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Smart and Sustainable Built Enviro

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Journal:	*Smart and Sustainable Built Environment*
Manuscript ID	SASBE-12-2021-0224.R1
Manuscript Type:	Original Research Paper
Keywords:	Supply chain 4.0, Industry 4.0, Construction supply chain, Wood construction, Digitalization, Scientometric-Thematic analysis

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Abstract. The wood construction industry has been described as slow in adapting efficiency-increasing activities in its operations and supply chain. The industry is still facing challenges related to digitalization, such as fragmentation, poor traceability, and lack of real-time information. The digital supply chain, or Supply Chain 4.0, focuses on building a new kind of supply network that is resilient and responsive. Capturing the value of Industry 4.0, utilization in supply chains has been explored and discussed in recent research. However, the existing literature still lacks a comprehensive review of the potential of a digitalized supply chain, especially in the construction industry. This study evaluates the status of digitalization in construction supply chains by thematically analyzing the existing literature and mapping research trends. The literature review results will help develop a comprehensive framework for future research direction to create a clearer vision of the current state of digitalization in supply chains and focus on the wood construction supply chain, thus, fully achieving the benefits of Supply Chain 4.0 in the wood construction industry. This framework is pivotal to continue explaining and observing the best ways to accelerate and implement Supply Chain 4.0 practices for digitalized supply chain management while focusing specifically on the wood construction industry. A review of the key literature from 2016–2021 was performed. The results highlight various technologies and their applications within supply chains and identify research gaps, especially between theoretical frameworks and actual implementation using a scientometric-thematic analysis. This paper provides a conceptual framework to further aid researchers in exploring the current trends in Supply Chain 4.0 and its applications in the wood construction industry compared to other more advanced industries. Suggested directions for future research in the wood construction Supply Chain 4.0 are outlined.

Keywords. Supply Chain 4.0, Industry 4.0, Construction supply chain, Wood construction, Digitalization, Scientometric-Thematic analysis

1 Introduction

Supply chain management (SCM) is constantly challenged mandating changes (Lagorio et al., 2020). Meanwhile, the industrial revolution has forced rapid adjustments, and traditional methods may no longer be sufficient (Hogberg et al., 2020). There is a need for 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 (Liu et al., 2018). Recently, the focus has shifted to disruptive concepts, such as I4.0 (I4.0). Internet of things, cloud computing, artificial intelligence, big data analytics, digital twins, robotics, and blockchain applications, among others, increase the operational effectiveness and leverage emerging digital supply chain business models. I4.0 connects the largely discrete, siloed supply chains and transforms them into a completely integrated system fully transparent to all stakeholders (Hogberg et al., 2020).

The digital supply chain, known as Supply Chain 4.0, focuses on building a new kind of supply network that is resilient and responsive. It is envisioned as an integrated system starting from integrated planning and execution, logistics visibility, Procurement 4.0, smart warehousing, efficient spare parts management, autonomous and B2C logistics, prescriptive supply chain analytics, and digital supply chain enablers. Combining these pieces into an integrated system will significantly benefit supply chain business models in terms of flexibility, productivity, and cost reduction (Figorilli et al., 2018). The McKinsey report (2016) revealed that the potential impact of Supply Chain 4.0, in the next two to three years, could reduce the operational cost up to 30%, the lost sales by 75%, and decrease inventories by up to 75%, while simultaneously increasing the agility of the supply chains significantly (Mckinsey, 2016).

Capturing the value of I4.0, utilization in supply chains has been explored and discussed in recent research. However, the existing literature still lacks a comprehensive review of the potential of a digitalized supply chain, especially in the construction industry (Cueva-Sanchez et al., 2020). To close this gap, create a clearer vision of the current state of digitalization in supply chains in general, and highlight the wood construction supply chain, we conducted a bibliometric literature review to develop a comprehensive framework for future research direction. Thus, fully achieving the benefits of Supply Chain 4.0 in the wood construction industry.

In the recently published scientific work concerning supply chain digitalization, only a few articles examined the adoption of I4.0 technologies their attributes, benefits, and drawbacks that can result from their application (Maryniak, 2020, Abdirad, 2020, Kohl, 2021). Lagorio et al. (2020) explored the trend toward new technologies in logistics and identified the main research trends and gaps. However, this study focuses only on high-level supply chain attributes. Other studies attempted to narrow the research to specific technologies, in particular, a study by Koot et al. (2021) who focused on their research on exploring the utilization of the Internet of Things (IoT) and big data analytics (BDA) in the supply chain context. However, the study was limited to the decision-making aspect and revealed multiple gaps. Similarly, a study by Hogberg et al. (2020) examined the trend of blockchain in supply chain and logistics. The results revealed several possibilities and uses of blockchain, such as enhancing the flow, streamlining transactions, and using sensors in logistics tracking and registry. The study also argued about the potential benefits of blockchain adoption in terms of cost, traceability, and security; however, the study claims there is still a scarcity of information on blockchain (BC) in SCM, indicating further research necessity. However, a review of the existing literature shows that the focus on the construction supply chain, especially on the wood construction supply chain, is extremely limited. Thus, this research aims to identify the status of I4.0 adoption in the wood construction supply chain by examining each technology concerning current utilization and future possibilities to provide a clear path for future research.

This study attempts to create a holistic framework for I4.0 utilization in the construction supply chain for future research using a scientometric-thematic analysis. Moreover, this study highlights the reluctance and slow adaptation of the wood construction industry to adopt digitalization compared to other industries.

The rest of this paper is structured as follows: section 2 lists the research gap and motivation, followed by section 3, which describes the methodology; the literature is reviewed using both quantitative and qualitative analysis methods, as described in sections 4 and 5, respectively; the research gaps and future agenda are further discussed to arrive at the conceptual framework in section 6, and in section 7 we derive the overall conclusion of this research.

2 Research Gaps and future motivation

As this study builds on previous literature on I4.0 technologies, supply chain digitalization, and wood construction supply chain, it is important to initiate the study by examining the preceding literature and identifying the research gaps. Table 1 summarizes a selection of similar studies and their limitations.

Table 1. Relevant literature review research

Author/year	Research focus	Methods	Limitations
(Lagorio, 2020)	Explore new technology adoption in logistics	Manual literature review	This study discussed supply chain in general; however, the construction industry was not sufficiently covered, nor the applications of the technologies related to a specific industry.
(Manavalan & Jayakrishna, 2019)	Explore the use of the IoT to achieve sustainability	Scientometric Analysis	This study addressed only one technology, IoT, focusing on sustainable supply chains.
(Kumar & Shoghli, 2018)	Explore IoT applications in supply chain optimization of construction materials	Manual literature review	This study focused on the construction industry; however, only from the material supply chain perspective and using only IoT. Moreover, the study was conducted in 2018, and significant development in both technologies has taken place in the last three years.
(Koot et al., 2021)	Explore the IoT and BDA applications in supply chain decision making,	Systematic literature review	This study focused on the decision-making drivers and two main technologies specifically.
(He et al., 2020)	Explore the IoT enabled supply chain planning and coordination with big data services	Critical literature review	This study covered multiple technologies; however, the focus was only on planning and coordination within the supply chain. Additionally, the study only highlighted theoretical implications.
(Pournader et al., 2020)	Explore the use of Blockchain in supply chains	Systematic literature review	This study only focused on blockchain technology in the transportation stage of the supply chain
(Raut et al., 2020)	Explore the enabling technologies for I4.0 manufacturing and supply chain	Systematic literature review	This study focused on a wide range of technologies; however, the review focused mainly on the manufacturing industry.

Given the limitations presented in Table 1, further research is needed to address certain gaps: (1) evaluate the current level of digitalization using I4.0 through a scientometric analysis; (2) critically review the existing research on supply chain digitalization in construction to draw a map for future researchers to deal with the identified limitations, and (3) fulfill the aim of this research, focusing on

I4.0 applications in the wood construction supply chain. Thus, this study bridges the three gaps mentioned in existing review papers.

3 Research Methodology

This study focuses on the digitalization of supply chains using I4.0 technologies, emphasizing the wood construction industry by analyzing and classifying the existing literature between 2015–2021 through quantitative and qualitative research methods. The bibliometric literature review used in this study aims to provide a quantitative analysis using statistical methods. Trends of academic publications are analyzed to understand the current research on the topic and identify patterns. The bibliometric review is performed in three steps (see Figure 1): (1) deciding appropriate keywords leading to the most related articles and conducting the first search in the Scopus database; (2) filtering to narrow down the pool of articles; and (3) examining the content to exclude irrelevant or out of scope papers.

The search was initiated by conducting a keywords search in the Scopus database using the selected keywords: (1) “supply chain; “ (2) “digitalization;” (3) “Industry 4.0;” (4) “wood industry;” and (5) “wood construction;” which resulted in 1196 articles. Additionally, results were filtered to include only publications in the English language, resulting in 1092 articles. Next, papers published before 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. This helped identify research gaps and derive future research directions. The content analysis was conducted using Nvivo software, a qualitative data analysis software providing structure to content and can help derive patterns from academic content.

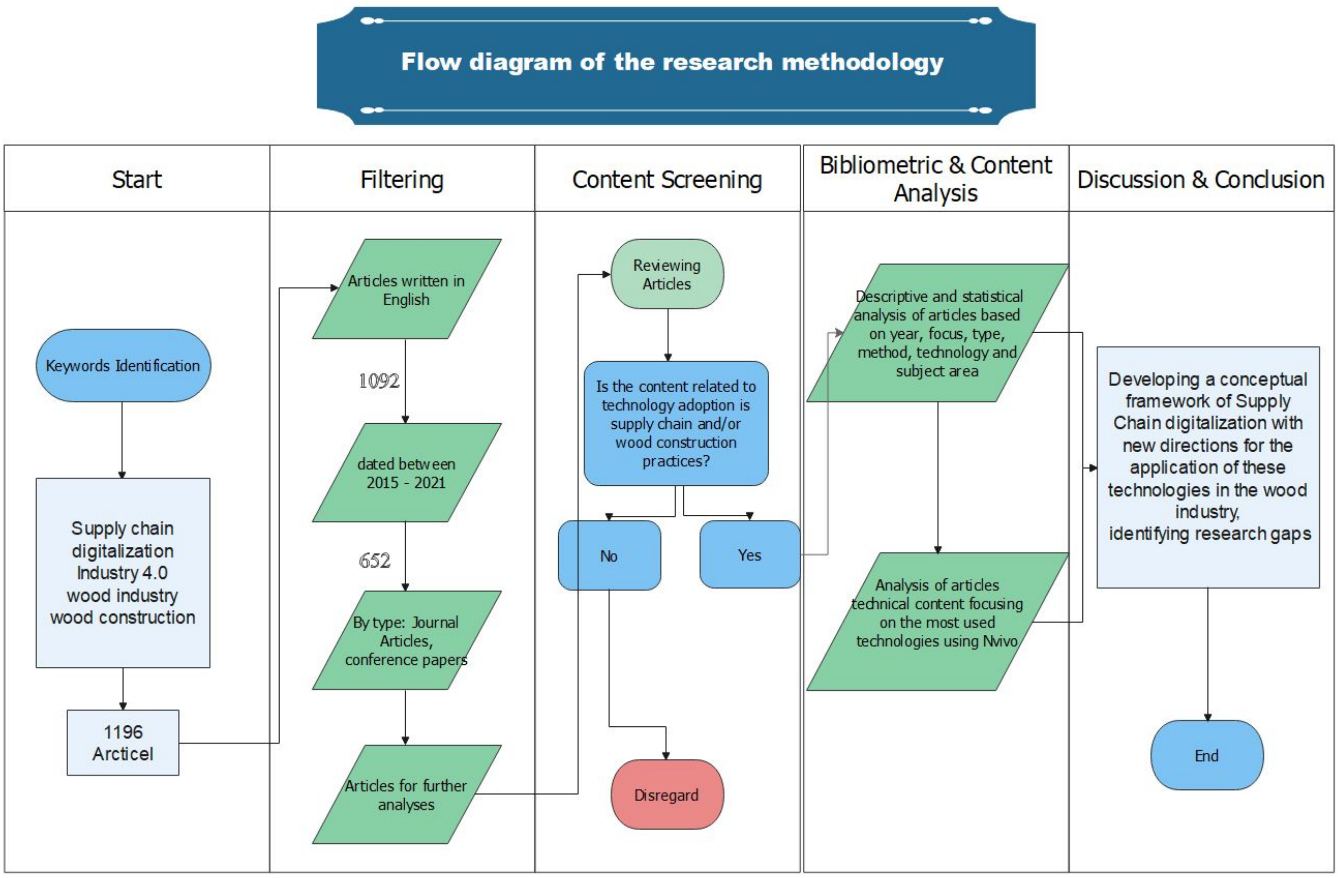

Figure 1. Flow diagram of research methodology

4 Bibliometric analysis results

As technological development can vary rapidly from year to year, the research was limited to relevant recent publications; only papers from 2015–2021 were selected. However, analysis of the yearly published article count (Figure 2.) shows that this topic has received increased attention in recent years, indicating its current and increasing importance.

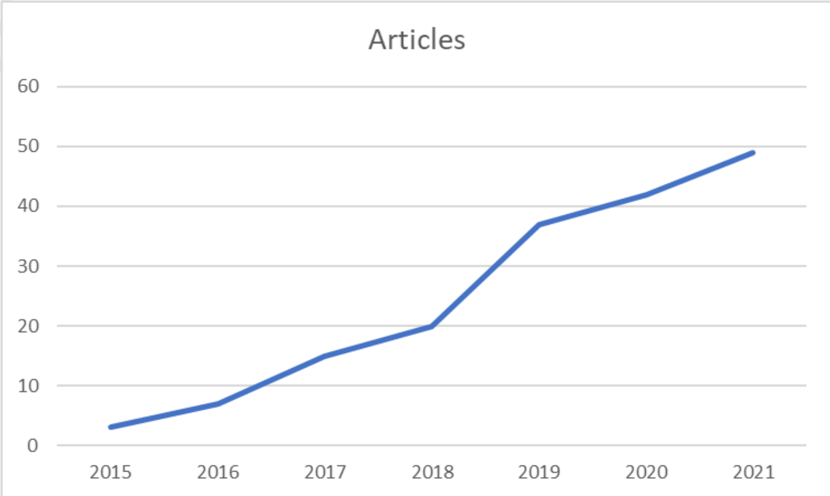

Figure 2. Articles per year

Of the 173 articles, 55 were based solely on reviewing previous literature. However, most of the literature reviewed focused on a limited scope, such as a specific technology or supply chain drivers, highlighting the need for a holistic review addressing all I4.0 technologies in the wood construction industry.

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 "data," "technology," "information," "IoT," and "process," as they were related to this research topic.

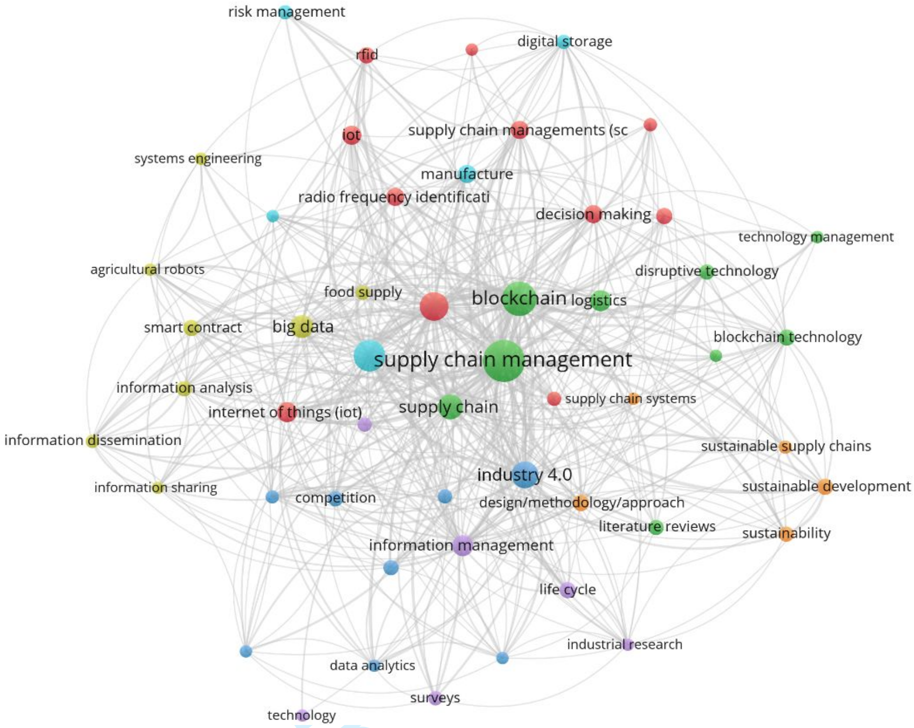

Figure 3. Mapping of the most used words.

There was a noticeable use of the terms "traceability" and "transparency," especially when connected with blockchain. The content analysis later explained that blockchain technology was mostly used in supply chain transactions to achieve transparent and traceable supply chain processes. Figure 3 illustrates the mapping of the most frequent keywords. The mapping was created using the VOSviewer platform to build a visualized bibliometric keywords network.

Although the articles were published worldwide, only some research has focused on a specific country. The analysis found a significant number of articles focusing on food supply chains that 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. Thus, great research efforts are focused on increasing the security, traceability, and transparency of medical supply chains. Articles focusing on the wood industry were mainly from Sweden, Finland, and Canada, considering that wood production is a major contributor to the economy of these countries.

Furthermore, the analysis examined the relationship between the most used technologies and the focus of each research to define the most common traits that each technology was utilized to achieve. Figure 4 illustrates the most frequently used technologies in the selected research. The analysis result d promoted the following content analysis on the most discussed technologies (i.e., IoT, blockchain, BDA, cloud computing, cyber-physical systems, and digital twins). The analysis showed significant attention had been placed on blockchain technology in recent years.

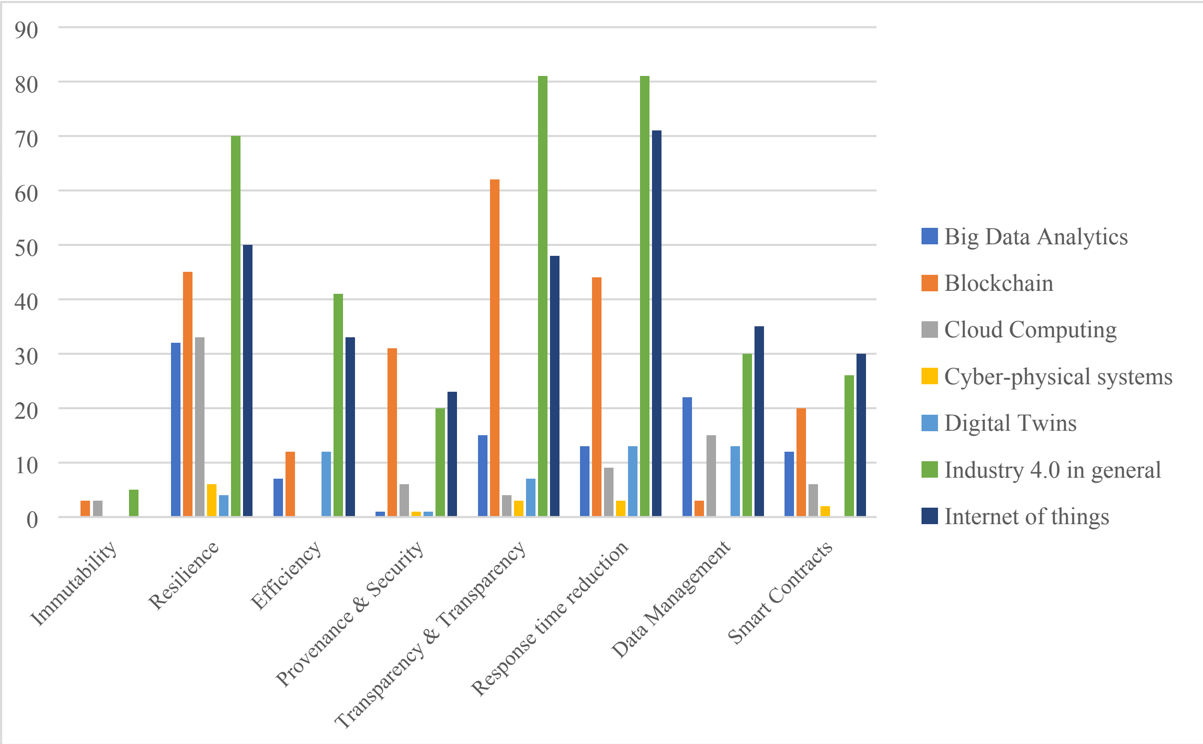

Figure 4. Most used technologies for each research focus

5 Content Analysis

Further, a qualitative analysis was conducted on the reviewed articles to derive patterns and propose future research agendas. The analysis was conducted in a categorized structure on the main technologies from previous research. Several approaches and techniques related to the I4.0 implementation have been demonstrated in various SCM activities in various industries. Figure 5 shows the content analysis results in which articles were categorized based on the technology used and the research focus. This classification helps generate a detailed idea about the most used applications of I4.0 in SCM and the technology corresponding to this application.

The analysis revealed that I4.0 technologies were used or examined to enhance various supply chain aspects and solve fragilities. The results also helped define eight main drivers and draw a map between the utilization of the main technologies and the methods of applications to digitalize the supply chains to achieve improvements within those areas. While blockchain has received the largest amount of attention in the analyzed articles, the technology has been linked to the concepts of traceability and transparency very often (Abdullah et al., 2020; Chang et al., 2019; Cueva-Sanchez et al., 2020; Elghaish et al., 2021; Fernández-Caramés et al., 2019; Figorilli et al., 2018; Fosso Wamba et al., 2020; Ghode et al., 2020; Gonczol et al., 2020; Habib et al., 2020; Hogberg et al., 2020; Ivanov et al., 2019; Jawaji et al., 2020; Karamchandani et al., 2021; Köhler & Pizzol, 2020; Kumiawan et al., 2020; Li et al., 2020; Morozova, 2021; Parung, 2019; Peña et al., 2020; Pooja et al., 2020; Queiroz et al., 2020; Saurabh & Dey, 2021; Sobb et al., 2020; Zhuang et al., 2018). Moreover, several researchers have proposed smart contracts as a companion technology for blockchain (Augusto et al., 2019; Chinedu & Awasthi, 2019; Divya et al., 2020; Habib et al., 2020). Although this technology has been the focus of many recent studies (Köhler & Pizzol, 2020; Pooja et al., 2020; Tayal et al., 2021), most of these publications were mainly reviews of blockchain and supply chains and propositions of blockchain benefits and applications. Supply chains still lack a practical and actual blockchain implementation.

5.1 Internet of things

The IoT is a recent term used in technology that describes a state of connectivity among several devices, anytime, anywhere. Others have described it as the ability of things to operate in smart spaces and have personal identities and virtual personalities. They can exchange information and interact within different contexts (Ünal et al., 2020). These devices can share information and communicate in an internet-enabled space (Fatorachian & Kazemi, 2021).

IoT has already been adopted and is expected to continue to digitize supply chains and logistics. The visibility it provides can be deployed in all products and processes to revolutionize the industry (Fatorachian & Kazemi, 2021). When all devices, products, machines, and elements along the supply chain are embedded with sensors connecting them, it will foster a high level of interaction and connectivity. An IoT environment facilitates the seamless flow of information, bringing advanced visibility to operations enhancing the supply chain performance (Abdullah et al., 2020). The technologies that enable IoT applications include radio frequency identification (RFID), wireless sensing, electronic labeling (EPC), global positioning systems (GPS), and reader devices (Avilés-Sacoto et al., 2019). These technologies act in four major stages in an IoT-enabled environment: (1) data collection, (2) data processes and transfer, (3) service, and (4) interface stages. They are expected to display the information to the end-user of the system (Augusto et al., 2019; Hogberg et al., 2020).

Several scholarly articles have addressed the potential and advantages of IoT technology in SCM. IoT has drastically changed the process of tracking items and individuals in real-time along the supply chain. This automated tracking method reduces the need for human interaction, decreasing time and cost and eventually improving the quality of operations (Ivankova et al., 2020). Literature shows the several benefits of the automation of the supply chain through IoT technologies, such as reducing security issues (Jachimczyk et al., 2021; Koot et al., 2021), real-life monitoring of resources and workflow (Feng & Audy, 2020), speeding up data analysis and decision making (Fatorachian & Kazemi, 2021), reducing manual processes and eventually reducing time and cost (Singh et al., 2021), and improving quality (Dutta et al., 2020; Ivankova et al., 2020).

IoT-based models and prototypes were proposed in several recent research in various industries. A study by Ahmadi et al. (2020) proposed a framework for drug tracking along the supply chain of pharmaceutical companies to minimize theft, especially in less developed countries. The study proposed using IoT through identification tags attached to medicine packages (Ahmadi et al., 2020). Al-Amin et al. (2021) proposed a model for reducing manual data entry and recording processes and verifying information using IoT combined with smart contracts (Al-Amin et al., 2021). Avilés-Sacoto et al. (2019) studied IoT's potential to achieve a green supply chain and increase the agility, leanness, and resilience of supply chains (Avilés-Sacoto et al., 2019). Witkowski (2017) proposed a framework to enhance warehouse management using IoT, allowing objects in the inventory to provide information regarding location, quantity, physical condition, and general atmosphere information (Witkowski, 2017).

IoT applications have been present in the wood industry operations as well, providing real-time monitoring of forest environments, real-time tracking of forest activities, fire and accident reporting through advanced wireless communication technologies, systems such as Lidar, and smartphone applications for automated forest detection, data collection, and inventory estimation (Singh et al., 2021). However, using such technologies is still considered limited. One reason is that the operations of forests are usually conducted in locations where internet connectivity might not be available. Moreover, few articles have mentioned IoT use in the wood industry other than the forest stage, such as wood production and the wood supply chain.

Sperandio (2017) stressed the importance of wood origin tracing using a wood traceability system to ensure adherence to the European certification system of sustainable forest management, launched to prohibit wood trading from illegal origins. The proposed system used RFID tags attached to every wood piece from forest to sawmill to ensure traceability along the entire supply chain (Sperandio, 2017). A similar prototype was proposed by Figorilli et al. (2018), adding a blockchain platform to the design, as they claimed that this model is the first to introduce a completely automated system for wood tracing from standing trees to the end-user (Figorilli et al., 2018). A review of the literature reveals that the implementation of IoT in the wood industry is still limited to the traceability of wood in particular, especially when combined with other technologies such as blockchain and smart contracts (Cueva-Sanchez et al., 2020). However, it is highly anticipated that the wood industry will shortly follow other industries and overcome its current slow advancement (Cueva-Sanchez et al., 2020).

5.2 Blockchain

Blockchain was first introduced in 2008 to serve as a public ledger for cryptocurrency transactions, mainly Bitcoin (Al-Amin et al., 2021). Less than ten years after blockchain was introduced to the world, a study by PwC revealed that financial industries worldwide are already relying on blockchain for the security and efficiency of their transactions. Other industries, such as manufacturing, healthcare, food, and pharmaceuticals, follow this trend (Al-Amin et al., 2021; Elghaish; et al., 2021). Supply chain leaders believe that the potential of blockchain for SCM transactions can be compared to the Internet's influence on businesses (Abou Maroun et al., 2019; Elghaish; et al., 2021). The neutral ground offered by the blockchain's centralized platform can be considered more secure and lowers the risk of fraud than conventional centralized platforms and databases.

The main idea behind blockchain is to achieve network security, transparency, and visibility, which combines elements such as smart contracts, consensus algorithms, storage systems, and data encryption (Dutta et al., 2020). Blockchain can be described as a series of connected blocks, each having its own ID. The transaction history can be easily traced between blocks, giving the technology its transparent and secure characteristics, especially if any transaction is validated and authorized by the users in the network (Dutta et al., 2020).

Blockchain practitioners have identified several characteristics of blockchain that make it ideal for supply chain operations enhancement, such as its decentralized and transparent nature, where all data on the system can be stored, monitored, validated, and accessed through multiple access points, with consensus from participants in the network (Dutta et al., 2020). Blockchain security stems from the fact that stored data are immutable, irreversible, and verifiable. A main application of blockchain is smart contracts, or contract automation, where contracts can be drafted and executed digitally with more security and less time and cost. Additionally, the conditions of the contract are coded and applied to all stakeholders transparently and efficiently (Kouhizadeh et al., 2021).

Blockchain has been investigated in many studies as a tool to increase the traceability and transparency of transactions along the supply chain. Abdullah et al. (2020) proposed a framework for secure and smart SCM using blockchain and RFID. Each product has a control chip that can be read using the RFID reader, which will send an encrypted message to the blockchain, functioning as a public ledger. The saved nodes cannot be altered or manipulated, although the information will be shared for everyone to read. This system is proposed to provide secure authentication and high levels of transparency among all stakeholders (Abdullah et al., 2020). A similar model was proposed by Ahmadi et al. (2020) to improve the traceability and visibility of drugs along a pharmaceutical supply chain to reduce the risk of counterfeit drugs in the pharmaceutical industry (Ahmadi et al., 2020). A cost optimization model using blockchain and RFID in healthcare supply chain operations was proposed by Divya et al. (2020) to create a decentralized system containing all information regarding the medicine that will minimize counterfeiting and theft issues and simplify drug warehouse management. However, the system needs further development to address security issues, especially the integrity of the data entered by various parties (Divya et al., 2020). Modum, a Swiss company, tested a blockchain traceability model that can monitor the temperature of drug storage along the supply chain using heat sensors and smart contracts (Sunny et al., 2020).

Similar attempts have been made in the agro-food supply chains to reduce the complexity of traditional food supply chains using blockchain between two-sided creditors (Al-Amin et al., 2021), suggesting that the blockchain platform allows both buyers and suppliers to make payments, display their products, and even negotiate offers without intermediaries and lengthy processes. The traceability of food and agriculture supply chains through blockchain has been tackled by several studies, theoretically and using case studies (Behnke & Janssen, 2019; Bumblauskas et al., 2020; Köhler & Pizzol, 2020), arguing the effectiveness of such models to enhance food supply chains in general. Pooja et al. (2020) proposed a model that uses smart contracts and Ethereum currency to provide farmers with a chance to negotiate and quote prices fairly and securely, while smart contracts ensure that all conditions are satisfied before completing the purchase. Similar models were introduced to track food back to their origin, for example, to track the source of meat, fruits, or even wine. IBM tested a pilot study for food traceability using blockchain. The results showed that the origin of a shipment of mangoes could be traced in less than 2s (Sunny et al., 2020).

Blockchain offers promising solutions for courier services, cargo, and manufacturing logistics, and several novel systems have been proposed for parcel and shipment tracking along the supply chain using blockchain platforms combined with IoT devices, sensors, and tags, among others (Sunny et al., 2020). Big corporations have already adopted blockchain in their tracking processes, such as FedEx, Walmart, Mastercard, and others (Tayal et al., 2021).

Very few studies have tackled deploying blockchain in the wood industry optimization. Notably, Figorilli et al. (2018) developed a prototype to track wood along the supply chain using RFID sensors and open-source technology to ensure quality and authenticity. A simulation of the entire forest was used, and the entire supply chain was modeled from trees to the final product. The prototype used several IoT devices (IoT) and tags to trace wood along the supply chain (Figorilli et al., 2018). Despite the immense potential of blockchain in wood production and its supply chains, there lacks a holistic view of blockchain applications beyond the portfolio of technologies.

A review of recent research revealed a noticeable tendency for blockchain adoption to enhance authentication and security of information in financial transactions and various supply chains of different industries (Al-Amin et al., 2021). Although this technology has been the focus of many recent studies (Köhler & Pizzol, 2020; Pooja et al., 2020; Tayal et al., 2021), most of these publications were mainly a bibliometric review of blockchain and supply chain papers, propositions of blockchain benefits, and applications that remained at demonstration and pilot study stages where an actual prototype implementation was still missing. Available studies have not adequately covered the enablers of technology adoption and have not provided evidence of the effect of blockchain adoption on supply chain performance (Fosso Wamba et al., 2020).

5.3 Big Data Analytics

BDA is a technical term that refers to analyzing massive data sets that are growing rapidly (i.e., big data) to extract useful information and data patterns that can be of value for businesses (Koot et al., 2021). It is an essential element of I4.0, particularly the IoT, as enormous amounts of data are collected and go beyond manual or conventional data analysis methods (Avilés-Sacoto et al., 2019).

The core success elements of SCM rely on using available data; hence, BDA can revolutionize SCM by facilitating concurrent and methodical data collection, analysis, and rapid decision-making. This will provide substantial performance improvements in various processes (Fatorachian & Kazemi, 2021). The data collected from different resources can be utilized for risk management, market prediction, warehouse management, supplier selection, and to conclude valuable trends and patterns (Fatorachian & Kazemi, 2021). BDA allows for the immediate analysis of several data streams, generating valuable information for planning and forecasting, which results in a detailed framework for SCM operations. For example, the analysis of previous purchasing patterns can facilitate the identification of the most profitable customers (Seetha Raman et al., 2018).

BDA technology can also optimize transportation, one of the main logistics operations, by enhancing data exchange within the supply chain. Information such as best routes, traffic congestion, and effective navigation can ultimately enhance the safety, quality, cost, and time of deliveries (Fatorachian & Kazemi, 2021). Integrating BDA and IoT can promote quick designs and reduce prototyping time (Li & Liu, 2019). 3D printing is an example of this instant data exchange between digital and physical entities, allowing rapid design and prototyping and less time to produce and market (Papadopoulos et al., 2017).

Recent research has highlighted the integration of BDA in various business processes and operations, and SCM has received a great deal of attention. Li and Liu (2019) proposed a framework to support what they identified as data-driven supply chain management (DSCM). This framework is still in the conceptual stage; however, it is currently being validated in a major auto manufacturer in China (Li & Liu, 2019). Kazancoglu Y. et al. (2021) tried to identify the barriers to deploying BDA in dairy supply chains by developing a framework with proposed solutions for each barrier (Kazancoglu Y. et al., 2021). Several studies have attempted to address sustainability issues in the supply chain using BDA. AlNuaimi B.K. et al. (2021) investigated the impacts of BDA capabilities (BDAC) on e-procurement (EP) and environmental performance (ENP) and claimed to find a significant and positive effect on the environmental performance of the supply chain (AlNuaimi B.K. et al., 2021). Chen J. et al. (2021) developed a framework for supply chain risk assessment using BDA, which was tested in an illustrative case study to demonstrate the implementation of the procurement risk assessment using BDA (Chen J. et al., 2021). Although the applications proposed in recent research can be applied to various industries, BDA applications in the wood industry have not been conducted.

5.4 Cloud Computing

Cloud computing is a model for enabling global, shared, on-demand access to a shared network of configurable computing resources that can be used with minimal effort and provider interaction (Jahani et al., 2021). Cloud computing is evolving as one of the major enablers of the manufacturing industry and could transform traditional manufacturing to create intelligent factory networks, defined as cloud manufacturing (Avilés-Sacoto et al., 2019). In a cloud manufacturing environment, enormous datasets are stored, analyzed, and subsequently shared with physical resources using virtualization technologies (Avilés-Sacoto et al., 2019).

Similarly, enormous amounts of information can be seamlessly shared and transmitted between different participants using cloud computing in supply chains (Fatorachian & Kazemi, 2021). This shared information forms large communication platforms for enterprises to enhance communication and collaboration, providing high storage capacity and high computing speed, with secure data accessibility, anytime and anywhere (Jahani et al., 2021). Cloud computing can improve decision-making and responsiveness to demand, opportunities, and threats of various supply chain operations and provide a more intelligent form of BDA (Zhao et al., 2019).

Several research articles discussed the benefits of cloud computing in SCM. Chen and Chang (2021) examined the potential of cloud supply chains concerning benchmarking and market-driven decision-making by introducing a cellular automatic simulation model. The model was tested by comparing the cloud performance against conventional data centers (Chen & Chang, 2021). Moshood et al. (2021) conducted a literature review on applying digital twins and cloud computing to achieve visibility of supply chains. They claimed that digital twins would help companies grow predictive metrics, diagnostics, forecasts, and physical asset illustrations for their logistics when combined with cloud computing (Moshood et al., 2021). Bergier et al. (2021) developed a mobile application for the live stocking of beef in Brazil using cloud edge computing. The application aims to increase sustainability by reducing transactions costs and strengthening the relationships between the business stakeholders (Bergier et al., 2021). Most studies used cloud computing in their propositions to manage big data generated during the entire SCM process.

Similarly, enormous amounts of data can be compiled throughout the supply chain in the wood industry. For example, log scaling, where logs are measured and counted accurately in stacked piles and a major part of the wood supply chain, is currently done manually and is subject to human error and labor consumption. A study by F. Martí et al. (2021) presents a solution for counting and scaling logs using LiDAR, where all the collected data could be transferred and analyzed on a cloud library (F. Martí et al., 2021). Cloud-based applications such as Tapio and smart trees are already used for selecting, cutting, and preparing wood using IoT technologies such as RFID and sensors (Šulyová & Koman, 2020). However, beyond the data collection and analysis, only a few studies on the further implementation of cloud technology or cloud manufacturing in the wood industry exist.

5.5 Cyber-physical systems

In a cyber-physical system (CPS), physical objects are connected to the Internet and each other using sensing, computing, control, and networking (Gupta et al., 2020). The difference between CPS and the IoT is that objects, processes, and computations are integrated into CPS, creating an integrated system of objects and systems. This enhanced form of connection and automation is valuable for supply chains and offers a great platform for information exchange that facilitates responsiveness and decision-making throughout the supply chain (Fatorachian & Kazemi, 2021; Tonelli et al., 2021).

Previous research has discussed many key benefits of CPSs in inventory and warehouse management (Chen & Chang, 2021). Similarly, preventive maintenance can be achieved by processing information related to spare parts and technical issues to enhance machine life and productivity levels (Tonelli et al., 2021). For example, the study by Sobb et al. (2020)presented a CPS approach in inventory management to automatically schedule maintenance appointments when the machine's temperature was higher than normal. Another study conducted by Ivanov et al. (2019) utilized the information to calculate the expected life cycle costs of the machines and predict potential failure in advance.

CPSs have efficiency-related effects on supply chains. Chen et al. (2020) proposed a model to evaluate the cost composition of an interrupted supply chain. Researchers then compared the results to an integrated supply chain working in the proposed CPS environment. CPSs positively impact cost and time performance and significantly reduce errors (Chen et al., 2020). Other security benefits were mentioned in the literature. Yeboah-Ofori and Opoku-Akyea (2019) used a risk breakdown structure and a probability distribution model to analyze the likelihood of risk occurrence in a CPS supply chain. Researchers have found that the system can mitigate many threats compared to traditional supply chains (Yeboah-Ofori & Opoku-Akyea, 2019). CPSs have also been explored in the planning stage. In a case study, a steel production company tested a CPS morphological box involving CPSs in early management decisions and identified several technical and process-related benefits (Hetterscheid & Schlüter, 2019).

5.6 Digital Twins

A digital twin is a virtual digital representation of a physical object or process. The concept combines simulation, machine learning, and reasoning to create a fully digitalized system imitation. In other words, a digital twin is a computer program that utilizes real data to predict or simulate how a process or object behaves (Zhang et al., 2021). Like other I4.0 technologies, digital twins have been explored in supply chain areas and are regarded as a promising approach in SCM.

A study by Zhang et al. (2021) developed a digital twin supply chain framework using the SC operations reference model. An individual sub-digital twin is created for every process in the supply chain system. The framework covered physical, virtual, and information processing layers of the supply chain. However, the framework was only tested using a sample SC (Zhang et al., 2021). A similar attempt was made by Santos et al. (2020) in the pharmaceutical industry, where a simulation of the SC was created using digital twin technology to create a planning tool and predict monthly capacity needs for supply chain managers (Santos et al., 2020). Another study from the food industry used digital twins to simulate the thermal behavior of fruits and vegetables in cold weather. Digital twins efficiently deliver corresponding information in the supply chain, enabling a better understanding, recording, and prediction of events and reducing food loss due to temperature change (Defraeye et al., 2019). Despite digital twins being a recent concept and the lack of evidence of actual implementation in the SCM process, several studies exploring digital twins' deployment in SCM acknowledge its vast potential.

Digital twin applications in the construction industry can be directly linked to building information modeling (BIM). However, previous literature on the application of digital twins in construction is not easily found because this concept is usually referred to as BIM. One way to combine the two concepts is by looking at BIM to control the data, while the digital twin uses this data (El Jazzar et al., 2020). In other words, a digital twin in construction will build on BIM to connect a model to the real world, allowing for better performance of the physical object of a building (Moshood et al., 2021).

One way to use BIM to operate a physical building is to digitalize operation and maintenance processes, interpreting the digital twin concept. Chen et al. (2018) suggested the automation of maintenance work schedules using BIM to enhance decision making (Chen et al., 2018). Suprabhas and Dib (2017) added sensor data into facility management, reported through the BIM model, and proposed a system to facilitate predictive maintenance and issue detection (Suprabhas & Dib, 2017). Matarneh et al. (2019) created a system to facilitate information exchange directly between BIM and the facility management system (Matarneh et al., 2019). However, there is a lack of research directly addressing the wood construction industry regarding building operations through digital twins.

6 Discussions and Findings

Existing literature reveals a lack of technical and analytical research focusing on feasible ways for utilizing I4.0 applications in the supply chain and an evident lack of research on wood construction supply chains. The results show 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 is present and obtainable, while the Supply Chain 4.0 is still far from full implementation in wood construction.

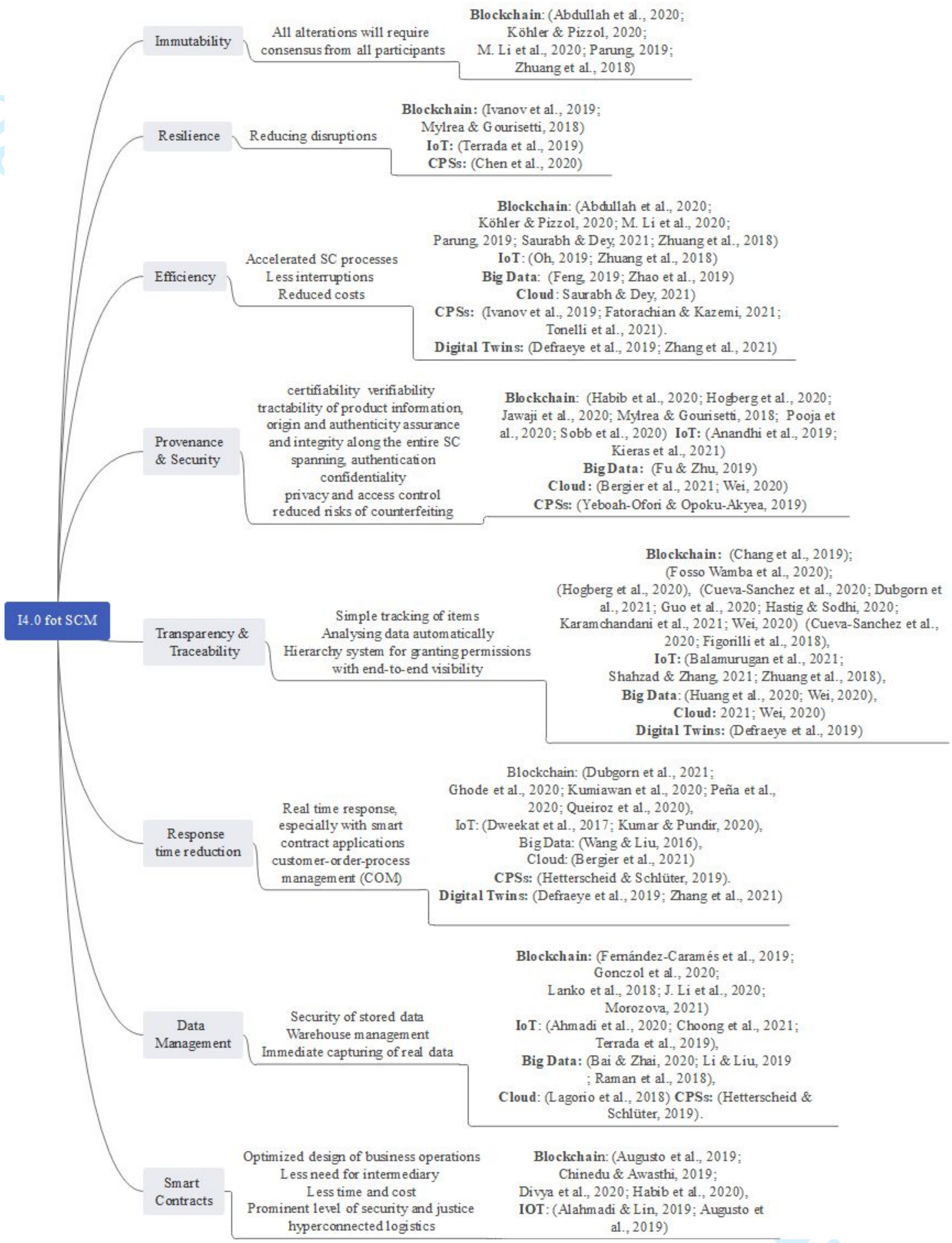

Figure 5. Content analysis map

The reviewed articles in this study shared the goal of modernizing and digitalizing the supply chain processes to increase efficiency, reduce cost and time, achieve better quality and sustainability, and minimize risk and security issues, among 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. Accordingly, the purpose of this research was to identify these gaps in the holistic overview of Supply Chain 4.0 in various industries, highlight the wood industry in particular, and propose future research directions.

Supply chain research on wood construction focusing on digitalization is very limited, and there is little research on the implementation of I4.0 technologies in SCM beyond theoretical studies and proposals. Thus, testing and implementing these ideas in a real context to verify the applicability and benefits of these proposals is necessary. Moreover, available studies have not adequately covered the enablers of these technologies and the technical barriers that might constrain these applications, such as the connectivity and coverage in forests and distant locations, limiting the utilization of various IoT devices. Thus, there is a need for research that provides solutions for these barriers and technical issues.

Regarding data management and utilization, a major field of I4.0 applications, there is a lack of research on data utilization in the wood manufacturing industry, especially planning and forecasting activities. There is a need for future work to apply I4.0 technologies in production planning and prediction. Furthermore, the research has identified another gap in data security: the lack of trust and insecurity that combines high-risk technologies has not been adequately addressed. Although there has been extensive use of the terms "trust" and "security" within all research containing decentralized and shared data platforms, research is needed to address data security and provide solutions to overcome the security risks of I4.0 applications. The analysis shows that most endeavors to digitalize supply chains have focused solely on one technology. For a holistic perspective, future research should examine the potential of combining technologies to explore the full potential of I4.0. The use of technologies to leverage and boost the potential of these applications (Fosso Wamba et al., 2020). Finally, the review found that most studies focusing on Supply Chain 4.0 only discuss the readiness phase. There is an apparent lack of research exploring 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 the social and economic levels of the industry, such as its impact on the labor force or internal structures of businesses. Other topics worth further investigation includes management resistance, market instability issues, training and capacity building needs, and financial constraints, among others. Figure 6 outlines a conceptual framework with new directions for applying I4.0 technologies in supply chain digitalization, applicable to the 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 construction industry. Additionally, it defines eight drivers for further research in alignment with the defined research gaps.

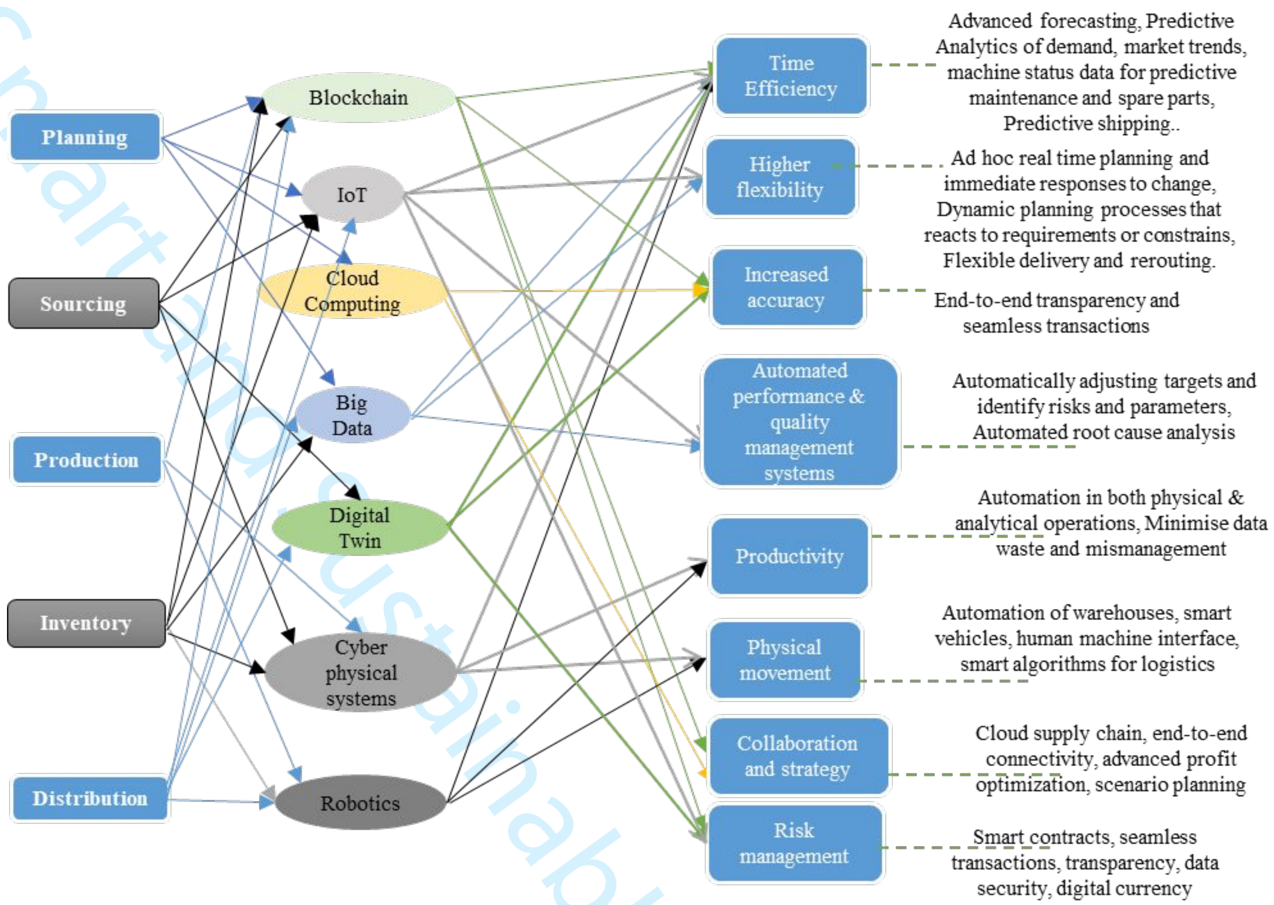

Figure 6. Framework for future research

7 Conclusion

This study presents an overview of the current status of research on digitalization in SCM utilizing I4.0 technologies, with a focus on the supply chain of wood construction. A total of 173 articles published between 2015 and 2021 were selected and reviewed, following systematic refining and selection criteria. A bibliometric literature review was conducted using both descriptive and content analysis methods. The existing literature gaps and future research recommendations have been identified.

The descriptive analysis showed an increasing and obvious interest in supply chain digitalization, consistent with the recent research focus on I4.0. However, the analysis highlighted the reluctance and slow digitalization adoption of the wood construction industry compared to other industries. The descriptive review also revealed the lack of relevant research on the wood manufacturing supply chain concerning digitalization. The content analysis on the main technologies mentioned in the analyzed articles revealed the main drivers behind using these technologies. The analysis covered research from various industries while specifically highlighting wood construction.

The research addressed the main technologies of I4.0 in terms of the applicability and potential to enhance supply chain operations. An evident tendency toward using blockchain was found, especially for traceability, security, and seamless transactions, which is still limited in wood construction. Similarly, several IoT applications have been identified for tracking and tracing, some of which are linked to traceability in the wood construction industry. The review results clearly showed an agreement among articles to further investigate the utilization of IoT applications for further benefits. IoT technologies are usually linked to BDA, which also holds great potential for SCM in general. However, a study on wood construction supply chains utilizing BDA was not conducted.

The wood construction supply chain and operations often require accurate management of large data sets, especially those that accumulate using IoT technologies. Several studies have proposed cloud computing as a secure and seamless tool for securing and managing data. However, there has been a lack of research on cloud computing beyond data collection and analysis applications in the wood construction industry. The research also highlights CPSs' applications in the supply chain and finds several arguments about the cost benefits and efficiency improvements. Concerning the digital twins technology, despite the research addressing the deployment of digital twin technology in SCM, there has been an agreement that this technology holds great potential for the construction industry, especially with the emerging use of BIM in the supply chain of the construction industry and the wood construction industry in particular.

The review concluded that I4.0 technologies hold enormous opportunities for the digitalization of supply chains beyond the current status of Supply Chain 4.0, and the identified gaps were used to draw a framework for future research directions that can further enhance the current supply chain management and should also benefit the wood manufacturing industry.

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