [39]. And the databases of previous reviews in the theme of PC and SCM have been summarized in Table 2. To ensure the integrity of retrieval results, Elsevier, Web of Science (WoS) core, Emerald, and EBSCO Host are added as additional databases.

Step2: Data retrieval. Keywords of PCSCM were chosen based on the systematic review of these previous papers of PCSCM definitions which is presented in Table 2 [17]. 516 initial records were obtained using the retrieval syntax in Figure 2. Search in the “Title/Abstract/Keywords” field. There was no limit to the publication, and the date range was set to “all years to the present”. The earliest record retrieved was published in 2001.

Step3: Literature screening and supplement. Some inclusion/exclusion criteria still need to be set to ensure the accuracy of the retrieval results. First, the initial retrieved records were imported into software EndNote X8 to filter duplicates. Next, the following two types of articles were deleted, a) articles that were clearly unrelated to PCSCM (e.g., finance, medicine, manufacturing); b) articles in a wide range of categories as “editorial”, “book review”, “discussion and conclusion”, “letters” and “newspaper articles”. Then, a backward search (cross-referencing) was performed in the references to avoid missing important references. Finally, 152 qualified articles were screened out, as shown in the Appendix A Table A1.

Table 2. Databases and keywords of previous reviews.

| Theme          | Authors | Databases | Keywords                                                                 |
|----------------|---------|-----------|--------------------------------------------------------------------------|
| Construction   | Hosseini | Scopus    | “off site” or “onsite” or “tilt up” or “prefabricated” or “modular” or   |
|                | et al.  |           | “industrialized” or “prefabricated” or “modular” or “penalized”) and      |
|                |         |           | (“supply chain” or “supply network” or “industrial chain” or “logistics”)|
|                |         |           | and (“construction” or “building” or “housing”) |
|                |         |           | AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)                   |
|                |         |           | A backward search (cross-referencing) was performed in the references to avoid missing important references |
Additionally, the papers on supply chain management/prefabrication/construction in broad sense were not directly adopted because the focus of this work is on PCSCM rather than the broad field it covers. Nevertheless, views from these areas might be used to strengthen the analysis, although the papers might not be included in the literature review portfolio.

Table 2. Databases and keywords of previous reviews.

| Theme                  | Authors                      | Databases       | Keywords                                                                 |
|------------------------|-----------------------------|-----------------|--------------------------------------------------------------------------|
| Prefabricated construction | Li et al. (2014) [1]        | Scopus          | “prefabrication”, “prefabricated construction/building”, “off-site construction”, “industrialized building/housing”, “modular construction/building” |
|                        | Mostafa et al. (2016) [2]   | Scopus, Emerald, Elsevier | “industrialized building”, “off-site building”, “penalized construction”, “offsite construction”, “prefabricated construction” |
|                        | Hosseini et al. (2018) [17] | Scopus          | “Off-site construction” OR “Off-site building” OR “Prefabricated construction” OR “Industrialized building” OR “Panelized construction” OR “Modular construction” OR “Tilt up construction” OR “Precast” OR “Offsite construction” OR “Precast construction” OR “Tilt-up construction” |
| Supply chain management | Fahimnia et al. (2015) [40] | Scopus          | “Supply Chain Management” OR “Industrial Chain Management”               |
|                        | Nguyen et al. (2017) [41]   | Elsevier, Emerald, Scopus, and EBSCO | “Supply Chain Management” OR “Logistics”                                 |

Figure 3 shows the annual number of publications from 2001 to 2018. Through simple statistical analysis, it can be found that the research on PCSCM has been growing rapidly in recent years, with the number of papers in 2018 reaching 37.

Figure 3. Yearly publications from 2001 to 2018.

4.2. Descriptive Statistics of the Reviewed Literature

4.2.1. The Cross-Journal Publication Distribution Experiment

The results of the cross-journal publication distribution experiment can reflect the contributions of each journal to the PCSCM field to some extent. Under the selection criteria of the minimum publication quantity and citations of 3 and 10 articles respectively, the top 10 of 38 journals included in our literature review portfolio are shown in Figure 4. The node size and font size of the journal name increase with the number of publications published in the journal. The lighter the color, the closer
the year of the article published. The thickness of the link between nodes indicates the frequency of references between two journals.

![Figure 4. Publication Distribution across Journals in PCSCM.](image)

Table 3 details the total link strength, number of articles, total citations, average publication years, average citations and average normalized citations. The first three of them are usually highly correlated, and are used as quantitative indicators to measure the productivity of journals. Average citations and average normalized citations are taken as qualitative indicators to measure the impact of the journal. In terms of the publications number, Automation in Construction, Journal of Construction Engineering and Management, Journal of Cleaner Production, and Sustainability are the top four Journals. It also can be found that the most influential journal is Automation in Construction in the field due to its high average of normalized citations.

| Source                        | Total Link Strength | Number of Articles | Total Citations | Avg. Pub. Year | Avg. Citations | Avg. Norm. Citations |
|-------------------------------|--------------------|--------------------|-----------------|----------------|----------------|---------------------|
| Automat. Constr.             | 70                 | 26                 | 462             | 2014           | 18             | 1.28                |
| J. Constr. Eng. M. ASCE      | 37                 | 8                  | 141             | 2011           | 18             | 0.72                |
| Cleaner Prod.                | 31                 | 10                 | 78              | 2017           | 8              | 2.22                |
| Sustainability               | 25                 | 6                  | 10              | 2017           | 1              | 0.72                |
| Can. J. Civ. Eng.            | 24                 | 6                  | 33              | 2013           | 7              | 0.44                |
| Expert Syst. Appl.           | 19                 | 4                  | 39              | 2011           | 20             | 1.01                |
| J. Comput. Civ. Eng.         | 16                 | 4                  | 31              | 2010           | 16             | 1.25                |
| Int. J. Prod. Res.           | 13                 | 3                  | 11              | 2016           | 4              | 0.59                |
| J. Civ. Eng. M.              | 10                 | 3                  | 24              | 2012           | 8              | 0.51                |
| KSCE J. Civ. Eng.            | 5                  | 3                  | 21              | 2018           | 11             | 0.99                |

It can be found that as a cross-disciplinary subject, PCSCM’s influential journals mostly belong to management field (e.g., engineering management and environmental management), while civil engineering field pays little attention to this topic [42]. The research on SCM based on the characteristics of civil engineering should be strengthened later.
4.2.2. Citation of Articles

According to the citation statistics of SCOPUS database, the top ten papers are shown in Table 4 with citation number ranges from 36 to 103. Specifically, the top three of citations are \[32,43\] and \[44\], which are cited 103, 58, and 54 times respectively.

| Author                | Title                                                                 | Year | Citations |
|-----------------------|-----------------------------------------------------------------------|------|-----------|
| Ergen & Akinci [32]   | Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and gprs | 2007 | 103       |
| Yin et al. [43]       | Developing a precast production management system using rfid technology | 2009 | 58        |
| Chen et al. [44]      | Decision support for construction method selection in concrete buildings: prefabrication adoption and optimization | 2010 | 54        |
| Bankvall et al. [45]  | Life-cycle data management of engineered-to-order components using radio frequency identification | 2010 | 50        |
| Ergen et al. [46]     | Strategies for Integrating the Use of Off-Site Production Technologies in House Building | 2012 | 44        |
| Pan et al. [47]       | Life cycle design and prefabrication in buildings: a review and case studies in hong kong | 2014 | 43        |
| Jaillon & Poon [48]   | Just-in-time management of precast concrete components                 | 2001 | 42        |
| Pheng et al. [49]     | Constraint programming approach to-precast production scheduling      | 2002 | 40        |
| Chan et al. [50]      | GA-based resource-constrained flow-shop scheduling model for mixed precast production | 2002 | 36        |

Ergen and Akinci (2007) [32] innovatively integrated RFID into PCSCM, effectively avoiding construction delay and labor cost increase caused by repeated processing, parts dislocation and incorrect installation. Yin et al. (2009) [43] built a precast production management system combined Personal Digital Assistant (PDA) and RFID, which solved the difficulties of data storage and record audit, avoided repeated data entry and facilitated immediate feedback. Chen et al. (2010) [44] proposed a transparent construction method selection model (CMSM) to assist scientific prefabrication decisions.

The three papers all focus on the combination of modern information technology (e.g., RFID, PDA) and PCSCM, so as to achieve the purpose of reducing cost, shortening construction period and improving work efficiency. It shows that the application of advanced information technology and supply chain efficiency are the focus of PCSCM.

4.2.3. Keywords Co-Occurrence Experiment

Keywords reflect not only the core themes of the literature, but also the main content of a particular field [18]. So, through the keyword co-occurrence experiment, the focus of current PSCSM field can be found. There are two kinds of keywords in VOS Viewer: (i) the initial keywords provided by the author, and (ii) added keywords based on journal, title, abstract and other data. The frequency of co-occurrence of two keywords is taken as the link strength between them [52]. Among the 536 keywords in all literatures, 61 met the setting condition of the minimum link strength of 3. Then, combine the synonyms, such as “BIM” and “building information modeling”, and omit general terms such as “prefabrication”, “supply chain” and “management”. Finally, PCSCM research topic relational network is generated as shown in Figure 5, which contains 24 nodes and 132 links.
Based on the frequency and co-occurrence probability of keywords, the 24 keywords shown were further divided into clusters with different node colors by VOS Viewer, which has been practiced in many literatures [18]. For example, as shown in Figure 5, yellow node cluster includes RFID, BIM and technology, etc. Keyword co-occurrence analysis is only to obtain the general topic and classification of PCSCM. Whether the topic matches the literature it includes is further modified after the authors browse the full text, as shown in Table 5. By browsing the full text of literature within each cluster, adjusting the inaccurate and inappropriate classification, extracting the keyword commonality of each classification, and naming the cluster as:

1) Strategic research and overall design (red nodes): focus on the integrated management and sustainability performance evaluation of the whole process of PC management. Much of the research is based on the China case.

2) PC supply chain process design and optimization (green nodes): focus on the modeling and simulation [53] of the four main parts of PCSCM: ordering [54], manufacturing [55], transportation and installation [56]. Genetic algorithm is the most commonly used algorithm.

3) Supply chain integration and management (blue nodes): focus on the internal integration and external integration. The former aims to improve the interests of all stakeholders, while the latter focuses on the cooperation and communication [57]. Much of the research is based on the Hong Kong case.

4) Application of advanced technology (yellow nodes): focus on adopting advanced technologies, including BIM, RFID, and lean, etc., to solve highly decentralized PCSCM problems [58] and optimize the efficiency of the supply chain [59].

Table 5 further summarizes the quantitative measurement of keywords. Construction management, optimization, and performance have the highest link strength, reflecting the overall focus of the study. The number of keyword occurrence is similar to the ranking of link strength. According to the average publication year, BIM, internet, information, and sustainability seem to be emerging keywords, which shows the importance and necessity of the application of advanced technology and sustainability. In contrast, although there are many researches on the design and optimization of PCSCM route based on genetic algorithm, the popularity of it has decreased significantly. Tracking, BIM, and RFID show
prominent performance in the average normalized citations index, which further shows the degree of attention of advanced technology applications in PCSCM. A detailed thematic discussion is given in Section 6.

### Table 5. Summaries of most frequently studied keywords in PCSCM.

| Category                                           | Keyword                          | Link Strength | Occurrences | Avg. Pub. Year | Avg. Citations | Avg. Norm. Citations |
|----------------------------------------------------|----------------------------------|---------------|-------------|----------------|----------------|---------------------|
| **Strategic management**                           | Construction Management          | 43            | 21          | 2014           | 19             | 1.06                |
|                                                   | Barriers                         | 9             | 3           | 2017           | 8              | 0.86                |
|                                                   | Integration                      | 19            | 8           | 2015           | 10             | 0.49                |
|                                                   | Sustainability                   | 11            | 3           | 2018           | 1              | 1.21                |
|                                                   | China                            | 28            | 10          | 2017           | 11             | 1.19                |
|                                                   | Innovation                       | 17            | 7           | 2015           | 14             | 1.02                |
| **Route design and optimization in PCSCM**         | Model                            | 32            | 19          | 2016           | 10             | 1.39                |
|                                                   | Simulation                       | 27            | 12          | 2014           | 9              | 1.06                |
|                                                   | Optimization                     | 43            | 18          | 2016           | 6              | 0.9                 |
|                                                   | Genetic algorithm                | 29            | 16          | 2013           | 11             | 0.87                |
|                                                   | Scheduling                       | 12            | 4           | 2010           | 16             | 0.7                 |
|                                                   | Productivity                     | 12            | 4           | 2011           | 15             | 0.69                |
| **Supply chain integration and management**        | Project Management               | 7             | 4           | 2016           | 9              | 0.89                |
|                                                   | Design                           | 32            | 10          | 2015           | 9              | 0.81                |
|                                                   | Inventory                        | 10            | 6           | 2014           | 5              | 0.46                |
|                                                   | Information                      | 9             | 3           | 2018           | 2              | 0.69                |
|                                                   | Hong Kong                        | 40            | 20          | 2017           | 10             | 1.25                |
|                                                   | Performance                      | 37            | 12          | 2016           | 7              | 0.73                |
| **Application of advanced technology**             | Lean construction               | 14            | 5           | 2017           | 3              | 0.51                |
|                                                   | RFID                             | 20            | 11          | 2013           | 24             | 1.24                |
|                                                   | Technology                       | 19            | 6           | 2017           | 3              | 1.08                |
|                                                   | BIM                              | 18            | 7           | 2017           | 8              | 1.46                |
|                                                   | Internet                         | 12            | 3           | 2018           | 2              | 0.79                |
|                                                   | Tracking                         | 7             | 4           | 2015           | 30             | 2.26                |

5. **Thematic Discussion**

Based on the results of scientometrics analysis, we further divided the four important directions of current research (Table 5) into the management and technical levels shown in Figure 6 for discussion. Obviously, the management level includes (1) strategic research and overall design, and (2) supply chain integration and management, while the technical level includes (3) supply chain process design and optimization, and (4) the application of advanced technology. Then, according to the convention, this study proposed the research gap and the future research direction. Finally, an innovative and reasonable framework was constructed to promote the development of PCSCM.

At the management level, it is necessary to clarify the obstacles and driving factors of all enterprises in the SC, and then optimize their cooperation mode and information exchange mode, so as to promote the implementation of the SC from the perspective of overall benefit maximization. In implementation level, under the guidance of the management philosophy of overall benefit maximization, all enterprises optimize the supply chain process through the application of advanced technologies to achieve economic and sustainable goals. In general, the optimization of management is the basis for the optimization of implementation, and the optimization of implementation is the driving force for the optimization of management. Only if the two develop together can PCSCM be efficient and sustainable.
which is reflected in every link of the supply chain, including the cost increase caused by the long decision-making time of the supply chain [24]. In addition, the lack of understanding of PCSCM [64] and complicated implementation processes [65] are also important factors hindering the advancement of PC [66]. Definitively, PCSCM is driven by many obvious factors, such as sustainable competitive advantage [67] and favorable policy environment [68], technological innovation [14], and diversified market demand [69].

5.1. Strategic Research and Project Evaluation

In general, the development of PC is still a long way from large-scale application [25]. Regional industrial layout and enterprise level strategic research still cannot meet the needs of market development [60]. Although as the main body of the project management the enterprises or projects are aware of the importance of supply chain management, and most of the innovative management modes developed were still centered on the construction and installation management on the site, instead of substantially extending to the whole supply chain [61]. Market awareness and the acceptance of PC is still insufficient [62]. The market almost passively accepts the government’s policy regulation and has not been able to actively participate in the strategic planning of PCSCM development [63]. The research level also focuses on three core issues in the process of promoting the development of PCSCM and market cognition: obstacles and drivers, sustainable performance evaluation, and risk evaluation.

5.1.1. Obstacles and Drivers

Compared with conventional techniques, cost is the main obstacle to the adoption of PC, which is reflected in every link of the supply chain, including the cost increase caused by the long decision-making time of the supply chain [24]. In addition, the lack of understanding of PCSCM [64] and complicated implementation processes [65] are also important factors hindering the advancement of PC [66]. Definitively, PCSCM is driven by many obvious factors, such as sustainable competitive advantage [67] and favorable policy environment [68], technological innovation [14], and diversified market demand [69].

5.1.2. Sustainable Performance Evaluation

Sustainable performance evaluation mainly includes environmental performance, economic performance, and social performance [70]. In terms of economic performance, the implementation of effective supply chain management on prefabricated projects can increase enterprise profits by nearly 40% [71]. For environmental performance, PC itself has better life cycle performance in energy performance [72]. Effective integration of PCSCM has more significant social effects, such as reducing labor consumption and energy conservation. In a word, the considerable sustainable performance of PCSCM is the main reason why it is favored by the government and the market.

5.1.3. Risk Evaluation

Risks in the whole PCSCM are diverse, dynamic, uncertain, and interactive [73]. Due to the complexity of the supply process, schedule risk is recognized as the most important and should be
Supply chain integration and management includes external integration and internal integration, as shown in Figure 7. External integration of supply chain management ensures real-time information exchange among all participants by looking for effective cross-organization cooperation mode, and realizes the sharing of market demand, inventory status, production plan, demand forecast, and delivery plan. The advantages of external integration of supply chains have been widely proven in the manufacturing and logistics industries, which promotes sustainable economic development by strengthening cooperation among enterprises. For PCSCM, no matter in research or practice, enterprises are still trying to improve their own interests through internal integration [77], but ignore the overall interests of the supply chain.

5.2.1. Internal Integration

Supply chain participants improve construction profit through self-integration within the enterprise [78]. Production plan [79], purchasing decision [80], and supplier selection [81] are the core issues of internal integration. Operations research is the main research method to deal with the complexity of internal integrated management decision-making, accounting for about 70% of the research methods in this part of the literature [82]. Among them, the traditional multi-objective optimization algorithm (e.g., constraint programming) accounts for 15% of the research methods, and the multi-objective genetic algorithm accounts for 45%. It can be seen that multi-objective genetic algorithm is the main research method in this field. It is necessary for the supplier to develop an appropriate inventory management plan of prefabricated components for the delivery requirements of multiple contractors [83]. In contrast, contractor procurement decision-making includes multi-component coordination and supplier relationship management [84]. Supplier selection affects the performance of PCSCM, and its evaluation criteria include procurement process, operational efficiency, relationship coordination, and strategic adjustment [85].
5.2.2. External Integration

External integration focuses on supply chain cooperation mode and information communication. The main purpose of the research on cooperation mode is mainly to design reasonable models of cost sharing [86], risk [87] and benefit distribution [88]. Game theory is an effective theory for dynamic analysis of supply chain participants’ cooperation and competition behavior, accounting for 60% of the research methods of cooperation mode module, including evolutionary game [89], comprehensive game, differential game [90] and so on. For example, [91] explored the factors influencing the formation and disintegration of a cooperative network. Information communication mainly uses advanced information technology to realize real-time communication, so as to reduce delay and waste and create the greatest common interests [92]. Supply chain integration ensures that all participants in the supply chain can transmit and obtain information in a timely manner, so as to better help each participant in the prefabricated construction achieve their profit objective, to achieve sustainable economic development.

5.3. Supply Chain Process Design and Optimization

PCSC is very different from traditional SC. PCSC is customized, and the total number of components matches the requirements of construction site, so there is no need to keep safety inventory [93]. The PC supply chain process design consists of four stages: ordering, manufacturing, transportation and assembly, as is shown in Figure 8. Simulation is mostly used in the process design to evaluate its effectiveness. The PC supply chain process optimization with time or cost as its objective is developing towards multi-objective optimization [94].

![Figure 8. Research framework of process design and optimization.](image)

5.3.1. PC Supply Chain Process Design Based on Simulation.

Dynamic simulation of PCSC process could help participants to predict the profit level under different behavioral decisions, so as to make rational decisions [95]. Wang et al. (2018) [94] proposed a simulation model for disturbance assessment to evaluate the uncertainty of PCSCM, which can prevent various disturbances in time and improve profits. In addition, simulation can effectively improve the professional quality of practitioners and their understanding of PCSC concepts and knowledge [96].

5.3.2. PC Supply Chain Process Optimization Based on Sustainability

The optimization method of PCSC has developed from traditional technology (e.g. linear programming and integer programming) [88] to modern technology (e.g., genetic algorithm, ant colony optimization and particle swarm optimization) [97]. Similarly, the optimization objective is gradually shifted from the traditional single objective, such as progress, to multi-objective optimization [98]. Among optimization goals, construction schedule is considered to be primary. Timely delivery of prefabricated components is the main bottleneck restricting project productivity. Delays may result in prolonged construction cycles and higher labour costs. But early delivery can also lead to additional storage costs and wasted space [99]. Based on the cost target, resource constraints such as molds [100], workers, inventory [101], and workspace [102] were integrated into the model to develop the production scheduling scheme with the lowest production cost. Supply chain process design and optimization is the best way to improve the production efficiency and competitiveness and realize cost control for
assembly construction suppliers and contractors. It should be noted that most of the current research belongs to the normative research, which is accounting for 70%, and the application of empirical analysis method and hybrid method needs to be further strengthened.

5.4. Application of Advanced Technology

The application of advanced technology runs through the whole process of PCSC, including information technology and management technology, which is presented in Figure 9. Management technology could reduce waste and improve efficiency to achieve optimal allocation of resources [70]. Information technology enables the real-time tracking and positioning of precast components and real-time communication between participants [82].

![Figure 9. Research framework of advanced technology](image)

5.4.1. Management Technology

Management technology mainly includes lean construction and agile construction. Wet construction in the traditional construction industry limits the promotion of lean construction [103]. However, lean construction is valued and promoted in PC because of the standardized design, factory-based parts and integrated information. The advantage of lean construction is that its strict production plan and process can effectively reduce waste and constantly improve the PC supply chain [104]. Agile principles are an important complement to lean concepts in PCSCM. The lean principle applies to stable conditions (stable requirements of quantity), while the PC is characterized by uncertainty (e.g. changes in demand) [105]. Therefore, it is necessary to supplement agile principles to reduce these uncertainties [106].

5.4.2. Information Technology

Information technology applied in PCSCM can be divided into the following four categories: mobile terminal devices (PDA, mobile phones, wearable equipment), mobile terminal enabling technology (RFID, GPS), access network (WLAN, Zigbee) and application service (AR/VR, cloud computing) [107]. The purpose of applying information technology is to promote the real-time acquisition and sharing of information among different stakeholders of PCSCM and reduce human error [108]. One research focus is the real-time tracking of prefabricated components or materials in the whole supply chain. For example, BIM and RFID-based prefabricated component management system can actively and accurately facilitate the collection and transmission of information related to material
storage and use, so as to timely adjust production objectives and plans [32]. The RANSAC model, an RFID-based optimal management system, can quickly and automatically screen a large amount of RFID data to obtain effective information [109], and provide the data to mobile terminal equipment (e.g., PDA) or mobile terminal enabling technology (e.g., GPS), so as to strengthen quality control and improve supply chain efficiency [43]. Another type of research focuses on rapid communication in supply chains. Such as, the 3D dynamic interaction model of mobile client based on virtual reality can promote the information exchange of the whole supply chain [110]. Cloud computing and BIM provide solutions for data sharing among the architecture, engineering, and construction (AEC) industries, which further reduces supply chain costs [111] and time [112]. Applying advanced technology to collect and process large amounts of data quickly and accurately can effectively reduce manpower and material resources, thus improving the quality, efficiency, and management level of prefabrication construction.

5.5. Research Gap and Future Research Direction

5.5.1. Collaborative PCSCM with Advanced Technology

Many advanced technologies have been applied in PCSCM, but they are still low-level applications. Fast and accurate processing of massive data in PCSCM, especially rich tacit knowledge and knowledge sharing of supply chain, achieving multi-technology integration and collaboration with the whole process of PCSCM, could effectively promote the reduction of cost and schedule of prefabricated construction. Big data and cloud computing, which are increasingly used in manufacturing SCM, may provide more efficient support for the construction industry supply chain management’s timely interaction with and tracking of prefabricated components.

5.5.2. Sustainable Cooperative Mode of PCSCM

The cooperation mode of supply chain and the contract system are the core problems of PCSCM. They reflect the complexity of supply chain marketing and construction contracts. Theoretical research and application are limited to the analysis of risk sharing model and other local relations [98]. Distributable benefits in the supply chain are not just profits. A benefit sharing model or contract terms should also adapt to the complex prefabricated construction supply chain environment and cooperation model, rather than adopt a certain paradigm. Therefore, an important research direction is to develop sustainable innovative PCSCM cooperation mode to optimize the costs, risks and benefits of each participant. Ultimately, win–win cooperation will be achieved.

5.5.3. Introducing Third-Party Logistics into PCSC

Third party logistics (TPL) refers to the contractor employ logistics professionals to manage all logistics activities. The employment of TPL helps to centralize the control and management of prefabricated components from multiple suppliers and avoid the inconsistencies caused by the producer’s separate responsibility for the transportation of their own products. But this will bring about a redistribution of responsibility and new coordination management problems. Integrating TPL into PCSCM can optimize delivery time and production cost. This creates a logistics management platform that allows suppliers and contractors to share information, thereby avoiding uncertainty and reducing operating and total supply costs. The application of TPL may be a new development direction in the outsourcing of PC, which is conducive to the improvement of efficiency and sustainability from the perspective of PCSCM.

5.5.4. Multi-Level Strategy Research based on Market Characteristics

The development of technology cannot be separated from the market characteristics and industrial level of the region. Most of the current studies take China and Hong Kong as the empirical background. It is obvious that more extensive research in more regions will contribute to the promotion and theoretical development of PCSCM. Supply chain optimization and industrial integration depend
on the interaction of governments, contractors, suppliers and carriers. Internal integration and optimization of each independent level is the premise. In addition, compared with supply chain management of manufacturing industry, PCSCM has unique construction technology and market environment. Based on this, the conceptual development framework of PCSCM is presented in Figure 10.

| Framework to promote PCSCM |
|-----------------------------|
| **Decisions of main participants** |
| **Supplier** | **Government** |
| Reduce costs+Increase profits | Increase social benefits |
| 1) Integrate lean and agile to optimize production planning and inventory management | 1) Integrate lean and agile to optimize production planning and inventory management |
| 2) Optimize production layout management | 2) Optimize production layout management |
| 3) Improve product standardization to reduce errors | 3) Improve product standardization to reduce errors |
| 4) Coordinate with contractor on production lead time hedging (PLTH) and buffer space hedging (BSH) | 4) Coordinate with contractor on production lead time hedging (PLTH) and buffer space hedging (BSH) |
| 5) Consider material characteristics and logistics selection | 5) Consider material characteristics and logistics selection |

| **Contrator** | **Developer** |
|--------------|--------------|
| Reduce costs+Increase profits+Shorten construction period | Reduce costs+Increase profits |
| 1) Cost sharing/profit sharing/risk management under different contract modes | 1) Standardize market behavior |
| 2) Order strategy: quantity, delivery date | 2) Perfect incentive mechanism |
| 3) Select partners and formulat evaluation standard of supplier | 3) Standardize contract model |
| 4) Resource scheduling in the production/transportation/assembly phase considering cost and time targets | |
| 5) Realize the whole process information collection, real-time communication, positioning and performance monitoring | |
| 6) Make assembly production layout plan | |

| **Strategic Alliances** |
|------------------------|
| **Government** | **Supplier** |
| 1) Identify obstacles/risks/incentives | 1) Integrate lean and agile to optimize production planning and inventory management |
| 2) PCSC performance evaluation | 2) Optimize production layout management |
| 3) Cost sharing/profit sharing/risk management under different contract modes | 3) Improve product standardization to reduce errors |
| 4) Monitor security/schedule/cost | 4) Coordinate with contractor on production lead time hedging (PLTH) and buffer space hedging (BSH) |

| **Market circumstances** |
|--------------------------|
| **Standardized market operation** | **Management philosophy** |
| 1) Improve the modular coordination standard | Contractors control the SC |
| 2) Realize PC standardization/modularization | Different stages have different core enterprises |

| **Technological base** |
|------------------------|
| **Information technology** | **Construction technology** | **Management technology** |
| 1) BIM | 1) Assembly tech | 1) Lean and agile |
| 2) IOT | 2) Node waterproof tech | 2) JIT |
| 3) AR/VR/RFID | 3) Node connection tech | |

**Figure 10.** A conceptual development framework for PCSCM

5.6. A Conceptual Development Framework for PCSCM

The conceptual development framework to facilitate PCSCM implementation consists of three parts: technology base, market circumstances, and decisions of main participants, as shown in Figure 10. Strengthening the practical application of technology and standardization of market environment is the basis to promote the implementation of PCSCM. The decision optimization of participants based on the integration of industrial chain can further optimize the PCSC efficiency.

Technology base. Technology, including management technology, information technology, and construction technology, is the basis to promote PCSCM. At present, the joint waterproof, joint connection and other construction technologies have developed more perfect. Combining lean and
agile management methods to create a flexible supply chain at minimal cost and to adapt to the diversity of contractor needs is the focus of further research. BIM, RFID, and other information technologies have been widely used in PC SCM, but how to process a large amount of data quickly and accurately is one of the current problems.

Market circumstances. Favorable market circumstances can further promote the implementation of PC SCM and achieve sustainable development. The first is the standardized operation of the market, including clarifying the standard system of the key links of PCSC and realizing PC standardization and modularization. It is necessary to establish the codes and standards for the design, production, construction and acceptance of prefabricated buildings. In addition, the implementation of generalization, standardization, and modularization has become a consensus. Standardization is the symbol of industrialization level. Only with high standardization level can mass production be realized, and mass production is also the main means to reduce the cost of prefabricated construction. The second is the change of management philosophy. PC SCM is transformed from being dominated by the contractor to having different core enterprises in different stages. The traditional construction supply chain is a satellite enterprise group with contractors as the core. However, for prefabricated buildings, the schedule and cost are largely limited by the production and transportation stages, thus forming a group of enterprises with relatively balanced rights.

Decisions of main participants. PCSC involves many participants, such as contractors, suppliers, developers, governments, etc. Different participants must have different goals and conflicts of interest. Major participants should make decisions based on the concept of win-win cooperation and sustainable development. After integrating the responsibilities of all parties, two aspects are obtained: optimization of production process design and optimization of contract system. In terms of production process design, suppliers need to integrate lean and agile concepts, optimize production planning, inventory management, and coordinate production lead time hedging (PLTH). The contractor needs to consider factors, such as the delivery time and volume of prefabricated components, to develop a reasonable production layout plan. A whole-process resource scheduling scheme combining cost and time objectives need to be developed. Further, BIM and other information technologies needs to be combined to realize the real-time communication, information collection, performance monitoring and positioning functions. For the optimization of contract system, the optimal cost sharing, profit distribution and risk management measures under different contract modes are the further research direction. In addition, due to the strong positive externalities of PC, the government plays an indispensable role in the early stage. The government needs to formulate incentives such as subsidies and penalties, so as to guide enterprises to enter the PC market reasonably and form a good construction market operation mechanism.

Only through the coordinated development of technology, market circumstances and decision-making level of participants, can the PCSC form an integrated whole, so as to optimize the efficiency and sustainability of the PC industry and improve its level.

6. Conclusions

PC supports urban economy and sustainable development, and it is a new trend for the construction industry to cope with environmental pollution and the severe shortage of social resources. At present, PC SCM has become a critical factor restricting the popularization and development of PC. The present situation, trend and gap of PC SCM research were reviewed in this paper, and further puts forward the research framework to promote the development of PC SCM. Retrieval databases include Elsevier, Emerald, Scopus, WOS, and EBSCO. From 516 records, the author screened out 152 records which were closely related to PC SCM.

First of all, the bibliometric software was used to analyse the cross-journal publication distribution, article citation and keyword co-occurrence of the included literature. The author further browsed the whole paper of all the reviewed literature, optimized the keyword clustering results, and separated the research topics reasonably.
Then, the research topics included strategic research and project evaluation, PC supply chain process design and optimization, supply chain integration and management, and application of advanced technology. A series of themes, including collaborative PCSCM with advanced technology, cooperative mode of PCSCM, introducing third-party logistics into PCSC, and multi-level strategy research based on market characteristics, were proposed to improve the research of PCSCM.

At last, a PCSCM implementation framework was constructed. This framework set out the recommendations to promote the development of PCSC from three levels of technology base, market conditions, and decisions of main participants, respectively, so as to achieve the purpose of reducing the prefabricated construction cost, shortening the schedule, and improving the efficiency and sustainability. The findings contribute to the acquisition of academic knowledge, research frontiers, and emerging trends about PCSCM research, help solve the problems and difficulties faced by PC, and further facilitate PC to develop into an environmentally friendly and economically sustainable construction mode. Future research could complement the literature by adopting the other theoretical lens (e.g., the theory of swift and even flow). The uses of different theoretical lenses would complement and provide a more complete map of PCSCM.

However, there is a problem that the collected literature may not be complete. First, while we believe that the right keywords have been selected to achieve our goals, they may be improved in the future to search articles more comprehensively. Second, the collected literatures do not include non-English books, reports, manuscripts, etc. Existing literature can effectively summarize the research status, so the summary of the research trend and the proposal of the framework are relatively accurate.

Author Contributions: The review was performed and written by Y.L.; J.D. and L.S. contributed by guiding the review work, discussing ideas, and supervising the writing of this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Appendix A

| No. | Author (year)      | Journal                                      | Volume (issue), Page | Research Topic                                      |
|-----|--------------------|----------------------------------------------|----------------------|----------------------------------------------------|
| 1   | Chang et al. (2018)| Resources Conservation and Recycling         | 139, 259–261         | Strategic research and overall design              |
| 2   | Liu et al. (2018)  | Sustainability                                | 10(9), 3046          | Strategic research and overall design              |
| 3   | Finnie et al. (2018)| Proceedings of the Institution of Civil Engineers - Management Procurement and Law | 171(4) 176–185 | Strategic research and overall design              |
| 4   | Dallasega et al. (2018)| Buildings                                       | 8(5), 38            | Strategic research and overall design              |
| 5   | Hosseini et al. (2018) | Automation in Construction                  | 87, 235–247         | Strategic research and overall design              |
| 6   | Li et al. (2018)   | Journal of Management in Engineering         | 34(2), 4017053      | Strategic research and overall design              |
| 7   | Sahin et al. (2018)| International Journal of Construction Management | 18(1), 34–52       | Strategic research and overall design              |
| 8   | Arashpour et al. (2018)| Automation in Construction                  | 84, 146–153         | Strategic research and overall design              |
| 9   | Viana et al. (2017)| Energies                                     | 10(10), 1622        | Strategic research and overall design              |
| 10  | Li et al. (2017)   | Journal of Cleaner Production                | 153, 692–706        | Strategic research and overall design              |
| No. | Author (year)                  | Journal                                               | Volume (issue), Page | Research Topic                      |
|-----|--------------------------------|-------------------------------------------------------|----------------------|-------------------------------------|
| 11  | London and Pablo (2017)        | Construction Management and Economics                 | 35(8), 553–577      | Strategic research and overall design |
| 12  | Ismail (2017)                  | Industrial Management & Data Systems                  | 117(7), 1485–1502    | Strategic research and overall design |
| 13  | Goh and Loosemore (2016)       | Construction Management and Economics                 | 35(5), 288–304      | Strategic research and overall design |
| 14  | Schoenwitz et al. (2017)       | International Journal of Production Economics         | 183, 79–90          | Strategic research and overall design |
| 15  | Ramaji and Memari (2017)       | Journal of Construction Engineering and Management    | 142(10), 4016047    | Strategic research and overall design |
| 16  | Mao et al. (2015)              | Journal of Management in Engineering                  | 31(3), 04014043     | Strategic research and overall design |
| 17  | Jaillon and Poon (2014)        | Automation in Construction                            | 39, 195–202         | Strategic research and overall design |
| 18  | Wu and Feng (2013)             | Architectural Science Review                          | 57(2), 105–113      | Strategic research and overall design |
| 19  | Zhang et al. (2014)            | Habitat International                                 | 41, 176–184         | Strategic research and overall design |
| 20  | Zhang et al. (2013)            | Journal of Production Research                        | 51(23-24), 6923–6949 | Strategic research and overall design |
| 21  | Azman et al. (2014)            | Journal of Civil Engineering and Management           | 19(Supplement_1), S131-5140 | Strategic research and overall design |
| 22  | Da Rocha (2014)                | Computers & Operations Research                       | 9, 214–219          | Strategic research and overall design |
| 23  | Chen et al. (2010)             | Automation in Construction                            | 19(6), 665–675      | Strategic research and overall design |
| 24  | Hofman et al. (2009)           | Building Research & Information                       | 37(1), 31–42        | Strategic research and overall design |
| 25  | Shi et al. (2018)              | Sustainability, 10(4)                                 | 1260                | Strategic research and overall design |
| 26  | Teng et al. (2017)             | Journal of Cleaner Production                         | 152, 387–398        | Strategic research and overall design |
| 27  | Tam et al. (2015)              | Journal of Cleaner Production                         | 109, 216–231        | Strategic research and overall design |
| 28  | Nguyen et al. (2018)           | Computers & Operations Research                       | 98, 254–264         | Strategic research and overall design |
| 29  | Bankvall et al. (2010)         | Supply Chain Management: An International Journal     | 15(5), 385–393      | Strategic research and overall design |
| 30  | Vrijhoef et al. (2000)         | European Journal of Purchasing and Supply Management  | 6(3), 169–178       | Strategic research and overall design |
| 31  | Zhao (2017)                    | Automation in Construction                            | 80, 37–47           | Strategic research and overall design |
| 32  | Li et al. (2014)               | Habitat International                                 | 43, 240–249         | Strategic research and overall design |
| 33  | Mostafa et al. (2016)          | Construction Innovation                               | 16(4), 483–525      | Strategic research and overall design |
| 34  | Boafo et al. (2016)            | Sustainability                                        | 8(6), 558           | Strategic research and overall design |
| 35  | Han and Wang (2016)            | Journal of Civil Engineering and Management           | 24(5), 364-377      | Strategic research and overall design |
| 36  | Höök and Stehn (2008)          | Construction Management and Economics                 | 26(10), 1091–1100   | Strategic research and overall design |
| 37  | Kamali and Hewage (2016)       | Renewable and Sustainable Energy Reviews              | 62, 1171–1183       | Strategic research and overall design |
| 38  | Jin et al. (2018)              | Journal of Cleaner Production                         | 202, 1202–1219      | Strategic research and overall design |
| 39  | Jaillon and Poon (2008)        | Construction Management and Economics                 | 26(9), 953–966      | Strategic research and overall design |
| 40  | Jiang et al. (2018)            | Sustainability                                        | 11(20), 5658        | Strategic research and overall design |
Table A1. Cont.

| No. | Author (year) | Journal | Volume (issue), Page | Research Topic |
|-----|---------------|---------|----------------------|----------------|
| 41  | Wang et al. (2018) | Sustainability | 11(12), 3450 | Strategic research and overall design |
| 42  | Jiang et al. (2018) | Sustainability | 11(1), 42 | Strategic research and overall design |
| 43  | Mao et al. (2017) | KSCE Journal of Civil Engineering | 22(8), 2678–2690 | Strategic research and overall design |
| 44  | Jiang et al. (2018) | Sustainability | 10(7), 2516 | Strategic research and overall design |
| 45  | Hong et al. (2018) | Journal of Cleaner Production | 172, 649-660 | Strategic research and overall design |
| 46  | Sacks et al. (2004) | Journal of Construction Engineering and Management | 130(2), 206–215 | Strategic research and overall design |
| 47  | Polat (2008) | Journal of Construction Engineering and Management | 134(3), 169–178 | Strategic research and overall design |
| 48  | Voordijk et al. (2006) | International Journal of Operations and Production Management | 26(6), 600–618 | Strategic research and overall design |
| 49  | Sertyselisik (2014) | Optimization and Control Methods in Industrial Engineering and Construction | 179–196 | Strategic research and overall design |
| 50  | Zeng et al. (2018) | Sustainability | 10(10), 3581 | Strategic research and overall design |
| 51  | Akram Syed Zakaria et al. (2018) | Architectural Engineering and Design Management | 14(1–2), 27–45 | Strategic research and overall design |
| 52  | Le et al. (2018) | International Journal of Construction Management | 1–20 | Strategic research and overall design |
| 53  | Aloini et al. (2012) | Business Process Management Journal | 18(5), 735–761 | Strategic research and overall design |
| 54  | Jaillon and Poon (2008) | Construction Management and Economics | 26(9), 953–966 | Strategic research and overall design |
| 55  | Yashiro (2014) | Construction Management and Economics | 32(1–2), 16–39 | Strategic research and overall design |
| 56  | Yang et al. (2018) | Mathematical Problems in Engineering | 2018, 1–16 | Supply chain integration and management |
| 57  | Zhai et al. (2018) | International Journal of Production Economics | 200, 192–206 | Supply chain integration and management |
| 58  | Wang et al. (2018) | Journal of Cleaner Production | 177, 232–244 | Supply chain integration and management |
| 59  | Xue et al. (2018) | Journal of Cleaner Production | 184, 490–502 | Supply chain integration and management |
| 60  | Wang et al. (2018) | Mathematical Problems in Engineering | 2018, 1–5 | Supply chain integration and management |
| 61  | Zhai et al. (2017) | International Journal of Production Research | 55(14), 3984–4002 | Supply chain integration and management |
| 62  | Han et al. (2017) | Sustainability | 9(11), 2069 | Supply chain integration and management |
| 63  | Chen et al. (2017) | Canadian Journal of Civil Engineering | 44(6), 393–406 | Supply chain integration and management |
| 64  | Feng et al. (2017) | Mathematical Problems in Engineering | 2017, 1–6 | Supply chain integration and management |
| 65  | Kim et al. (2016) | Canadian Journal of Civil Engineering | 43(4), 287–293 | Supply chain integration and management |
| No. | Author (year) | Journal | Volume (issue), Page | Research Topic |
|-----|---------------|---------|----------------------|----------------|
| 66  | Demiralp et al. (2012) | Automation in Construction | 24, 120–129 | Supply chain integration and management |
| 67  | Hong et al. (2018) | Journal of Cleaner Production | 172, 649–660 | Supply chain integration and management |
| 68  | Albuquerque et al. (2012) | Automation in Construction | 22, 348–356 | Supply chain integration and management |
| 69  | Wang and Hu et al. (2018) | International Journal of Production Research | 56(16), 5386–5401 | Supply chain integration and management |
| 70  | Xue et al. (2018) | Sustainability | 10(2), 159 | Supply chain integration and management |
| 71  | Khalili and Chua (2014) | Journal of Construction Engineering and Management | 140(2), 04013052 | Supply chain integration and management |
| 72  | Sutrisna and Goulding (2018) | Construction and Architectural Management | 26(2), 267–284 | Supply chain integration and management |
| 73  | Goulding et al. (2014) | Architectural Engineering and Design Management | 11(3), 163–184 | Supply chain integration and management |
| 74  | Estehardian et al. (2013) | KSCE Journal of Civil Engineering | 17(2), 262–270 | Supply chain integration and management |
| 75  | Wong et al. (2010) | Journal of Construction Engineering and Management | 136(10), 1116–1128 | Supply chain integration and management |
| 76  | Purvis et al. (2014) | International Journal of Production Economics | 151, 100–111 | Supply chain integration and management |
| 77  | Horta et al. (2013) | Journal of Construction Engineering and Management | 139(8), 910–917 | Supply chain integration and management |
| 78  | Pero et al. (2015) | International Journal of Production Economics | 170, 602–615 | Supply chain integration and management |
| 79  | Tennant and Fernie (2013) | Construction and Architectural Management | 20(1), 83–98 | Supply chain integration and management |
| 80  | Briscoe and Dainty (2005) | Supply Chain Management: An International Journal | 10(4), 319–326 | Supply chain integration and management |
| 81  | Dawood, N., & Marasini, R. (2003). | Automation in Construction | 12(2), 113–122 | Supply chain integration and management |
| 82  | Dainty (2001) | Supply Chain Management: An International Journal | 6(4), 163–173 | Supply chain integration and management |
| 83  | Cagliano et al. (2006) | International Journal of Operations & Production Management | 26(3), 282–299 | Supply chain integration and management |
| 84  | Power (2005) | Supply Chain Management: An International Journal | 10(4), 252–263 | Supply chain integration and management |
| 85  | Doran and Giannakis (2011) | Supply Chain Management: An International Journal | 16(4), 260–270 | Supply chain integration and management |
Table A1. Cont.

| No. | Author (year)                  | Journal                                                      | Volume (issue), Page | Research Topic                                      |
|-----|-------------------------------|--------------------------------------------------------------|----------------------|-----------------------------------------------------|
| 86  | Huuhka et al. (2015)          | Resources Conservation and Recycling                        | 101, 105–121         | Supply chain integration and management             |
| 87  | Lee et al. (2014)             | KSCE Journal of Civil Engineering                            | 18(5), 1528–1538     | Supply chain integration and management             |
| 88  | Ko et al. (2015)              | Making formwork construction lean. Journal of Civil Engineering and Management | 21(4), 444–458       | Supply chain integration and management             |
| 89  | Li et al. (2016)              | Schedule risks in prefabrication housing production in Hong Kong: a social network analysis. Journal of Cleaner Production | 134, 482–494         | Supply chain process design and optimization        |
| 90  | Li et al. (2010)              | Expert Systems with Applications                             | 37(12), 8406–8416    | Supply chain process design and optimization        |
| 91  | Ma et al. (2018)              | Optimized rescheduling of multiple production lines for flowshop production of reinforced precast concrete components. Automation in Construction | 95, 86–97            | Supply chain process design and optimization        |
| 92  | Hsu et al. (2018)             | Automation in Construction                                   | 94, 47–61            | Supply chain process design and optimization        |
| 93  | Kong et al. (2018)            | Journal of Cleaner Production                                | 193, 684–701         | Supply chain process design and optimization        |
| 94  | Arashpour et al. (2015)       | Automation in Construction                                   | 50, 72–80            | Supply chain process design and optimization        |
| 95  | Chang and Hu (2002)           | Journal of Construction Engineering and Management           | 128(6), 513–521      | Supply chain process design and optimization        |
| 96  | Wang et al. (2018)            | Automation in Construction                                   | 86, 69–80            | Supply chain process design and optimization        |
| 97  | Kong et al. (2017)            | Automation in Construction                                   | 81, 34–43            | Supply chain process design and optimization        |
| 98  | Wang et al. (2017)            | Journal of Computing in Civil Engineering                    | 31(4), 4017013       | Supply chain process design and optimization        |
| 99  | Yang et al. (2016)            | Automation in Construction                                   | 72, 321–329          | Supply chain process design and optimization        |
| 100 | Anvari et al. (2016)          | Automation in Construction                                   | 71, 226–241          | Supply chain process design and optimization        |
| 101 | Arashpour et al. (2016)       | Automation in Construction                                   | 71, 262–270          | Supply chain process design and optimization        |
| 102 | Ahmadian et al. (2016)        | Journal of Construction Engineering and Management           | 142(1), 4015050      | Supply chain process design and optimization        |
| 103 | Ko (2013)                     | Journal of Civil Engineering and Management                 | 19(3), 335–347       | Supply chain process design and optimization        |
| 104 | Hong et al. (2014)            | Automation in Construction                                   | 41, 50–59            | Supply chain process design and optimization        |
| 105 | Ko and Wang (2011)            | Expert Systems with Applications                             | 38(7), 8293–8302     | Supply chain process design and optimization        |
Table A1. Cont.

| No. | Author (year)          | Journal                                                    | Volume (issue), Page | Research Topic                                |
|-----|------------------------|------------------------------------------------------------|----------------------|-----------------------------------------------|
| 106 | Pan et al. (2012)      | Journal of Construction Engineering and Management         | 138(11), 1331–1340   | Supply chain process design and optimization  |
| 107 | Ko (2011)              | Canadian Journal of Civil Engineering                      | 38(2), 191–199       | Supply chain process design and optimization  |
| 108 | Ko (2010)              | Journal of Civil Engineering and Management                | 16(3), 418-427       | Supply chain process design and optimization  |
| 109 | Im et al. (2009)       | Canadian Journal of Civil Engineering                      | 36(9), 1444–1458     | Supply chain process design and optimization  |
| 110 | Ko and Wang (2010)     | Automation in Construction                                | 19(7), 907–916       | Supply chain process design and optimization  |
| 111 | Chan and Hu (2002)     | Journal of Construction Engineering and Management         | 128(6), 513–521      | Supply chain process design and optimization  |
| 112 | Chan and Hu (2002)     | Journal of Computing in Civil Engineering                  | 16(3), 165–174       | Supply chain process design and optimization  |
| 113 | Pheng and Chuan (2001) | Journal of Construction Engineering and Management         | 127(6), 494–501      | Supply chain process design and optimization  |
| 114 | Wang et al. (2018)     | Journal of Construction Engineering and Management         | 144(11), 4018098     | Supply chain process design and optimization  |
| 115 | Leu et al. (2002)      | Automation in Construction                                | 11(4), 439–452       | Supply chain process design and optimization  |
| 116 | Moon et al. (2018)     | KSCE Journal of Civil Engineering                         | 22(10), 3697–3706    | Supply chain process design and optimization  |
| 117 | Lee et al. (2013)      | KSCE Journal of Civil Engineering                         | 17(4), 806–814       | Supply chain process design and optimization  |
| 118 | Ren et al. (2012)      | Journal of Civil Engineering and Management                | 18(5), 642–654       | Supply chain process design and optimization  |
| 119 | Pan et al. (2012)      | Construction Management and Economics                     | 29(11), 1081–1099    | Supply chain process design and optimization  |
| 120 | Wan and Sidwell (2011) | Construction and Architectural Management                  | 16(3), 208–223       | Supply chain process design and optimization  |
| 121 | Fang and Ng (2100)     | Construction Innovation                                    | 11(3), 259–281       | Supply chain process design and optimization  |
| 122 | Wang et al. (2018)     | Journal of Civil Engineering and Management                | 24(2), 106–115       | Supply chain process design and optimization  |
| 123 | Luu et al. (2009)      | International Journal of Project Management                | 27(1), 39–50         | Supply chain process design and optimization  |
| 124 | Cavaco et al. (2018)   | Engineering Structures                                    | 156, 210–223         | Supply chain process design and optimization  |
| 125 | Ji et al. (2018)       | Journal of Cleaner Production                             | 173, 124–134         | Supply chain process design and optimization  |
Table A1. Cont.

| No. | Author (year) | Journal | Volume (issue), Page | Research Topic |
|-----|---------------|---------|----------------------|----------------|
| 126 | Kim et al. (2016) | Journal of Civil Engineering and Management | 22(5), 634–644 | Supply chain process design and optimization |
| 127 | Vaghei et al. (2017) | Earthquake Engineering and Engineering Vibration | 16(1), 97–117 | Supply chain process design and optimization |
| 128 | Xu et al. (2018) | Automation in Construction | 93, 123–134 | Application of advanced technology |
| 129 | He et al. (2018) | Sustainability | 10(8), 2613 | Application of advanced technology |
| 130 | Li et al. (2018) | Automation in Construction | 89, 146–161 | Application of advanced technology |
| 131 | Altaf et al. (2018) | Automation in Construction | 85, 369–383 | Application of advanced technology |
| 132 | Chen et al. (2017) | International Journal of Computer Integrated Manufacturing | 31(4), 349–361 | Application of advanced technology |
| 133 | Li et al. (2017) | Journal of Cleaner Production | 165, 1048–1062 | Application of advanced technology |
| 134 | Wang et al. (2017) | Computer-Aided Civil and Infrastructure Engineering | 32(6), 499–514 | Application of advanced technology |
| 135 | Zhong et al. (2017) | Automation in Construction | 76, 59–70 | Application of advanced technology |
| 136 | Arashpour et al. (2015) | Automation in Construction | 53, 13–21 | Application of advanced technology |
| 137 | Ergen and Wakefield et al. (2008) | Journal of Construction Engineering and Management | 134(2), 112–121 | Application of advanced technology |
| 138 | Nasir et al. (2017) | Canadian Journal of Civil Engineering | 37(4), 588–599 | Application of advanced technology |
| 139 | Ćuić-Babić et al. (2014) | Computers in Industry | 65(2), 345–353 | Application of advanced technology |
| 140 | Yin et al. (2009) | Automation in Construction | 18(5), 677–691 | Application of advanced technology |
| 141 | Ergen et al. (2007) | Automation in Construction | 16(13), 354–367 | Application of advanced technology |
| 142 | Shin et al. (2010) | Automation in Construction | 20(5), 706–715 | Application of advanced technology |
| 143 | Ergen et al. (2007) | Advanced Engineering Informatics | 21(4), 356–366 | Application of advanced technology |
| 144 | Xu et al. (2018) | Enterprise Information Systems | 1–20 | Application of advanced technology |
| 145 | Shi et al. (2016) | Automation in Construction | 72, 143–154 | Application of advanced technology |
Table A1. Cont.

| No. | Author (year)        | Journal                                                                 | Volume (issue), Page | Research Topic                  |
|-----|----------------------|--------------------------------------------------------------------------|----------------------|---------------------------------|
| 146 | Bilal et al. (2015)  | International Journal of Sustainable Building Technology and Urban Development, | 6(4), 211–228        | Application of advanced technology |
| 147 | Irizarry et al. (2013)| Automation in Construction                                               | 31, 241–254          | Application of advanced technology |
| 148 | Ahmadian et al. (2017)| Engineering Construction and Architectural Management                    | 24(4), 668–695       | Application of advanced technology |
| 149 | Tserng et al. (2005) | Computer-Aided Civil and Infrastructure Engineering                      | 20(4), 242–264       | Application of advanced technology |
| 150 | Zhong et al. (2015)  | Ifac-Papersonline                                                        | 48(3), 1079–1086     | Application of advanced technology |
| 151 | Wang et al. (2007)   | Advanced Engineering Informatics                                         | 21(4), 377–390       | Application of advanced technology |
| 152 | Zare Mehrjerdi (2009)| Assembly Automation                                                       | 29(2), 174–183       | Application of advanced technology |

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