sustainability

Review

A Scientometric Review of System Dynamics Applications in Construction Management Research

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Abstract: Construction management can be regarded as a complex and dynamic system. In recent years, system dynamics (SD) has been widely applied to solve the complex and dynamic problems in the construction management. However, there is a lack of a scientometric analysis to investigate SD applications in construction management from an objective perspective. To fill out this research gap, this study retrieved a total of 222 relevant articles from the Scopus database. Then, VOSviewer was employed to analyze the collected literature from five aspects (i.e., co-authorship, published journals, co-occurring keywords, article citations, and regions). Based on the analysis results, four mainstream research themes were identified and discussed, including "risk management", "waste management", "energy management", and "construction productivity". In addition, future research directions, such as "construction risk allocation in PPP projects", "evaluating the economic feasibility of construction waste landfilling centers", "identifying the variables affecting lighting infrastructure energy consumption", and "assessing construction productivity for technology-intensive activities", were proposed. The contribution of this study lies in that it helps both scholars and practitioners to solve the complex and dynamic problems in construction management.

Keywords: scientometric analysis; literature review; visualization; system dynamics (SD); construction management

1. Introduction

The construction project can be regarded as a complex and dynamic system, in which internal and external factors are directly or indirectly related to each other [1]. The internal factors include, but are not limited to, uncertainties related to projects, funds, human resources, and conflict of interest amongst different parties (e.g., developers, contractors, designers), while the external factors consist of uncertain factors related to government, economy, social conditions, laws, natural environment, etc. Solving complex and dynamic problems is the key to success of construction management. On the one hand, with the booming development of the construction industry, the complexity of construction projects, such as organizational complexity and technological complexity, has also increased dramatically. There has been an investigation, which indicates that increased project complexity can reduce the probability of project success [2]. On the other hand, the influence of these multiple factors is usually dynamic and relatively unstable [3]. However, traditional methods, such as delay analysis and the critical path method, cannot accurately understand the complexity of projects and evaluate the dynamic change [4]. Accordingly, it is significant to solve complex and dynamic problems in construction management research.

In recent years, system dynamics (SD) has been more and more widely implemented to solve the complex and dynamic challenges in construction management. Since it was first proposed by Forrester in 1958, SD has been implemented to address a variety of research domains [5]. Unlike conventional research approaches, SD considers the dynamic relationship between structure, function, and behavior of complex systems from a global perspective, which assists in project managers making a reasonable assessment of the dynamic change [6,7]. At the same time, the plans of construction management constantly change with time [8]. Therefore, SD is very suitable for simulating and analyzing construction projects to maximize the positive impact of complex and dynamic factors [9].

For these mentioned reasons, SD has gained increasing popularity among construction management scholars, and the applications in research are quite multiple. For example, SD was applied to grasp the complex and dynamic factors affecting rework and project performance, which could improve construction quality and reduce the cost of rework [10]. In some recent articles, SD was utilized to avoid cost overrun and construction delays [11,12]. In addition, some scholars used SD to identify key factors in construction management, such as key risk factors in construction projects [13] and key factors that improve the success possibility of green buildings [14]. Furthermore, SD could also be implemented to analyze the impact of new policies and technologies on the industry [15]. As can be seen from the above, the applications of SD in construction management have been very abundant and comprehensive. Xu and Zou [16] claimed that a literature review of SD in the construction management field was critical in understanding the new and noteworthy research directions. In addition, scientometric analysis has been employed by more and more researchers to overcome subjective issues in the literature review [17–19]. However, in the existing studies, there is a lack of a holistic scientometric review to evaluate SD applications in the overall construction management domain. To address this research gap, there is a need to map the relevant literature. The novelty of this study lies in that it investigates SD applications in construction management from an objective perspective.

This study aims to identify the current research status and provide insights into future research directions of SD applications in construction management. In the following sections, first the research methodology is introduced. Then, the collected articles are analyzed from five aspects, including co-authorship, published journals, co-occurring keywords, article citations, and regions. Following the scientometric analysis, four current mainstream research themes (i.e., risk management, waste management, energy management, and construction productivity) are discussed. Based on the discussion, future research directions are further proposed. Last but not least, a conclusion section is given at the end of this paper.

2. Research Methodology

The literature sample was retrieved from Scopus, which is considered to be the world's largest peer-review database. Compared to any other available literature database (such as Web of Science), Scopus covers more journals and publications [20]. It is the objective of this study to collect as much as possible all the literature of SD applications in construction management. To realize this target, the literature search was divided into two stages. First, the range of literature search was enlarged from construction management to the whole construction domain. The following keywords were utilized in the literature search: TITLE-ABS-KEY ("system dynamics" AND "construction" OR "civil" OR "infrastructure"). Moreover, the time range was set from 2011 to 2019. Only journal articles were selected for this study because journal articles are generally considered to be of higher quality and greater impact than other types of publications [21]. In the second stage, through manual screening one by one, only articles that focus on the management aspect were left, and a total of 222 articles were collected as the literature sample.

After collecting the literature sample, a scientometric analysis was carried out. With the rapid development of technology, a variety of existing tools can conduct the scientometric analysis. In this study, VOSviewer was chosen to draw science mappings, because it is suitable for larger networks and has special text mining capabilities [22]. In construction management research, VOSviewer has been employed by more and more researchers to construct science mappings, such as public-private partnerships [23], Building information modeling [24], and building control [25]. In addition, Zhao [26] indicated that this software could also be applied to other potential research areas. Then, a total of 222 collected articles were analyzed from 5 aspects, including co-authorship, published journals, co-occurring keywords, article citations, and regions. This is because, in the literature review study, these five categories are generally regarded as the core parts of the scientometric analysis, assisting researchers in easily and clearly understanding the current research status [27]. The major measurements consist of total citations, documents, average publication year, and average normalized citations [28].

3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. Co-Authorship Analysis

In academic research, it is common for scholars to cooperate, which can enhance academic productivity [29]. In this study, the minimum number of documents and citations of an author were respectively set at 2 and 30. As a result, a total of 38 authors attained the selection criteria for this study. Since some authors were not connected, the 12 most influential authors were visualized in Figure 1.

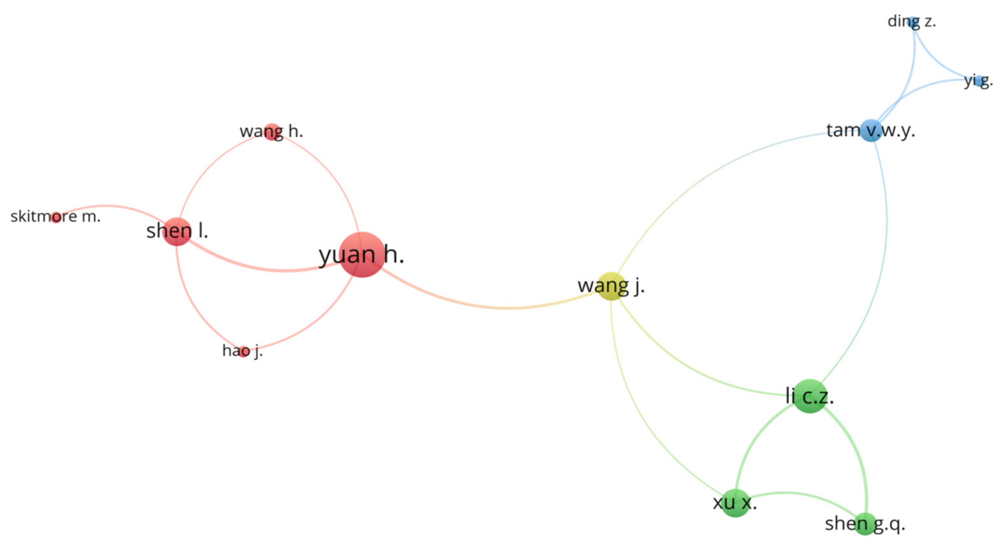

Figure 1. Science mapping of co-authorship.

In Figure 1, it can be seen that these authors were clearly divided into four research groups in terms of the color, for example, the research group of Yuan H., Shen L., Wang H., Hao J., and Skitmore M. Among the 12 authors, Wang J. was located in the center of this mapping and related to all the other three groups of researchers, showing that he kept close academic collaboration with leading scholars in the field. Yuan H. cooperated closely with many authors, and his node was larger than those of the other authors, indicating that Yuan H. was one of the top researchers in this research filed. More detailed information on the co-authorship was shown in Table 1.

Table 1. Details of co-authorship.

Scholar	Affiliation	Documents	Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
Shen L.	Chongqing University	5	335	2012	67	2.31
Yuan H.	Guangzhou University	8	331	2014	41	2.36
Tam V.W.Y.	University of Western Sydney	4	143	2017	36	4.68
Wang J.	Shenzhen University	5	128	2016	26	1.89
Li C.Z.	Shenzhen University	6	150	2017	25	2.50
Shen G.Q.	Hong Kong Polytechnic University	4	93	2017	23	2.32
Xu X.	Swinburne University of Technology	5	44	2018	9	1.77

Table 1 demonstrates that in the aspect of total citations, Shen L. ranked the top with 335 citations, followed by Yuan H. with 331 citations. In terms of average citations, Shen L. still ranked the first with 67 average citations and Yuan H. ranked the second with 41 average citations. According to the average publication year, Shen L. comparatively earlier linked SD to construction management, whose average publication year was around 2012. Regarding published articles, Yuan H. published the greatest number of articles. As mentioned above, it is not difficult to have the conclusion that Shen L. and Yuan H. were the most influential researchers in this domain.

3.2. Published Journals Analysis

Research results are usually shared and communicated in multiple published journals. In this study, the source journals of the collected documents were identified by VOSviewer and presented in Figure 2. For this analysis of published journals, the minimum number of documents and citations of a source were set at three and 25, respectively. A total of 14 journals reached the threshold. Among them, totally 12 leading journals were connected to each other and presented in Figure 2. The nodes of the *Journal of Cleaner Production* and *Journal of Construction Engineering and Management* were the largest and connected to most of the other journals, indicating that these two important journals were both productive and influential in this research domain [30,31].

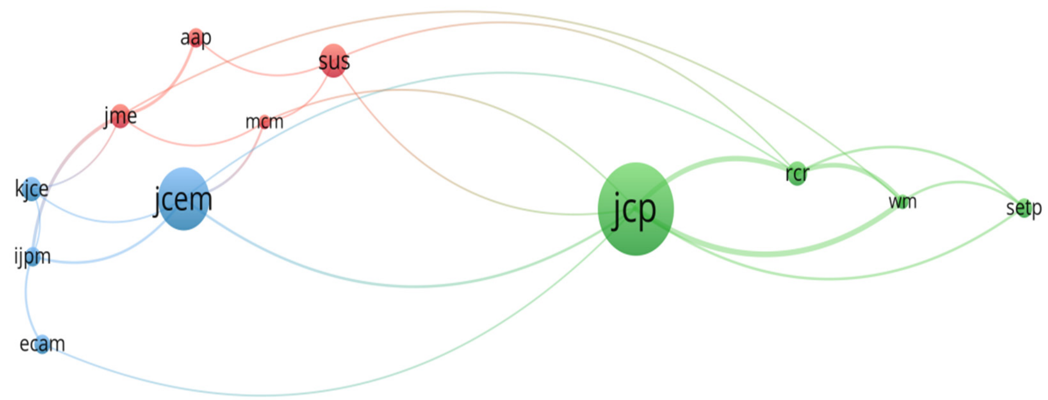

Figure 2. Science mapping of published journals.

It should be noted that the full name of journals may not be displayed in VOSviewer, and more detailed information of published journals was presented in Table 2. It is very easy to find that *Waste Management* had an outstanding performance, receiving the highest average citations and average normalized citations. In the aspect of total citations, *Resources, Conservation and Recycling* ranked the top. In terms of documents, the *Journal of Cleaner Production* published the most significant number of articles. Other most influential journals in this research domain included but were not limited to *Accident Analysis and Prevention*, the *International Journal of Project Management*, *Mathematical and Computer Modelling*, and the *Journal of Management in Engineering*.

Table 2. Details of published journals.

Full Name of Journal Sources	Acronym	Documents	Citations	Avg. Citations	Avg. Norm. Citations
Waste Management	WM	3	192	64	3.68
Resources, Conservation and Recycling	RCR	5	316	63	1.99
Accident Analysis and Prevention	AAP	4	221	55	2.59
International Journal of Project Management	IJPM	4	182	46	2.25
Mathematical and Computer Modelling	MCM	3	61	20	1.58
Journal of Construction Engineering and Management	JCEM	13	189	15	1.23
Journal of Management in Engineering	JME	5	72	14	1.66
Journal of Cleaner Production	JCP	19	231	12	2.68

3.3. Co-occurring Keywords Analysis

Through analyzing the keywords in the collected articles, current mainstream research topics and future research directions can be identified [32]. In this study, the minimum number of occurrences of a keyword was set at three. Initially, 41 out of 705 keywords met the threshold. There were a few keywords with the same meanings, such as "construction and demolition", "waste management", and "construction waste". Accordingly, these keywords with the same semantic meanings were combined in this study. In consequence, 25 keywords satisfied the threshold in total, and the identified keywords were visualized in Figure 3.

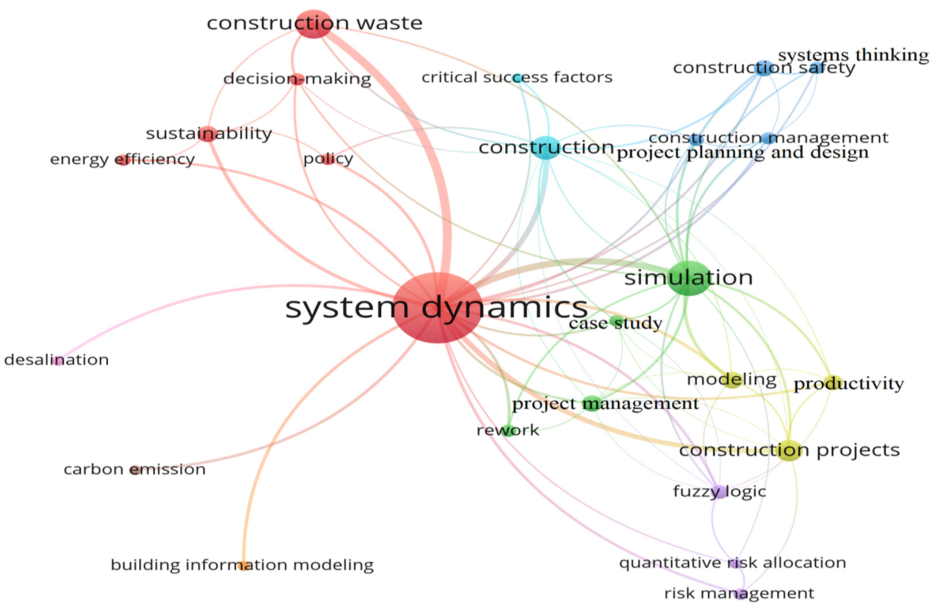

Figure 3. Science mapping of co-occurring keywords.

The research directions of SD applications can be seen in Figure 3. It is evident that the largest point of research directions was "construction waste", showing that SD has been mostly utilized in this area. In addition, the details of keywords were further shown in Table 3, and the occurrences of keywords correspond to those in Figure 3. According to the occurrences of the keywords, we can be aware that "construction safety management", "construction productivity", "energy management", and "risk management" were also included in the popular research topics. It can be inferred that SD is competent in evaluating the effects of various policies.

Table 3. Details of co-occurring keywords.

Keywords	Occurrences	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
Construction Waste	27	2016	28	1.95
Construction Safety	8	2016	24	1.75
Sustainability	8	2016	9	1.06
Productivity	7	2017	9	1.04
Energy Efficiency	4	2018	5	1.57
Policy	4	2016	5	0.37
Risk Management	4	2016	2	0.21
Critical Success Factors	3	2018	7	2.15
Carbon Emission	3	2016	7	0.6

As can be seen from Table 3, the average publication year of some topics was around 2018, such as "Energy Efficiency" and "Critical Success Factors". It shows that energy efficiency has become an emerging mainstream research topic in this research domain, and more and more scholars have employed SD to solve problems related to critical success factors in recent years. In addition, based on average normalized citations, we can also know which keywords were more influential themes in the research, such as "Critical Success Factors" with the highest average normalized citations.

3.4. Article Citations Analysis

This study aims to seek out the most significant academic achievements of SD applications in construction management research. To accomplish this goal, the minimum number of citations of a document was set at 20 in this study. As a result, 35 articles were meeting the threshold. Since some articles were not connected, a total of 15 articles were finally visualized in Figure 4.

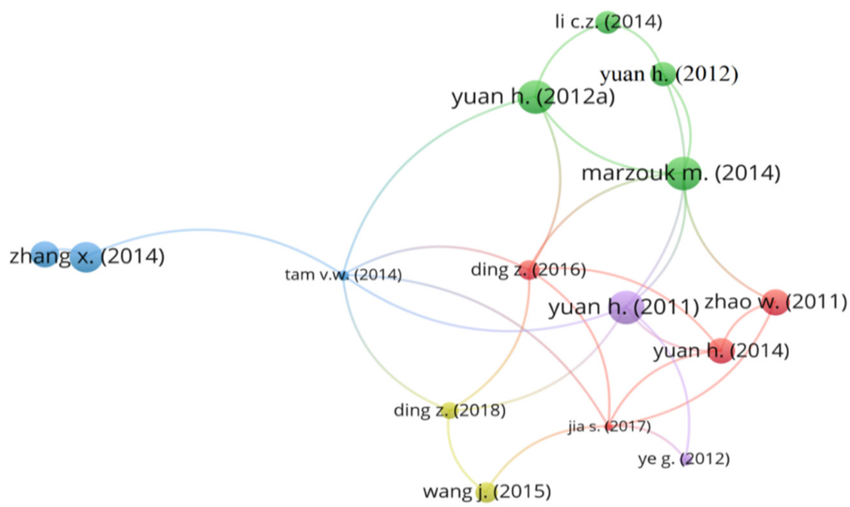

Figure 4. Science mapping of article citations.

More details of highly cited articles were further displayed in Table 4, including the name of authors, the full article title, total citations, and normalized citations. It can be easily found that the most fascinating research findings were mainly published in the area of sustainable construction, especially in waste management. From this, it can be concluded that the characteristics of SD are competent in solving problems related to waste management. It is anticipated that SD will be more widely applied in the future research of this topic.

Table 4. Details of article citations.

Article	Title	Citations	Norm. Citations
Yuan, Chini, Lu and Shen [5]	A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste	83	3.70
Marzouk and Azab [33]	Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics	83	2.77
Yuan et al. [34]	A model for cost-benefit analysis of construction and demolition waste management throughout the waste chain	83	2.26
Zhang et al. [35]	A prototype system dynamic model for assessing the sustainability of construction projects	76	2.54
Yuan and Wang [36]	A system dynamics model for determining the waste disposal charging fee in construction	63	2.11
Yuan [37]	A model for evaluating the social performance of construction waste management	60	2.67

In addition to research topics, the authors of these influential articles also get much attention. For the impact of a particular article, Yuan, Chini, Lu and Shen [5] received the highest citations in this filed and had the largest number of normalized citations in highly cited articles. In terms of the number of highly cited articles, four of the six most cited articles belong to Yuan H. Therefore, it can be concluded that Yuan H. has led a significant series of research on the SD applications in construction management. Furthermore, there were a few other researchers who also published the most influential research papers, including but not limited to Shen L., Marzouk M., and Zhang X.

3.5. Regions Analysis

In this study, the source regions of the researchers were identified, visualized, and evaluated by VOSviewer [22]. The connection between different regions is very close, and academic cooperation between different regions has become more extensive and frequent than ever [29]. For this analysis of regions, the minimum number of documents and citations of a region were set at two and 30, respectively. Accordingly, a total of 15 regions met the selection criteria.

In Figure 5, it can be seen that the regions were clearly divided into three research groups in terms of the color, for example, the research group of Australia, the United Kingdom, and Pakistan. It should be cleared that the node of China was the largest, indicating that Chinese scholars were the major contributors to applying SD to solve the problems in construction management. More detailed information was further shown in Table 5.

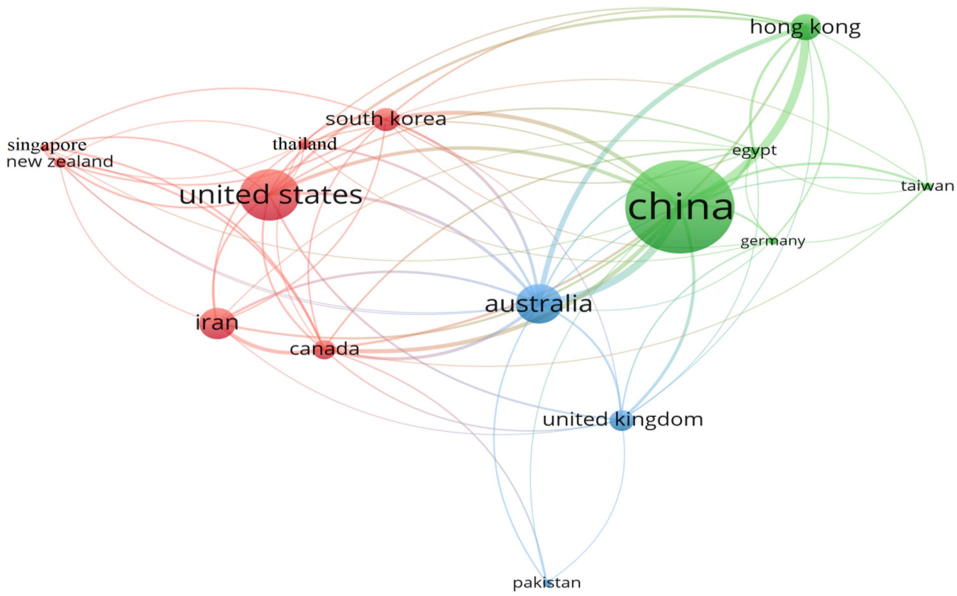

Figure 5. Science mapping of regions.

Table 5. Details of regions.

Region	Documents	Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
China	71	825	2016	12	1.27
United States	39	545	2016	14	1.01
Australia	30	469	2016	16	1.73
Iran	24	176	2017	7	0.76
Hong Kong	20	534	2015	27	1.95
South Korea	18	259	2016	14	0.90
United Kingdom	16	195	2015	12	0.88
Canada	15	341	2015	23	0.87
Germany	2	67	2015	34	1.09

As can be seen from Table 5, China ranked first place in both documents and total citations, indicating that Chinese scholars' applications of SD were very enlightening and greatly promoted construction management research. Last but not least, it should be made clear that although the land area of Hong Kong is not very large, scholars from Hong Kong still received the highest average normalized citations, indicating that researchers in Hong Kong were highly competitive and contributed significantly to this research domain.

4. Discussion

Following the scientometric analysis, this discussion summarized the current research status, and provided insights into future research directions.

4.1. Current Research Topics

Risk management is a hot topic in construction management research. SD can be implemented to facilitate solving risk management related problems. For instance, Nasirzadeh et al. [38] applied SD to determine the optimal percentage of risk allocation between owners and contractors, where the total construction cost is minimized. In addition, SD could be widely used to identify various risks that construction projects may encounter, including safety risk [39], investment risk [40], requirement risk [41], and schedule risk [42]. In addition, SD could be utilized to further analyze the interrelationships between the risk factors, which could facilitate preventing the occurrence of risks. In construction projects, owners and contractors often want to shorten the construction cycle; however, shortening the construction cycle may lead to higher security risks. SD could be utilized to investigate the risk transfer mechanism, which was caused by the interaction between the organizational and technical systems of contractors [43]. Based on the research results, it is found that contractors should continue to establish a good safety culture and not sacrifice safety in order to boost productivity.

Waste management is a significant branch of construction management. For the past few years, increasing high-level articles have emerged in the waste management domain and SD applications in the research are relatively abundant [44]. SD could be employed to quantitatively assess the influence of various strategies and policies on waste reduction. For instance, Li et al. [45] employed SD to discover that the combined effects of multiple strategies were greater than the simple sum of their individual effects. In addition, Wang et al. [46] implemented SD to find out the use of prefabricated components could have the most significant impact on construction waste reduction. For the past few years, the government and enterprises in different regions have introduced measures such as waste management fees, penalties, and subsidies. SD can assist in these measures maximizing their influence. For instance, in terms of waste management fees, SD could be used to determine the most appropriate waste management fee, which could reduce waste generation, maximize waste recovery and utilization, and minimize improperly discarded waste [47,48]. In the aspect of penalties and subsidies, SD could also be employed to determine the reasonable range of penalties for illegally dumped waste and subsidies for recyclable waste. From the research results, it was found that appropriate fines could greatly reduce the amount of illegally dumped waste, and suitable subsidies could enhance the amount of recyclable waste very effectively [36]. However, the generation of construction waste is inevitable, so the recycling of construction waste is very essential. Zhao et al. [49] applied SD to evaluate the economic viability of waste recycling centers. Furthermore, SD could even be employed to improve the construction waste recycling industry chain and develop sustainable construction waste [50].

The construction field has high potential for energy saving [51]. For this reason, energy management is a focus topic in construction management, and SD can be employed to facilitate solving energy-related problems. For instance, SD could be applied to analyze the relationship between the variables that affect the energy consumption of a building [52]. It is well known that energy consumption varies from building to building. According to Kamal et al. [53], developing countries should give priority to building efficient new buildings rather than renewing old buildings for energy and cost savings. In addition to traditional construction methods, prefabricated construction has become a mainstream construction approach. SD was utilized to study energy efficiency in prefabricated manufacturing processes, which could assist in reducing energy costs and increasing profits [54]. Moreover, renewable energy as a solution to reduce global warming has received increasing promotion by governments around the world [55]. SD could also be employed to help determine the optimal capacity and energy mix for renewable energy projects [56].

Construction productivity is a key part of construction management. SD has received increasing popularity with productivity researchers. For instance, SD was employed to assess labor productivity [57]. In addition, SD could be further applied to investigate the most critical factors affecting labor productivity and discover the root cause of labor productivity decline [58,59]. Additionally, contract changes often disrupt production schedules, which can further lead to productivity losses. SD could be employed to quantify the impact of contracts change on labor productivity [60]. It is well known that the construction industry is a labor-intensive industry, so most research focuses on labor productivity. However, equipment is the primary driver of productivity in equipment-intensive activities. Gerami Seresht and Fayek [61] applied SD to identify the key factors affecting productivity and to predict the productivity of equipment-intensive activities.

4.2. Future Research Directions

Based on the discussion of current research topics, future research directions were further proposed, as presented in Figure 6.

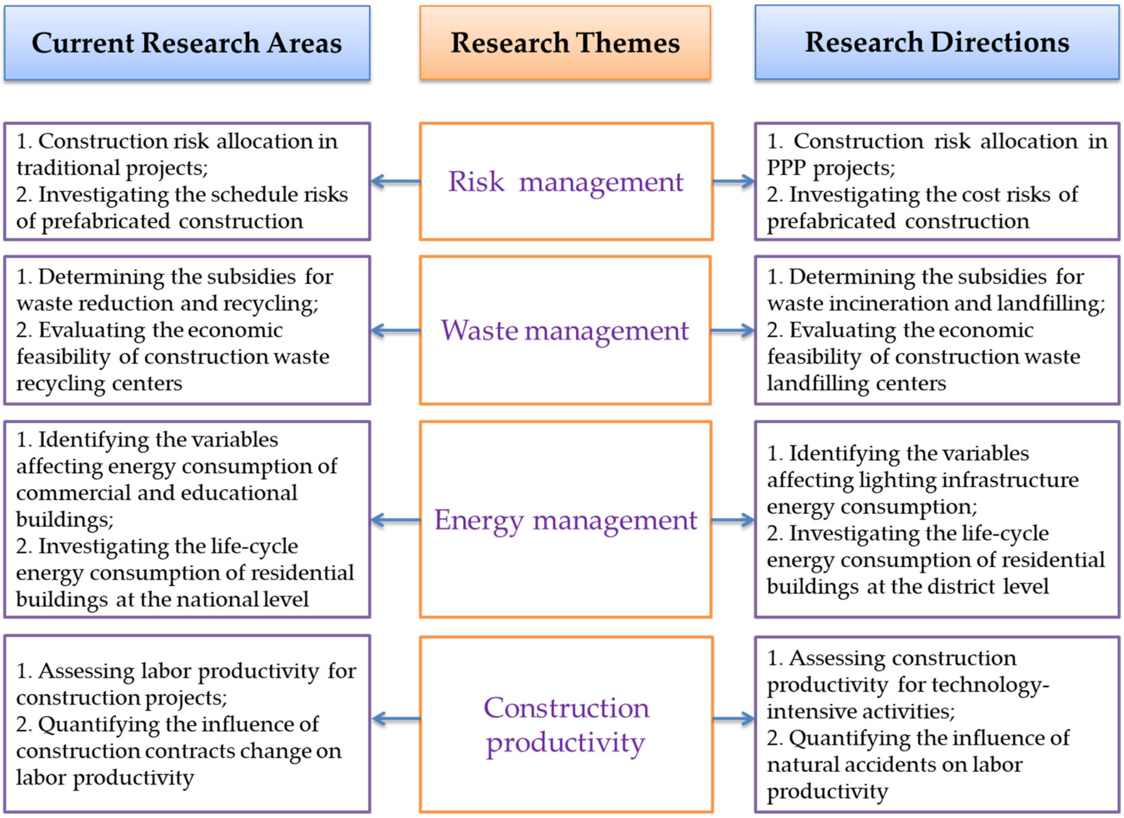

Figure 6. The connections between current research areas and future research directions.

4.2.1. Risk Management Research

In terms of risk management, the allocation of construction risks between the contractor and the owner affects the total cost of construction projects, which plays a fundamental role in the success of construction projects [62]. SD was utilized to determine the optimal risk allocation percentage for conventional construction projects, where the total cost could be minimized [38]. Besides traditional projects, public-private partnerships (PPP) projects have also been widely recognized in the last three decades, with its generally accepted benefits of lower project costs and higher project efficiency [63]. Due to the participation of multiple stakeholders, risk allocation in PPP projects is very complex and differs from traditional projects [64]. Currently, there have not been sufficient studies on applying SD to determine the optimal percentage in PPP projects, where the risk factors change over time.

In addition to risk allocation, investigating all aspects of risk factors is also crucial to the success of construction projects. For instance, prefabricated house as a sustainable building has received global recognition for its improving quality and efficiency [65]. However, various risk factors have an impact on the success of prefabricated construction. To help address these challenges, previous studies applied SD to investigate the schedule delay risks [66], but few of them focused on cost overrun risks for prefabricated construction. Since cost overrun is also a frequently encountered issue in prefabricated construction, there are still needs of employing SD to analyze various risk factors on cost overrun [67].

4.2.2. Waste Management Research

About waste management, waste disposal consist mainly of six strategies (i.e., reduction, reusing, recycling, composting, incineration, and landfilling), and each strategy is very important for sustainable construction [68]. To promote the strategies of waste disposal, there are needs for determining reasonable subsidies for the strategies. Although the existing literature has applied SD to determine subsidies for waste reduction and recycling, the subsidies for other strategies still remain to be investigated.

Since the stakeholders involved vary at different disposal strategies, the subsidy should be different as well. In recent years, incineration and landfilling have also got a lot of attention [69–71]. There is a need to employ SD to determine the subsidies for waste incineration and landfilling, which will further facilitate in the implementation of waste disposal strategies.

As such, with continuous construction of waste disposal centers, the economic viability of waste disposal centers has been a mainstream topic in construction management [49]. Since waste disposal includes six strategies, there are also six various types of waste disposal centers. According to Jia et al. [72], SD is well suitable to investigate the economic feasibility of recycling centers. However, the economic feasibility of other disposal centers, such as landfilling centers, has not been well studied by SD. Due to different income sources as well as construction and operating costs, waste landfilling centers are not the same as waste recycling centers in terms of key factors in economic feasibility. Thus, it is necessary to analyze the economic feasibility of waste landfilling centers, which can be beneficial to the construction of such centers.

4.2.3. Energy Management Research

Regarding energy management, due to the fact that construction industry is an energy-intensive industry, increasing studies have utilized SD to analyze the variables that affect energy consumption. SD was applied in an investigation of office building projects, which indicated that the strengthening of the partnership could result in 12% reduction in energy consumption and 37% reduction in CO2 emissions [4]. In addition, SD was employed to seek out a solution for reducing energy consumption in school buildings [52]. However, lighting infrastructure is also a major source of energy consumption, while the related research is still limited [73]. Since various types of buildings and facilities are used by diverse people and in different environments, the variables that affect their energy consumption are not identical. Therefore, to reduce energy consumption, there is a need to apply SD to identify the variables affecting the energy consumption in lighting infrastructure.

To reduce energy consumption, various regional governments have formulated corresponding policies [74]. The residential buildings are widely recognized as one of the greatest potential areas for energy efficiency [75]. To facilitate in government decision-making, previous research investigated the whole life cycle energy consumption of residential buildings at the national level [76]. However, the effectiveness of some residential building energy efficiency policies seems not to be ideal [77]. On the one hand, not the state, but local governments are the main implementers of policies to reduce local energy consumption. On the other hand, policies for reducing energy consumption may vary from district to district. There is a need to employ SD to characterize the whole life cycle consumption of residential buildings at the district level, which will help to make government decision-making more scientific.

4.2.4. Construction Productivity Research

In the aspect of construction productivity, assessment of productivity is very attractive to researchers. Due to the fact that the construction industry has long been a labor-intensive industry, previous studies have focused on SD applications in labor productivity [57]. However, with the advances of technology, more and more digital technologies, such as big data [78], building information modeling [79], and virtual reality [80], are emerging to improve construction productivity. In some technology-intensive activities, multiple technologies are important and major driver of productivity. At present, there have not been sufficient studies to assess construction productivity in technology-intensive activities. It is anticipated that SD will be utilized to solve this issue.

A variety of changes in construction projects can affect labor productivity [81]. SD is very suitable to evaluate the impact of some changes on labor productivity, such as the impact of contract changes [60]. However, the impact of natural disasters (e.g., typhoons and earthquakes) on construction productivity remains to be studied, which can also disrupt construction plans and affect labor productivity.

The difference is that, because of the higher uncertainty degree and inevitability of natural disasters, their influence on labor productivity is usually more serious than that of contract changes [82]. As a result, quantifying the impact of natural accidents on labor productivity would be an important challenge when the related articles are still rare.

5. Conclusions

Over the past few years, system dynamics (SD) has become a mainstream research method in construction management research, due to its effectiveness in solving complex and dynamic problems. To provide an objective picture of SD applications in construction management, this study employed the VOSviewer software to visualize the relevant articles published during the years 2011–2019. The objective picture of the current status was presented from five aspects, namely, co-authorship, published journals, co-occurring keywords, articles citations, and regions. The results indicated that Shen L. ranked the top in total citations and average citations, while Yuan H. published the greatest number of articles in this area. In the aspect of published journals, *Waste Management* received the highest average citations and average normalized citations. Based on keywords co-occurrence analysis, waste management was the most popular research topic. In terms of article citations, the article "A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste" received the highest citations in this field and had the largest number of normalized citations in highly cited articles. Through the analysis of regions, Chinese scholars were the major contributors in this research domain.

The results of this study can help scholars to get a clear picture of the current status and grasp potential research directions in the future. The applications of SD in the four mainstream themes, including "risk management", "waste management", "energy management", and "construction productivity", were analyzed in the discussion. The future research directions were further proposed, including "construction risk allocation in PPP projects", "investigating the cost risks of prefabricated construction", "determining the subsidies for waste incineration and landfilling", "evaluating the economic feasibility of construction waste landfilling centers", "identifying the variables affecting lighting infrastructure energy consumption", "investigating the life-cycle energy consumption of residential buildings at the district level", "assessing construction productivity for technology-intensive activities", and "quantifying the influence of natural accidents on labor productivity".

The results of this study can be beneficial to industries as well. For example, this study is helpful for industries to evaluate the economic feasibility of waste disposal centers. Additionally, this research can also assist industries in evaluating the productivity of construction projects and reducing the impact of various emergencies (e.g., natural disasters, contract changes) on productivity. In addition, this study can be beneficial for industries to reduce the cost and schedule risks of prefabricated construction.

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