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Supply Chain Digitalization in the Wood Manufacturing Industry: A Bibliometric Literature Review

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Abstract. The wood manufacturing industry has been described as slow in adopting efficiency increasing activities in its operations and supply chain, the industry is still facing challenges relating to digitalization such as fragmentation, poor traceability, and lack of real-time information. The integration of industry 4.0 technologies can enhance the supply chain performance in terms of efficiency, collaboration, quality, and transparency. This paper aims to evaluate the current status of digitalization in supply chains, by analysing the existing literature and mapping research trends. in an aim to create a clearer vision of the current state of digitalization in supply chains in general and focusing on the wood manufacturing supply chain in particular, the results of the literature review will be used to develop a comprehensive framework for future research direction, to fully achieve the benefits of supply chain 4.0 in the wood manufacturing industry. This framework serves as a departure point to continue explaining and observing the best way to accelerate and implement Supply Chain 4.0 practices for digitalized supply chain management while focusing specifically on the wood manufacturing industry. To achieve the overall purpose, a literature review of the key literature from 2016 to 2021 has been performed. using a bibliometric and content review analysis, the results shed light on various technologies and their applications within supply chains and identify research gaps especially between theoretical frameworks and actual implementation. This paper provides a conceptual framework to further aid researchers in the exploration of knowledge regarding the most current trends in Supply Chain 4.0 and its applications in the wood manufacturing industry compared to other advanced industries, as well as the directions of the new research in the wood manufacturing Supply Chain 4.0.

Keywords. Wood manufacturing, Supply Chain 4.0, Industry 4.0, Supply chain management, Digitalization

1 Introduction

Supply chain management (SCM) is constantly facing challenges that mandates changes [1], the industrial revolution forces rapid adjustments, were traditional methods may no longer be sufficient [2]. There is a need for a more connected, efficient, secure, transparent, and flexible supply chains, especially in the manufacturing industry, as it is rapidly being reshaped by the industry 4.0 (I4.0) revolution [3]. The wood manufacturing industry has been described as slow in adopting efficiency increasing activities in its

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operations and supply chain [4], the industry is still facing challenges relating to digitalization such as disintegration, lack of traceability, and absence of real-time information [5].

The digitalization of supply chains known as Supply Chain 4.0, focuses on the use of different technologies such as: Internet of Things, Cloud Computing, Artificial Intelligence, Big Data Analytics, Additive Manufacturing, Robotics, Block-chain, and Augmented Reality to generate products and services. the above-mentioned technological innovations, as the main enablers of I4.0, offers a high level of interconnectivity and integration between people, devices, and processes, through connecting them to each other and to the Internet and cloud systems [4]. This creates the vision of the future supply chains in which, systems, machines, and people can independently connect, communicate, and control each other. Industry 4.0 utilization is supply chains has many potentials that were discussed in recent research, however the literature still lacks a comprehensive review of the potentials of a digitalized supply chain, especially in the manufacturing industry [6], to close this gap, and in an aim to create a clearer vision of the current state of digitalization in supply chains in general, and focusing on the wood manufacturing supply chain in particular, we conducted a bibliometric literature review, that was used to develop a comprehensive framework for future research direction, to fully achieve the benefits of supply chain 4.0 in the wood manufacturing industry.

The rest of this paper will be structured as follows: section 2 will describe the methodology that was carried out in this research, the literature will be reviewed using both quantitative and qualitative analysis methods, as described in sections 3 and 4 respectively, the research gaps and future agenda will be discussed in section 5, which will end up with the conceptual framework, in section 6, we derive the overall conclusion of this research.

2 Research Methodology

This study focuses on the digitalization of supply chains using I4.0 technologies with an emphasis on the wood manufacturing industry by analysing and classifying the existing literature between the year 2015 and 2021, through conducting quantitative and qualitative research methods. The bibliometric literature review used in this study aims towards providing a quantitative analysis by using statistical methods to analyse trends of academic publications to get a sense of the current research status on the topic and to conclude an understanding of the identified patterns. The bibliometric review will be performed in three steps as explained in Figure. 1.: (1) deciding on the most appropriate keywords that can lead to the most related articles and conducting the first search on Scopus database; (2) applying filters to narrow down the pool of articles (3) examining the content of the papers to exclude the irrelevant or out of scope papers.

The search was initiated by conducting a keywords search in Scopus database using the selected keywords: (1) “supply chain“; (2) “digitalization”; (3) “industry 4.0”; (4) “wood industry”; and (5) “wood manufacturing”, which resulted in 1196 articles, secondly we filtered the results to include only publications in English language which

resulted in 1092 articles, thirdly, papers that were published before the year 2015 were excluded, reducing the number of articles to 652, and finally, a qualitative selection was made to exclude irrelevant articles based on their content reducing the final number of articles to 173.

A content analysis of the selected articles was performed as a qualitative method to extract valuable information from the technical content of the articles and conclude the research patterns which will help in identifying research gaps and to derive future research directions, the content analysis was conducted using NVivo software, which is a qualitative data analysis software that provides structure to content and can help derive patterns from academic content.

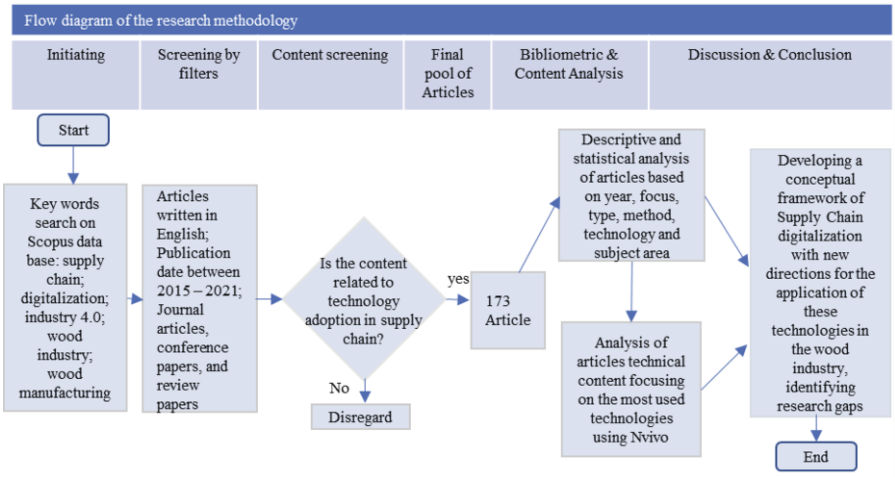


Figure. 1. Flow diagram of research methodology

3 Bibliometric analysis results

As the technological development can vary rapidly from year to year, the research was limited to relevantly recent publications, only papers from 2015 to 2021 were selected, the data was collected in March 2021, and accordingly any published article after the first quarter of 2021 has not been included in the analysis. The analysis of the yearly published articles counts (Figure. 2.) shows that this topic has received an increased attention in past couple years which indicates its current and increasing importance. There is a drop in 2021, but this might not reflect the entire year and the accurate publications count as this search was commenced in the first quarter of year 2021.

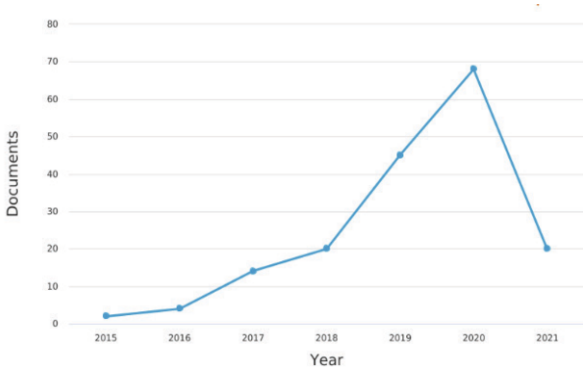


Figure. 2. Articles per Year (Jan 2015 – Mar 2021).

Scopus classified the refined publications into Journal Articles, Conference Articles, and review papers, the analysis showed that the total number of articles was almost equally distributed between journal articles and conference papers.

Several research methods were used in these articles, however, it was noticed that almost half of the amount of research papers was limited to literature reviews of certain topics, while around 20% of the examined articles proposed a framework for implementing their ideas or for future research. This indicates a lack of actual implementation of these technologies in the supply chain in general and suggests that most of the studies are still at the theoretical and proposition stage.

One should note that the analysed literature reviews were focused either on one technology at a time, such as blockchain or IoT in various supply chain activities, or focused on one single SCM driver such as traceability or security. In contrast, the approach here is to use a more integrative perspective regarding technologies as well as SCM drivers. The previous literature also lacks a holistic view of the supply chain digitalization using I4.0 technologies, where this study is needed to provide an assessment of the current level of digitalization, and to provide the base for future research direction which is built of the accurate and latest status of technology adoption within supply chain processes. A holistic overall study will also provide a platform for comparison between various technologies in terms of usability and performance.

A key words analysis was performed as a part of the bibliometric analysis, the results showed that “supply chain” and “blockchain” were the most used words, followed by the words “data”, “technology”, “information”, “IoT”, and process, this is not surprising as these terminologies are directly related to the topic of this research. There was a noticeable use of the terms “traceability” and “transparency” especially when connected with blockchain, this was later explained by the content analysis that blockchain technology was mostly used in supply chain transactions to achieve a more transparent and traceable form of the supply chain processes.

The selected articles were published by various industries and various publishers, and accordingly different areas of research had contributed to the same topic. Although the articles were published from all over the world, some research focused on a specific country. The analysis found a significant number of the articles focusing on food supply chains were research originated in India, while pharmaceutical research was mainly from

India and the United States, as these two countries are facing major counterfeit issues in their medicine supply chains and thus great research efforts are focusing on increasing the security, traceability, and transparency in medical supply chains. Articles focusing on the wood industry were mainly from Sweden, Finland, and Canada, which was expected considering that the wood production in a major contributor to the economy of these countries.

The analysis also examined the relationship between the most used technologies and the focus of each research, to try to define the most common traits that each technology was utilized to achieve. Figure. 3. illustrates the most frequent technologies that were used in the selected research, some articles examined the entire concept of I4.0 rather than focusing on a certain technology and hence this category was also added. The result of this analysis will be the drive for the following content analysis focusing on the most discussed technologies (i.e., IoT, Blockchain, BDA and Cloud computing), the analysis showed that significant attention towards blockchain technology has been paid during the recent years.

4 Content Analysis

A further qualitative analysis was conducted on the reviewed articles to derive patterns and propose future research agendas, the analysis was conducted in a categorised structure focusing on the main technologies from previous research, we demonstrate several approaches and techniques, which are related to the I4.0 implementation in various supply chain management activities from various industries, as found in previous literature. Table. 1. Shows the results of the content analysis where articles were categorized based on the used technology and the research focus, this classification helps in generating a more detailed idea about the most used applications of I4.0 in supply chain management and the technology corresponding to this application.

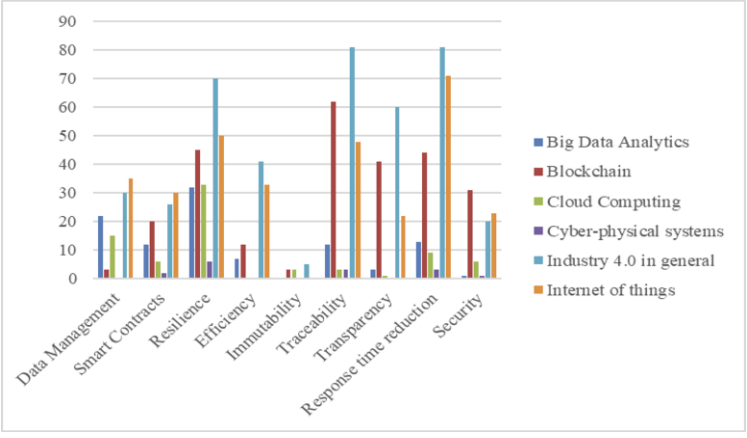


Figure. 3. Most used technologies Vs. focus of research

The analysis revealed that I 4.0 technologies were used or examined to enhance various supply chain aspects and solve certain fragilities, the results also helped in

defining eight main drivers and to draw a map between the utilization of the four main technologies and the methods of applications to digitalize the supply chains in an attempt to achieve improvements within those areas. Blockchain has received the largest amount of attention in the analysed articles, the technology has been linked to the concepts of traceability and transparency very often [2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28], moreover, smart contracts have been proposed by several articles as a companion technology for blockchain [15, 29, 30, 31]. Although this technology has been the attention of many recent studies [8, 17, 32], most of these publications were mainly a bibliometric review of blockchain and supply chain papers, and propositions of blockchain benefits and applications that remained at demonstration and pilot study stages where an actual prototype implementation is still missing.

IoT applications has also been examined by many articles and has been linked to several supply chain drivers as well, the most used enablers of IoT application were sensors and RFID devices [11, 33, 34], the review of the literature has revealed that the implementation of IoT in the wood industry is somehow still limited to the traceability of wood in particular, especially when combined with other technologies such as blockchain and smart contracts [6, 29, 35, 36, 37, 38, 39, 40, 41], however it is highly anticipated that the wood industry will shortly follow the steps of other industries and overcome its current slow advancement [6, 42].

Table. 1. Content analysis results

	Driver	Description	References
I4.0 for SCM	Immutability	- all alterations will require consensus from all participants	**Blockchain**: [7]; [8]; [9]; [10]; [11]
	Resilience	- reducing disruptions	**Blockchain:** [11]; **IoT:** [33]
	Efficiency	- accelerated SC processes - less interruptions - reduced costs	**Blockchain**: [7]; [8]; [9]; [10]; [14]; [11]; **IoT**: [34]; [11]; **Big Data**: [44]; [45]; **Cloud**: [14]
	Provenance & Security	- certifiability verifiability - tractability of product information, - origin and authenticity assurance and integrity along the entire SC - spanning, authentication - confidentiality - privacy and access control - reduced risks of counterfeiting	**Blockchain**: [15]; [2]; [16]; [17]; [18]; **IoT:** [35]; [36] **Big Data:** [46]; **Cloud:** [52]; [48]
	Transparency & Traceability	- simple tracking of items - analysing data automatically - hierarchy system for granting permissions with end-to-end visibility	**Blockchain:** [19]; [20]; [2]; [6]; [21; [4] **IoT:** [29]; [11]; **Big Data**: [47]; [48], [51] **Cloud:** [48]

	Response time reduction	- real time response, especially with smart contract applications - customer-order-process management (COM)	**Blockchain**: [22]; [23];[24]; [25]; **IoT**: [37]; [38]; **Big Data**: [49]; [51]. **Cloud**: [52]
	Data management	- security of stored data - warehouse management - immediate capturing of real data	**Blockchain:** [26]; [27]; [9]; [28]; **IoT**: [41]; [40]; [33]. **Big Data:** [50]; [51]; **Cloud**: [53]
	Smart contracts	- optimized design of business operations - less need for intermediary - less time and cost - prominent level of security and justice - hyperconnected logistics	**Blockchai**n: [29]; [30]; [31]; [15]; **IOT**: [39]; [29]

As supply chain management core success elements rely on making use of available data and hence big data analytics (BDA) can revolutionise SCM by facilitating concurrent and methodical data collection, analysis and rapid decision making which will provide substantial performance improvements in various processes [43, 44, 45, 46, 47, 48, 49, 50, 51], Similarly in supply chains, enormous amounts of information can be seamlessly shared and transmitted between different participants using cloud computing [14, 43, 48, 52, 53], Although the applications that were proposed in recent research can be applied to various industries, a study of BDA applications in the wood industry has not been found, and a lack of research on further implementation of cloud technology or cloud manufacturing in the wood industry.

5 Research gaps and future agenda

The review of the existing literature revealed that there is a general shortage of technical and analytical research that focuses on feasible ways for utilizing I4.0 applications in supply chain processes in general, and an evident lack of such research focusing on the wood industry supply chains. The review results found that there is a clear gap between the level of digitalization of forestry activities, and the supply chain of the after-sawmill stage or the production phase within the wood industry. The term forestry 4.0 seems to be present and obtainable, while the supply chain 4.0 of the wood manufacturing is still far from full implementation.

In view of the limitations, further research is needed specially to address certain gaps: (1) to evaluate the current level of digitalization using industry 4.0 technologies, (2) critically review the existing research in supply chain digitalization in the wood industry to draw a map for future researchers to deal with the identified limitations, and (3) fulfil the aim of this research which will focus on industry 4.0 applications in the wood industry supply chain. As such, this study aims to bridge the mentioned three gaps in the existing review papers.

The reviewed articles all shared a goal to modernize and digitalize the supply chain processes to increase the efficiency, reduce cost and time, achieve better quality and

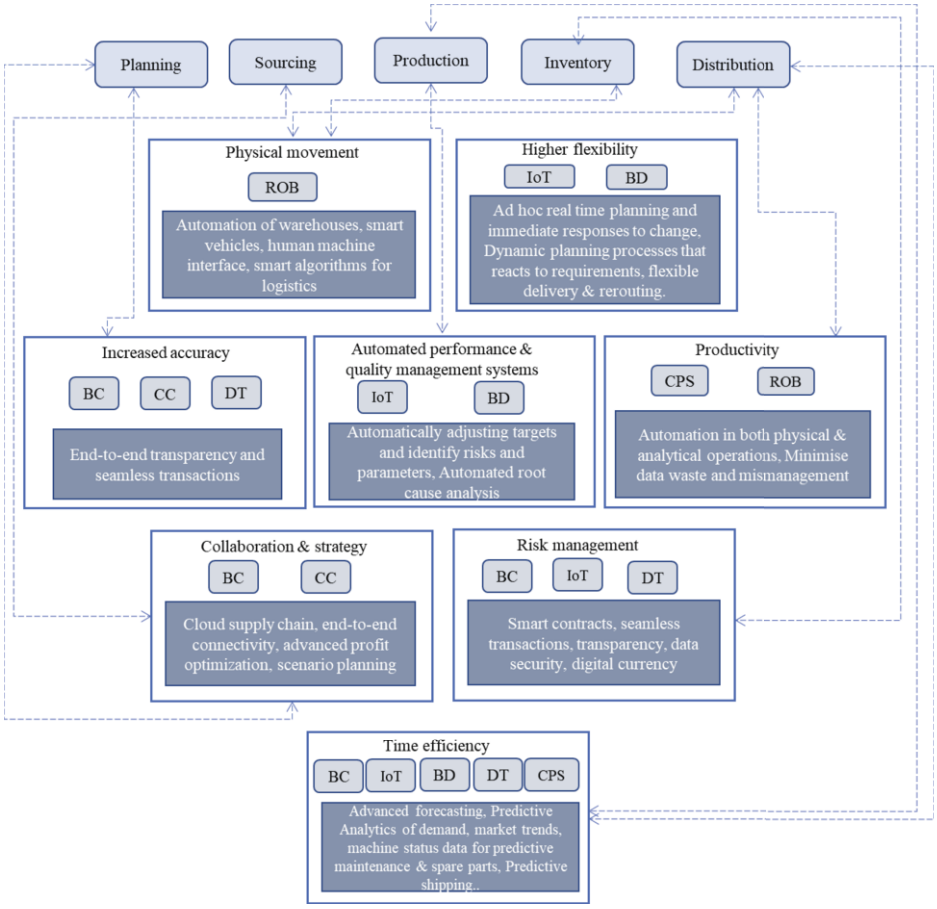
sustainability, minimize risk and security issues, among many other promising benefits. As some of these goals have already been achieved and evidence of I4.0 utilization has been found, other possibilities are still under examination or theoretical review, and accordingly the purpose of this research was to identify these gaps in the holistic overview of the supply chain 4.0 in various industries and to shed the lights on the wood industry in specific, and to propose future research directions to overcome these gaps and limitations.

Wood supply chain research focusing on digitalization is very limited, there is a shortage of research with actual implementation of I4.0 technologies in SCM, beyond theoretical studies proposals, and thus there is a need for these ideas to be tested and implemented in a real context in order to verify the applicability and benefits of these proposals. Moreover, available studies have not yet covered adequately the enablers of these technologies and the technical barriers that might constrain these applications, such as the connectivity and coverage in forests and distanced locations which is limiting the utilization of various IoT devices, there is a need for research that provides solution for these barriers and technical issues.

As for the data management and utilization which is a major field of I4.0 applications, there has been a lack of research on data utilization in the wood manufacturing industry, especially for planning and forecasting, there is a need for future work to apply I4.0 technologies in production planning and prediction. The research has also identified another gap related to data security, the issue of lack of trust and insecurity that combines the high-risk technologies has not been adequately addressed, although there has been an extensive use of the terms “trust” and “security” within all research containing decentralised and shared platforms of data, there is a need for research to tackle the issue of data security and to provide solutions to overcome the security risks of I4.0 applications. The analysis showed that most endeavours to digitalize supply chains has focused on one technology solely. For a holistic perspective, we suggest that future research should examine potentials of combining technologies, to explore the full potential of I4.0. This is mostly recommended to use technologies to leverage and boost the potentials of these applications [20], finally, the review found that the majority of research focusing on supply chain 4.0 has discussed the readiness phase only, there is a lack of research to explore what comes after the I4.0 implementation within enterprises such as the response, recovery and growth phases. It would be advantageous for more research to address the expected influence of these technologies on social and economic levels of the industry, such as how it might affect labour force, or how internal structures of businesses might be affected, other topics are worth further investigating such as management resistance, market instability issues, training, and capacity building needs, financial constraints and many more. Figure. 4 outlines a conceptual framework with new directions for the application of I4.0 technologies in the supply chain digitalization, the framework is applicable for wood manufacturing industry. This framework serves as a departure point to continue explaining and observing the best ways to accelerate and implement I4.0 technologies in supply chain practices while focusing specifically on the wood manufacturing industry, the framework defined eight drivers for further research in alignment with the defined research gaps.

6 Conclusion

This paper has presented an overview of the current status of research on digitalization in supply chain management utilizing I4.0 technologies, with a focus on the supply chain of the wood manufacturing. A total of 173 articles, published between 2015 and 2021, were selected and reviewed, following a systematic refining, and selecting criteria. A bibliometric literature review has been conducted using both descriptive and content analysis methods. Existing literature gaps and future research recommendations has been identified.



BC: Blockchain, DT: Data analytics, BD: Big data, CC: Cloud computing, ROB: Robotics.

Figure 4. Framework for future research

The descriptive analysis showed that there is an increasing and obvious interest in the subject of supply chain digitalization especially in line with the recent research focus

towards I4.0, the analysis highlighted the reluctance and slow adaption of the wood manufacturing industry to follow the digitalization stream when compared to other industries, the descriptive review also revealed the shortage of relevant research focusing om the wood manufacturing supply chain in regards of digitalization.

The review of the existing literature revealed that there is a lack of technical and analytical research that focuses on feasible ways for utilizing I4.0 applications in supply chain processes in general, and an evident lack of such research focusing on the wood construction supply chain. The review results revealed that there is a clear gap between the level of digitalization of forestry activities, and the supply chain of the after-sawmill stage or the production phase within the wood industry. The term forestry 4.0 seems to be present and obtainable, while the supply chain 4.0 of the wood manufacturing is still far from full implementation.

The content analysis focused on the four main technologies that were mentioned in the analyses articles and revealed the main drivers that the technologies are used to enhance, the analysis covered research from various industries while shedding the light on the wood manufacturing specifically. The review concluded that I4.0 technologies holds huge opportunities for the digitalization of supply chain beyond the current status of supply chain 4.0, the identified gaps were used to draw a framework for future research directions that can furtherly enhance the current supply chain management generally and should also benefit the wood manufacturing industry.

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