Systematic Review
Transformative Procurement Trends: Integrating Industry 4.0 Technologies for Enhanced Procurement Processes

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Abstract: Background: the advent of Industry 4.0 (I4.0) innovations has revolutionized supply chain management through technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) integrated into procurement processes. Methods: this study addresses a critical knowledge gap by conducting a comprehensive review of 111 papers sourced from the Scopus database. These papers are classified into seven sub-themes encompassing I4.0 or procurement 4.0 (P4.0), big data, IoT, additive manufacturing, blockchain, e-procurement, and AI. Results: the investigation reveals that I4.0 technologies, particularly e-procurement and blockchain, have garnered substantial attention. Such technologies offer diverse value propositions, encompassing streamlined supplier evaluation, lead time reduction, cost optimization, and enhanced data security. Conclusion: the paper underscores pivotal trends and insights for the evolution of Procurement 4.0, illuminating a path toward more efficient supply chain management.

Keywords: procurement; industry 4.0; digitalization; additive manufacturing; blockchain; procurement 4.0; internet of things; e-procurement

1. Introduction

The 4th Industrial Revolution, or Industry 4.0 (I4.0), represents generally the convergence of information and communication technologies (ICT), and the automation of machinery and infrastructure [1,2]. In manufacturing, it stands for the digitalization of factories and their related supply chain processes. As a result of advanced digitalization in manufacturing, a new concept known as ‘smart manufacturing’ has come into existence. Smart manufacturing revolutionizes the coordination of manufacturing elements by leveraging an integrated data chain system facilitated by the Internet, which made a critical improvement in strategic supply chain management [3]. Procurement is considered a critical part of the supply chain since it affects directly the overall performance of the whole supply chain.

Procurement is defined broadly in terms of any form of the buying process, whether it is in the form of purchasing, leasing, renting, or otherwise acquiring supplies, services, or construction from external suppliers [4,5]. This concept includes all management responsibilities which the managers are supposed to follow such as identifying, sourcing, accessing, and managing resources outside the company. Also, it suggests fulfilling of strategic objectives of the company to make significant business value and impact profit. From the perspective of supply chain management, the role of procurement is considered indispensable, as it plays a crucial role in highlighting the importance of ongoing enhancements within the procurement division [1].

Procurement 4.0 (P4.0), which is a term that encompasses a component of I4.0, introduces a network between all supply chain upstream partners, enabling dynamic and quick cooperation and coordination beyond organizational frontiers [6]. Companies have
increasingly embraced P4.0 techniques in their supply chain (SC) operating models, offering valuable support to procurement managers in overcoming purchasing challenges. This is made possible through the utilization of cutting-edge technologies such as the Internet of Things, e-procurement, big data, additive manufacturing (AM) or 3D printing, blockchain, artificial intelligence, and modularity. Table 1 provides a brief definition for each I4.0 component. These technologies affect every aspect of the value chain and empower procurement managers to optimize their processes and enhance decision-making capabilities for more efficient and effective procurement operations, including supplier sourcing, distribution, transportation, warehousing, and most importantly, customer satisfaction. Moreover, they have the potential to contribute to effectiveness, efficiency, cost reduction, and shorter lead times in the supply chain, thereby providing significant benefits for the supply chain industry [7].

Table 1. Brief definition for each I4.0 component [8].

<table>
<thead>
<tr>
<th>I4.0</th>
<th>Brief Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularity</td>
<td>Strategic division of complex systems into independent modules for efficient application management.</td>
</tr>
<tr>
<td>E-procurement</td>
<td>Electronic procurement processes enable streamlined sourcing, ordering, and transactions.</td>
</tr>
<tr>
<td>Big Data</td>
<td>Large-scale data analysis to uncover insights and patterns, enhancing decision-making.</td>
</tr>
<tr>
<td>IoT</td>
<td>Network of interconnected devices collecting and exchanging data for informed actions.</td>
</tr>
<tr>
<td>AM or 3D Printing</td>
<td>Layer-by-layer creation of objects, revolutionizing production and customization.</td>
</tr>
<tr>
<td>Blockchain</td>
<td>Decentralized and secure digital ledger ensuring transparency and trust in transactions.</td>
</tr>
<tr>
<td>AI</td>
<td>Simulation of human intelligence in machines, enabling data-driven insights and optimized decisions.</td>
</tr>
</tbody>
</table>

In procurement, the three primary components of I4.0 that play a pivotal role are automation, connectivity, and advanced analytics. With these evolving capabilities, procurement processes can be almost further automated, and decision-making processes can be supported through advanced analytics tools [9]. Although information technology systems have been in use to support procurement functions for many years, their emerging holistic use in each stage of the procurement process in the supply chain at present is unique and constitutes Procurement 4.0. It is believed that the scope of procurement processes will be even more expanded in the future as a result of new technological advancements. For instance, the development of modern intelligent systems, which will have the computing power, connectivity, and autonomy to be able to analyze historical and future-oriented data may bring newer mechanics to procurement processes. This will be capable of offering holistic, autonomous, and real-time task completions. Electronic procurement (e-procurement), for example, can offer electronic solutions to procurement processes. This is the first step for digitalization that gives procurement departments smart support for operational and tactical decisions [10]. However, these advantages of procurement are not well taken into the companies’ operations. Bogaschewsky and Müller [11] point out, in a survey made for procurement managers in different German companies, the majority of the interviewees (56%) are still reluctant to proceed with digitalization in their procurement department and this attitude must be overcome to adopt these developments.

There is an increasing trend for procurement decision-makers to invest in digital technologies in their quest for greater access to global markets to obtain competitive advantages through the interconnection between buyers and suppliers [12]. Executives
in procurement anticipate cost reductions without losing efficiency throughout the whole supply chain. However, many of them opt for digitalization in order to avoid being outdated [13]. In fact, a study by the European Economic and Social Committee states that people work more efficiently due to procurement digitalization [14]. Digitalization brings forth innovations and economic growth that create new methods and technologies. In short, one could argue that digitalization has multiple consequences as it creates and reduces jobs but its overall impact is yet to be determined [15].

The adoption of a P4.0 program requires an essential restructuring of business organizations. It calls for a new organizational strategy because several operational processes have to be modified in this new stage [16]. Through this restructuring, many processes of the companies such as procurement, production, logistics, and IT departments were connected to each other in terms of accounting and controlling their activities. Therefore, it is important to restructure interactions within supply chain management completely [17].

I4.0 is widely acknowledged as having the ability to provide new capabilities to procurement functions [9]. By using automated and internally integrated systems, a completely autonomous operational procurement system can be enabled. In p4.0, interactions between internal and external shareholders would be increased and more reliable data would be generated in which advanced analytics offer up-to-date information and new ways of analysis supporting decision-making processes.

To demonstrate the paradigm-shifting influence of I4.0 technologies on procurement procedures, the following few leading examples from diverse industries can be illustrated. In the manufacturing domain, Toyota emerges as a paradigmatic case. The seamless integration of I4.0 elements such as the IoT and AI has endowed Toyota with a streamlined supply chain marked by enhanced efficiency, minimized downtime, and amplified productivity. In the service sector, Amazon exemplifies the transformative potential of I4.0. Skillful application of advanced data analytics, automation, and AI-driven decision-making has not only expedited order fulfillment from 80% to 90% but also cultivated tailor-made customer experiences, epitomizing the burgeoning importance of these technologies in the contemporary consumer landscape [18].

Shifting the focus to the public sphere, the World Health Organization (WHO) magnifies the pivotal role of I4.0 technologies in global health management. Through data-driven insights and predictive analytics, WHO proactively addresses disease outbreaks, optimizes medical supply chains, and refines resource allocation [19]. In the private sphere, Walmart’s adroit integration of I4.0 technologies has ushered in a new era of astute procurement. Capitalizing on the potential of IoT and real-time analytics, Walmart deftly manages inventory levels, augments demand forecasting accuracy, and mitigates stockouts, thereby augmenting customer satisfaction and operational seamlessness [20].

These tangible examples demonstrate the undeniable pertinence and urgency of I4.0 technologies in the realm of procurement, motivating small and medium enterprises (SMEs) across industries to expertly employ these tools for strategic advantage.

Given the transformative potential of I4.0 technologies, the correlation between I4.0 and procurement demands further clarification. I4.0 introduces intelligent automation, data-driven insights, and enhanced connectivity, all of which can significantly enhance procurement processes. The significance lies in the amplified efficiency, strategic agility, and value-driven decision-making that these technologies facilitate. By harnessing I4.0 tools, procurement can achieve enhanced transparency, sustainability, and innovation, ultimately contributing to the overarching success of organizations.

To the best of our knowledge, an up-to-date, comprehensive review of the literature on the role of I4.0 in procurement management has yet to be explored. This work introduces a novel perspective by comprehensively synthesizing the existing literature on the integration of I4.0 technologies in procurement. While previous studies have explored individual applications of these technologies, this review uniquely consolidates diverse research to present a comprehensive understanding of the enhanced efficiency in supply chain management through the P4.0 process. This study seeks to explore the profound impact of I4.0 technologies on procurement processes, identify crucial drivers and challenges for
adoption, and assess how these technologies can optimize procurement efficiency, reduce costs, and revolutionize supply chain management. Additionally, we aim to unveil the current trend in smart procurement and anticipate its future direction, providing valuable insights into the evolving landscape of modern procurement practices. As such, we propose the following three research questions as primary motivators for presenting and discussing this structured review:

- Which procurement processes are predominantly impacted by Industry 4.0 technologies?
- What are the primary enablers and challenges in the adoption of Industry 4.0 technologies?
- What is the current trend in smart procurement and the future direction?

The purpose of this work is to give a thorough and well-structured review of the literature and explore the role of I4.0 technologies on P4.0 to address the aforementioned research questions. The article’s primary contribution is to describe the existing state-of-the-art literature on this topic.

The article is outlined as follows. Section 2 presents a brief on the journey to Procurement 4.0. Section 3 draws the specified methodology used to conduct the literature review and the criteria utilized to gather the listed publications. The review is broken down in Section 4 where the proposed categories are offered and discussed in Section 5. Section 6 provides the reflections and a conclusion.

2. Procurement Journey

Procurement, sourcing, and purchasing are essential activities for acquiring goods and services in a company. While often used interchangeably, it is crucial to understand their differences and develop effective procedures for each process. Strohmer et al. [21] emphasize the importance of recognizing the distinctions, especially considering the demographic range of operations, where purchasing and sourcing may vary. Procurement encompasses the entire procedure from identifying the need to payment, purchasing refers to acquiring goods or services, and sourcing involves evaluating potential providers.

Procurement entails acquiring goods or services and encompasses activities such as purchasing, transportation, quality control, and inspection. Supplier selection decisions are influenced by the total cost of ownership (TCO), making procurement relevant in project environments [22,23].

Sourcing is a strategic process that involves managing supplier relationships to gain a competitive advantage. It includes decisions on supplier quantity, relationship type, contract duration, negotiation type, and local or global sourcing. Strategic sourcing aims to reduce costs, ensure long-term supply stability, and minimize supply risk [24]. It involves building relationships, allocating business, and making decisions on terms, often guided by tools like Portfolio Analysis for segmenting suppliers and products based on their strategic importance and risk profile [25].

Purchasing focuses on identifying user requirements, finding suppliers, developing agreements, ensuring prompt payment, and evaluating effectiveness. It does not include responsibilities for materials planning, scheduling, inventory management, or quality control. Procurement refers to the transactional aspect and should be streamlined [26].

Table 2 provides a concise overview of the main differences between procurement, sourcing, and purchasing [21]. It outlines key criteria such as the definition of each term, the scope of their focus, the main activities involved, decision-making considerations, the aims pursued, and the relationships established.

Before exploring the role of I4.0 in procurement processes, this section briefly discusses the previous procurement stages that laid the foundation for P4.0. Historically, the evolving methods for procurement processes started along with the industrial revolutions. While procurement or purchasing was almost a clerical process in earlier times, it became a separate but crucial part of production as a result of mass production followed by the Industrial Revolution. Traditionally, procurement has been understood as a cost-reducing mechanism by ensuring goods are at the lowest possible cost for production. But now
it has grown to a proactive and strategic one as a result of advanced digital integration into procurement processes. In effect, purchasing, which has been hitherto understood as an important part of this process, has become just one part of a larger procurement operation today. This section aims to present a brief historical journey of procurement and its evolution from Procurement 1.0 to Procurement 4.0 (Smart Procurement) [2].

Table 2. Brief on main differences between Procurement, Sourcing, and Purchasing.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Procurement</th>
<th>Sourcing</th>
<th>Purchasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>The entire process from identification to payment</td>
<td>Locating and evaluating potential providers</td>
<td>Acquiring goods or services</td>
</tr>
<tr>
<td>Scope</td>
<td>Industry-specific focus</td>
<td>Strategic advantage in supplier management</td>
<td>Identifying user requirements and supplier evaluation</td>
</tr>
<tr>
<td>Main Activities</td>
<td>Purchasing, transportation, quality control</td>
<td>Supplier management, relationship building</td>
<td>Supplier identification, agreement development</td>
</tr>
<tr>
<td>Decision-making</td>
<td>Total cost of ownership, project considerations</td>
<td>Supplier selection, contract negotiation</td>
<td>User needs evaluation, prompt payment</td>
</tr>
<tr>
<td>Aim</td>
<td>Cost efficiency, governance</td>
<td>Cost reduction, supply stability</td>
<td>User satisfaction, continuous improvement</td>
</tr>
<tr>
<td>Relationship</td>
<td>Related to materials planning, inventory management</td>
<td>Related to strategic sourcing and supplier management</td>
<td>Related to user satisfaction, continuous improvement</td>
</tr>
</tbody>
</table>

Based on the Institute for Supply Management in India [27], the traditional procurement cycle can be summarized in the following main dimensions as illustrated in Figure 1: (1) Identify the needs, a business recognizes a required product or service for its own operational purposes; (2) Purchase approvals, making a purchase request and seeking approvals required from the appropriate stakeholders; (3) Vendor evaluation and selection, supply chain professionals solicit proposals from vendors, negotiate possible working relationships, and select their final supplier; (4) Contracting and payment, the purchase order will be approved by the vendor, at which point the relationship becomes one of the vendor relationship management processes.

![Figure 1. Main procurement dimensions.](image-url)
Procurement management has developed in tandem with every successive technological advancement. There is a progression in the attention paid to and the strategy used by the procurement processes and practices at each stage as summarized in Table 3.

### Table 3. Key characteristics and technological emphasis of each procurement stage.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Focus and Characteristics</th>
<th>Technological Emphasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procurement 1.0</td>
<td>Tactical procurement, cost reduction, operational</td>
<td>Transactional approach, cost containment</td>
</tr>
<tr>
<td></td>
<td>efficiency</td>
<td></td>
</tr>
<tr>
<td>Procurement 2.0</td>
<td>Value creation, category management, cross-functional</td>
<td>Information flow control, supplier relationship management</td>
</tr>
<tr>
<td></td>
<td>approach</td>
<td></td>
</tr>
<tr>
<td>Procurement 3.0</td>
<td>Supply-side optimization, cloud-based tools, automation and recording</td>
<td>Contextual data recording, AI-enabled predictive models</td>
</tr>
</tbody>
</table>

#### 2.1. Procurement 1.0: Tactical Procurement

This stage refers to an early form of procurement processes when procurement was understood as synonymous with purchasing. This stage is characterized by an emphasis on cost reduction and operational efficiency. Procurement is predominantly regarded as a tactical function, with a transactional approach serving as the predominant mode of operation, in which obtaining products and services at the lowest possible price while keeping procurement costs to a minimum level is the main objective at this stage [28]. Although procurement management works as a supporting function with a focus on cost containment, this basic form of procurement has been adopted by the vast majority of companies today [29]. In addition, in this conventional procurement phase, the focus is on the execution of tactical tasks including dealing with contract requests, operating RFXs (requests for information, requests for qualification, and requests for proposal), and facilitating communications and relationships with suppliers [30]. Therefore, it also can be called tactical procurement where procurement professionals are assigned to take care of multiple functions in a reactive and transaction mode.

With more automation options in the interaction between both ends of the supply chain, procurement has turned away from cost containment to deliver accelerated and broader value. It is a holistic process, that consists of risk mitigation strategies, supplier innovation, demand management, global perspectives, sustainability, and more.

#### 2.2. Procurement 2.0: From Cost Containment to Value Creation

Historically, procurement pursued a singular strategy of obtaining the best price, product, and situation available. However, with the advent of advanced internet technologies, procurement become able to create more complex and nuanced strategies [31]. This development is known as Procurement 2.0, where enterprises began to exert greater control over the flow of information, beyond basic informational tools. Procurement 2.0 is no longer solely focused on cost management [32] but instead emphasizes category management, a cross-functional approach, and supplier relationship management [33]. These enhancements mark a significant shift from the previous iteration of procurement, Procurement 1.0.

Recently, there has been a growing recognition of the potential value that procurement can bring to an organization through technological collaboration. By leveraging advanced technologies such as big data analytics and software tools, procurement can add value by addressing several key areas of concern, including working capital management, risk mitigation, and exploring new markets or business lines. The increased information flow and automation capabilities provided by these technologies can improve collaboration with suppliers and drive greater efficiency throughout the procurement process. This shift in focus from cost management to value creation is a central feature of Procurement 2.0. As a result, it has become necessary for organizations to re-evaluate the procurement
function itself and consider how it can be optimized to better support broader business objectives [34]. Businesses are recognizing the important impact that procurement can have on various business models and their competitive advantages [35]. By effectively communicating the value of procurement to various departments and business functions, organizations can better align their procurement strategies with overall business objectives and drive greater value creation.

The procurement landscape has undergone a significant transformation, largely driven by the increasing share of revenue attributed to procurement. To align procurement with corporate objectives, companies have developed category strategies [36]. This transformation has led to an increased role of procurement role in cross-organizational collaboration, which has been facilitated by technological advancements connecting all departments across the business. To streamline supply chain processes and achieve greater operational efficiency, a movement to centralize purchases and reorganize vendors has emerged [37]. This has resulted in procurement playing an increasingly important role in managing working capital and identifying risks to business performance. Through enhanced information flow and the development of software to identify risks, the efficiency of these areas has been greatly improved [38].

2.3. Procurement 3.0 (Supply-Side Optimization)

Procurement 3.0 is all about supply-side optimization. It is more than just an advanced digitalization in the procurement process. It signifies a drastic change in procurement structure and the use of high-edge technologies for procurement purposes. The E-Commerce revolution of the 1990s, which laid the foundation for Procurement 2.0, had facilitated a shift from on-premise toward cloud-based tools. It also formed the basis for emerging Procurement 3.0 technologies by making advancements in categorial improvement in functional efficiency. In this phase, the application of digital technology is more focused on automation and recording of the process: a transaction executed, an invoice paid, an item purchased, and a contract signed. A system of record-keeping (in the form of software) has been used in the procurement process which helps to understand contextual reasons by probing into what happened and why. This recording is important: it makes a foundation for AI-enabled predictive models which will make progress in future decision making. A fully matured application of such a technology can be seen in the next stage of procurement, which is known as Procurement 4.0.

The key objective of Procurement 3.0 is to optimize the supply side. In this stage, business strategy has been linked to the enterprise by ensuring that a good supplier base under the right commercial agreements and delivering the right goods and services. There are clear building blocks required to accomplish this evolution.

With the emergence of Procurement 3.0, procurement and business were connected to the information existing outside of their own data ecosystem and leveraging intelligent capabilities that do more than execute transactions to guide business decisions. Most of these emerging technologies effectuated enhancing the value of legacy systems which consider small investments, have low requirements for integration, and have payback periods measured in months not years [27]. Scholars like Mavidis and Folinas [39] have vividly discussed the e-procurement journey in the public sector and its results in improving access to information and transparency in management. In this study, they evaluate comparatively the challenges and problems between procurement technologies 3.0 and 4.0 and lay down a roadmap for achieving new procurement management in Industry 4.0.

3. Methodology

The approach that is used in this research draws relevant works from an online citation index (Scopus) that is easily accessible. These works have been published in peer-reviewed journals along with other reliable sources. This section describes the search strategy used to identify relevant works and discusses how those works were categorized in relation to I4.0 in the context of procurement management.
3.1. Literature Survey Process

This work comprises a literature review of the published papers on the role of I4.0 technologies in procurement processes, aiming (1) to collect information about unveiling the current trend in smart procurement and (2) to identify crucial drivers and challenges for adoption, and assess how these technologies can optimize procurement efficiency, reduce costs, and revolutionize supply chain management. The present study adhered to the rigorous PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [40] to ensure transparency and methodological robustness. It involves formulating research questions, conducting comprehensive database searches, applying strict inclusion/exclusion criteria, analyzing and extracting data from selected studies, synthesizing and interpreting findings, and producing a comprehensive review report analysis. Five stages are conducted in the identification, screening, and eligibility of works, as shown in Figure 2, which summarizes the stages in the review process.

Figure 2. Literature review process—Funnel approach.

In Step 1, keywords included in the title, abstract, and keywords (TITLE-ABS-KEY) relevant to the topic are identified as, TITLE-ABS-KEY((procurement AND 4.0) OR (procurement AND (‘additive manufacturing’ OR ‘3D print’ OR print)) OR (procurement AND blockchain) OR (procurement AND digit*) OR (‘digital procurement’), (procurement AND digitalization) OR (procurement AND ‘digital transformation’) OR (‘agile procurement’) OR (e-procurement) OR (‘smart procurement’) OR (procurement AND auto*) OR (procurement AND (‘smart contract’ OR ‘digital contract’)) OR (procurement AND ‘big data’) OR (procurement AND ‘artificial intelligence’) OR (procurement AND ‘Internet of Things’) OR (procurement AND (price* OR cost*)) OR (procurement AND risk*) OR (procurement AND suppl*) OR (procurement AND data)). These keywords are used for literature retrieval from the Scopus database, since this web search engine is globally recognized as the primary source of peer-reviewed literature, and its effectiveness as an index database has been demonstrated. Running the aforementioned research query resulted in a total of 1686 documents. In Step 2, the initial stage of filtering search criteria can be described as (a) the language of the article should be in English, (b) the timeframe should cover the range of years (2012–2022) as this range is considered to be the flourishing start of the fourth industrial revolution applications in manufacturing systems and supply chains, (c) document type chosen to include only articles or review articles, (d) published in journals only. The dataset after the first filtering procedure is comprised of 532 papers. The second filtering criterion, Step 3, represented in reading the titles and abstracts of the papers found and then selecting only the most relevant ones to the field of engineering.
management and decision sciences, e.g., engineering, business, management, decision science, economics, finance, and accounting. The pool of papers selected after this step amounted to 303 papers, which undergo a third filtering procedure, Step 4, that aims to ensure that all works to be reviewed are meaningful contributions to the topic and add significant value to the literature scope, which results in 209 papers. The third filtering criterion goes for in-depth full-text reading of the papers to ensure they are relevant to the proposed scope. Tables 4 and 5 present the inclusion and exclusion criteria and the final data set in Step 5 consists of 111 papers as a total number of articles.

Table 4. Inclusion criteria (IC).

<table>
<thead>
<tr>
<th>IC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC-1</td>
<td>Papers should be written in English</td>
</tr>
<tr>
<td>IC-2</td>
<td>The papers should be published between (2012 and 2022)</td>
</tr>
<tr>
<td>IC-3</td>
<td>Only journal articles and review papers are considered</td>
</tr>
<tr>
<td>IC-4</td>
<td>Papers that examine the use of Industry 4.0 technologies in procurement processes</td>
</tr>
<tr>
<td>IC-5</td>
<td>Papers that address one or more of the following procurement functions: sourcing, pricing, purchasing, supplier relationship management, or supplier performance management</td>
</tr>
<tr>
<td>IC-6</td>
<td>Papers that focus on data sharing, data security, or risk management in procurement processes</td>
</tr>
<tr>
<td>IC-7</td>
<td>Papers that report on improvements or enhancements to procurement key performance indicators (KPIs) facilitated by Industry 4.0 technologies</td>
</tr>
</tbody>
</table>

Table 5. Exclusion criteria (ExC).

<table>
<thead>
<tr>
<th>ExC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ExC-1</td>
<td>Conference, book, editorial, and report papers are not considered.</td>
</tr>
<tr>
<td>ExC-2</td>
<td>Papers that are written in languages other than English.</td>
</tr>
<tr>
<td>ExC-3</td>
<td>Papers that focus solely on technologies and are not related to procurement processes, e.g., automation in manufacturing or artificial intelligence in marketing, etc.</td>
</tr>
<tr>
<td>ExC-4</td>
<td>Papers that do not clearly state how Industry 4.0 technologies are utilized in procurement processes or do not provide enough details to be relevant to the review.</td>
</tr>
<tr>
<td>ExC-5</td>
<td>Papers that have a very narrow focus or only cover a specific aspect of procurement processes and are not relevant to the role of technologies within its scope.</td>
</tr>
</tbody>
</table>

3.2. Literature Review Classifications

Figure 3 summarizes the distribution of the selected papers per technology and per publication year. As shown, the number of publications has been rapidly growing over the last three years, which confirms the high interest in the use of I4.0 technologies in the procurement area.
Figure 3. Distribution of the data set per technology and publication year.

Figure 4 depicts the final number of papers (n = 111) included in the review, highlighting the prominence of e-procurement, blockchain, and I4.0 or P4.0 technologies in the literature. After diagnosing the data set, it becomes evident that e-procurement, blockchain, and I4.0 or P4.0 technologies have the highest number of published papers. These technologies have attracted significant attention and research interest in the field of procurement. The bar representing e-procurement stands out prominently, indicating a substantial body of literature dedicated to this area. It signifies the importance of e-procurement in the context of I4.0, as organizations seek to automate and digitize their procurement processes for improved efficiency and effectiveness. Similarly, the bar representing blockchain technology is notable, highlighting the growing interest in leveraging blockchain for secure and transparent transactions in procurement. Lastly, the bar representing I4.0 or P4.0 technologies demonstrates the significance of I4.0 in shaping the future of procurement. The inclusion of papers related to I4.0 or P4.0 indicates the recognition of its transformative potential and the need to understand its implications for procurement practices.

Figure 4. Distribution of Papers Included in the Review.

Figure 5 illustrates the title and the number of journals utilized in this study. The top three journals with the highest number of related selected articles are Sustainability Switzerland, IEEE Access, and the Journal of Cleaner Production. This figure provides an overview of the distribution of articles among different journals, highlighting the journals that have contributed significantly to the research in this field.
Figure 5. Titles and Number of Journals Used in the Study.

The current distribution of articles per country is visually presented in Figure 6, highlighting that the United States has the highest number of publications related to the topic, followed by the United Kingdom and India.

Figure 6. Distribution of Articles Per Country.

3.3. Relevant Literature

Table 6 exhibits the most relevant literature related to the procurement topic. The papers are classified into seven sub-themes, which include I4.0 or P4.0, E-procurement, big data, Internet of Things (IoT), Additive Manufacturing (AM), Blockchain, and Artificial Intelligence (AI). Most of the literature overlaps these sub-themes. However, they are classified differently for analytical purposes. Detailed reviews of these papers are discussed in the following section.
Table 6. Thematic division of the reviewed literature.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Number of publications</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>I4.0 or P4.0</td>
<td>24</td>
<td>[41–51], [6,52–59], [5,60–63]</td>
</tr>
<tr>
<td>E-Procurement</td>
<td>29</td>
<td>[64–73], [74–81], [82–92]</td>
</tr>
<tr>
<td>Big Data</td>
<td>10</td>
<td>[93–102]</td>
</tr>
<tr>
<td>Internet of Things</td>
<td>3</td>
<td>[103–105]</td>
</tr>
<tr>
<td>Additive Manufacturing</td>
<td>8</td>
<td>[106–113]</td>
</tr>
<tr>
<td>Blockchain</td>
<td>28</td>
<td>[4,92,114–121], [122–130], [131–139]</td>
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<tr>
<td>Artificial Intelligence</td>
<td>9</td>
<td>[105,140–147]</td>
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4. Literature Review

In this section, we present a comprehensive review of previous research papers related to the use of I4.0 technologies for enhancing and improving procurement processes. The literature review covers most of the I4.0 technologies and their applications in procurement. Although the implications of I4.0 concepts have been discussed individually in different industrial contexts, a limited number of studies have discussed the use of emerging technologies in procurement processes comprehensively. Therefore, this work is meant to potentially provide a comprehensive picture of the application of such technologies and offer some value propositions in order to enhance the procurement processes in a wide variety of industries.

The collected articles are divided into sub-themes, including I4.0 or P4.0, e-procurement, big data, IoT, additive manufacturing, blockchain, and AI. By analyzing separately the literature related to these themes, this study discusses the impact of different I4.0 technologies in the procurement processes and their roles within various areas of supply chain management.

Supply chain resilience has emerged as a key element in I4.0 to manage risk during out-of-stock conditions at a time of crisis. It has been used to optimize supply chains from end to end, leading to major impacts on value delivery. Researchers have discussed various ways in which supply chain resilience could be improved during crisis periods. In their insightful paper, Pereira et al. [148] discuss how procurement plays a significant role in detecting and dealing with intra- and inter-organizational problems to impact supply chain resilience. Using a systematic literature review, based on 30 published papers between 2000 and 2013, they revealed that achieving resilience in the supply chain requires efforts from both internal and external elements of the extended enterprise.

4.1. Industry 4.0 (I4.0) and Procurement 4.0 (P4.0)

Needless to say, digital transformation is a key component of the fourth industrial revolution, and it has increasingly grown overall in industrial sectors. According to Lasi et al. [51], I4.0 means advanced digitalization within industrial factories. As a result, it facilitates cyber-physical systems that describe the merger of digital with physical workflow [55]. It stands for a combination of internet technologies with future-oriented technologies in the field of “smart” objects (machines and products). Thus, it equips the industrial manufacturing system in such a way that products can control their manufacturing process. With the high-level digitalization in the industrial field, new ways of production have been created through the interactions between multiple technologies [52]. Scholars have discussed
how the application of such technologies transformed the overall business management structure, and individual aspects of companies including the value chain model, e.g., [59].

To shed light on the applications of I4.0 technologies in various contexts, it is essential to provide a concise overview of the relevant literature. In this regard, Chou and Liao [63] contribute to the field by presenting a procurement decision-making model specifically designed for the food processing machinery sector. The food processing industry has witnessed a significant influx of smart manufacturing equipment with advanced and fully automated technologies, enabled by technological advancements. Within this context, I4.0 serves as an integrating force, leveraging high-equipped technological innovations to harmonize demands, sales, and manufacturing resources in the procurement process. Employing such a tool in the food processing industry offers benefits such as accuracy, reliability, real-time applications, and a reduction in uncertainties associated with human-based decision-making [63]. I4.0’s emphasis on procuring subsystems for assembly into other manufactured parts is a critical feature that aligns with the evolving needs of modern manufacturing. It allows for modular production, customization, rapid prototyping, and collaborative supply chain practices. This approach empowers manufacturers to be more agile, innovative, and efficient, ultimately leading to increased competitiveness and improved customer satisfaction.

The advent of I4.0 has given rise to a paradigm shift in the realm of procurement, leading to the emergence of what is known as Procurement 4.0. This transformative development has introduced a range of significant advantages for companies, particularly in the domain of supply chain management [44]. It has been made possible through the implementation of advanced digitalization techniques within organizational structures and supply chain operations. Within an organization, the procurement division has assumed a pivotal role in driving this transformation. By transcending its traditional cost-centric approach, procurement has adopted a profit-centric perspective, thereby redefining not only what is procured but also how these acquisitions are made. This shift has prompted the procurement function to explore novel business models, enabling them to unlock untapped opportunities and enhance their strategic contributions to the organization. By embracing the principles of P4.0, companies can leverage the potential of digital technologies and data-driven insights to optimize their procurement processes, enhance supply chain efficiency, and achieve sustainable competitive advantages in the dynamic business landscape. Such a transition holds the promise of reshaping procurement practices and revolutionizing the way organizations approach their purchasing strategies and supplier relationships.

In a similar vein, Gottge et al. [5] underscore the importance of I4.0 technologies, such as big data, business intelligence, and the IoT, in the procurement process. Their study specifically focuses on the practical implications of these technologies on the purchasing activities of automotive manufacturers, employing a transaction cost economic approach to examine both theoretical and practical impacts. The authors adopt a multiple-case study methodology, utilizing qualitative content analysis and cross-case synthesis. The findings reveal that strategic purchasing processes benefit from the co-creation of specifications, parameter-based negotiations, an additional sub-process, and automated pre-qualification. Notable changes in operative purchasing processes include interactive call-offs and proactive troubleshooting. Through the application of these technologies, transaction costs decrease as uncertainty and supplier specificity are minimized, alongside reduced information search, monetary costs, and negotiations.

Ghadge and Goswami [62] delve into the impact of I4.0 implementation on the supply chain, offering a comprehensive framework to enhance its application across various industries. Through a critical literature review, the study investigates key drivers and barriers across organizational, strategic, technological, legal, and ethical dimensions. Building upon these identified factors, they develop a systematic assessment system to evaluate the impact of I4.0 on supply chain processes. Raja et al. [50] support the study and both shed light on the challenges encountered during implementation and put forward a novel
framework aimed at facilitating the effective integration of I4.0 concepts into the supply chain, including the procurement function as an integral part of these processes.

Rane and Narvel [41] examine the utilization of I4.0 technologies to enhance the agility of project procurement management (PPM) processes. Given the growing market demands and shorter time-to-market requirements, the existing PPM encounters challenges in responding with agility. To address this, the authors propose strategies for implementing I4.0 tools and leveraging selective critical success factors to enhance the agility of executive PPM processes. Furthermore, they explore the use of additional tools such as IoT, mobility, business intelligence, blockchain, and robotic process automation (RPA) to further improve agility in PPM.

Digitalization has ushered in a new era for procurement, enabling the utilization of data analytics to meet evolving business requirements. Referred to as Industry 4.0, this transformative paradigm offers promising opportunities and a host of capabilities to enhance procurement processes [42]. The continuous development and refinement of various technologies and tools have significantly bolstered procurement, fostering improvements in efficiency, effectiveness, and overall performance [57]. However, it is crucial to acknowledge the substantial costs associated with the development, acquisition, and implementation of these technologies. Therefore, meticulous analyses are indispensable to determine the potential impact, scope, and applicability of investments [6]. To cultivate a competitive environment, organizations endeavor to establish digitized procurement systems that prioritize customer preferences and exhibit the necessary agility to meet growing customer satisfaction. In this context, scholars have engaged in discussions concerning the systematic application of digitalization in procurement and its consequential effects on supply chain dynamics.

Rejeb and Appolloni [54] and Bag and Sivarajah [46], delve into the role of procurement digitalization in manufacturing operations and the circular economy. Through the analysis of survey data collected from working professionals in South Africa, the latter study identifies key resources required in a P4.0 environment to enhance remanufacturing operations and circular economy performance in emerging economies. Drawing on the resource-based view theory, the researchers explore the influence of resources on P4.0 and its impact on productivity in remanufacturing operations. They argue that improving the performance of remanufacturing operations can contribute to achieving circular economic outcomes. In a similar vein, Bag et al. [46] and Bag et al. [43] investigate the effects of digital transformation on P4.0 processes in terms of productivity within a circular economy context. Findings from a survey conducted among South African manufacturers suggest that P4.0 can be leveraged to optimize the buyer’s intentions and enhance circular economy performance.

Rejeb et al. [61], Pires et al. [53], and Richnak [56] investigate the utilization of emerging technologies in procurement processes to address the complexity of exchanging data and information in procurement logistics. Their study highlights the significance of digitalization and the adoption of technologies such as big data analytics, robotics, IoT, blockchain, and smart contracts in enhancing industrial procurement functions and tools. These technologies offer benefits such as improved predictability, transactional automation, and proactive supplier relationship management. The authors also discuss the potential of emerging technologies in procurement activities, as well as organizational barriers that impede their widespread implementation and suggest possible remedies.

Klünder et al. [58] examine the impact of digitalization on procurement costs, highlighting its potential to further reduce costs by ensuring supplies at a lower cost. Through empirical examination, explanatory surveys, and survey-based studies, the authors investigate the effects of digitalization on procurement costs, specifically material and commodity costs, and support the implementation of I4.0 technologies to achieve cost reduction in the procurement process. In a related study, Lorentz et al. [47] propose a procurement digitalization strategy, focusing on key drivers, technology interventions, and mechanisms. Based on data collected from interviews and workshops involving 48 digital interven-
tion projects, the study reveals the significant influence of internal-external dynamics on procurement digitalization. The findings indicate that internal complexity facilitates digitalization by enabling communication support and process structuring interventions, while external dynamism drives interventions for information processing and decision-making, particularly related to supply market knowledge, strategic alignment, and supplier capability assessment.

Hallikas et al. [60] delve into the role of data analytics in the digitalization of procurement and supply chains, specifically examining the relationship between digital procurement processes and supply chain performance. The analysis of survey data reveals several significant findings. First, there is a direct and positive association between digital procurement processes and supply chain performance. Second, the study demonstrates that data analytics capabilities play a crucial role in enhancing a firm’s competitiveness in procurement and supply chain management. However, it is important to note that the impact of data analytics differs when considering internal versus external sources. Internal data analytics have a positive influence on supply chain performance, whereas external data analytics directly enhance digital procurement capabilities, which in turn mediate their impact on supply chain performance. These findings highlight the importance of investing in data analytics capabilities to improve supply chain performance and optimize the digital procurement process.

Flechsig et al. [49] and Schiele [48] shed light on the application of Robotic Process Automation (RPA) in purchasing and supply management. While RPA has gained significant attention in digital transformation, its potential within purchasing and supply management, particularly in the public sector, remains relatively unexplored. Drawing upon multiple case studies encompassing both the public and private sectors, the authors offer valuable insights into the challenges, appropriate processes, and effective strategies for implementing RPA. The findings underscore the importance of organizations’ digital procurement readiness and maturity in determining the success of RPA adoption.

To classify and describe the many digital technologies and techniques used in building procurement, Ibem and Laryea [45] conduct a thorough literature survey. Their research highlights 36 unique digital technologies and solutions, such as web-based applications that improve construction supply chain interactions among different stakeholders in real time. The study highlights the need for a consolidated digital solution that integrates and unites all main construction procurement processes, providing purchasers with a full-fledged platform from which to oversee the whole procurement lifecycle.

4.2. e-Procurement

The increasing demand for automation in the business sector has led to the emergence of e-procurement as a vital component of digitalized procurement processes [89]. Chan et al. [84] provide a comprehensive overview of the evolution and development of e-procurement, highlighting its significance in optimizing the supply chain by reducing costs and improving efficiency. E-procurement encompasses various elements, such as e-sourcing, e-coordination, and e-communities [85]. In the context of public procurement, the application of e-procurement has been instrumental in promoting good governance [88,90] and reducing corruption within organizations [91].

Within this context, Basak [69] highlights the significance of e-procurement in the aviation industry’s maintenance, repair, and overhaul (MRO) sector by comparing it with traditional procurement methods. E-procurement offers advantages, such as simplified processes and increased transparency, making it a valuable tool for maximizing supply chain performance. It reduces costs throughout the value chain and enhances efficiency. In a highly agile supply chain, Chibani et al. [71] demonstrate the use of e-procurement for dynamic optimization. The buyer-supplier interactions in this context are volatile, requiring decisions on the quantity and selection of products based on price and capacity variations. Traditional optimization approaches are inadequate for addressing these dynamic challenges.
Kim et al. [70] investigate the influence of strategic sourcing and e-procurement on firm performance. Through a structured survey of 137 managers in US manufacturing firms, the study employs partial least squares-based structural equation modeling for data analysis. The findings reveal a positive impact of strategic sourcing and e-procurement on firm performance. Additionally, the study demonstrates that business characteristics and environmental factors, such as competition, market turbulence, firm size, and product life cycle stage, moderate these relationships. This research contributes to theory and practice by examining the effects of e-procurement on firm performance.

Sánchez-Rodríguez et al. [92] investigate the impact of e-procurement on small and medium-sized enterprises (SMEs), focusing on facilitators and obstacles that affect business performance. The study examines data from 199 managers in the manufacturing sector and identifies significant relationships between SMEs and factors, such as support of executive management, information technology obstacles, and strategic procuring. Furthermore, the research reveals positive associations between e-procurement, procurement efficiency, and overall business performance. These findings highlight the importance of e-procurement in enhancing the performance of SMEs.

Belisari et al. [73] investigate the positive and negative impacts of e-procurement adoption in the Italian market, encompassing both the public and private sectors. Through an examination of two Italian companies that have implemented over 150 e-procurement projects, the study highlights the effects of e-procurement solutions. The findings demonstrate that the adoption of e-procurement leads to improved purchasing performance and compliance with the procurement code. However, the manifestation of these benefits differs between the public and private sectors.

Hung [68] investigates the effects of a Web-based e-procurement system on companies’ organizational performance within the supply chain. Their model incorporates various contextual factors and was tested through a survey of 105 manufacturing firms in Taiwan. Utilizing the partial least-squares regression method, the study finds that e-purchasing activities significantly improve organizational and inter-organizational efficiency. Additionally, an enhanced partnership approach positively affects supplier and buyer performance. These findings highlight the positive impact of web-based e-procurement on organizational performance.

Kamarulzaman et al. [66,67] investigate the utilization of e-procurement technologies in the Malaysian Palm Oil Industry (MPOI). Through in-depth interviews and comprehensive analysis, the authors in both articles highlight the potential of e-procurement in enhancing purchasing efficiency by streamlining the search process, providing material information, and reducing human errors. However, the study reveals that certain products, such as fresh fruit bunch, crude palm oil, and crude palm kernel oil, face limitations in adopting e-procurement tools due to established suppliers’ limited utilization of such technologies in their purchasing activities.

Gupta [64] examines the impact of information technology (IT) on e-procurement in Indian organizations. Based on a survey conducted among 36 organizations, the author highlights the positive effects of IT usage, including improved business process efficiency, such as enhanced inventory control, cost and time reduction, and improved customer service. However, the study also identifies persistent security concerns that hinder the widespread adoption of IT infrastructure for e-procurement. Specifically, issues related to internet security, loss of information sharing, and legal legitimacy must be effectively addressed to establish trust in online transactions.

Adowo et al. [65] investigate the potential of e-procurement in combating corruption and unethical practices in construction project delivery in Nigeria. While e-procurement has been widely adopted to enhance supply chain management in various sectors, its role in addressing corruption has received limited attention. This is particularly significant in sub-Saharan countries where corruption levels are substantial. Through 759 cross-sectional surveys conducted across different fields in Nigeria, the researchers identify 18 anti-corruption capabilities associated with e-procurement in construction project de-
livery. These capabilities focus on ensuring inventory management, accountability, and reducing human involvement during the bidding process. Transparency in bidding fosters competition and aids in curbing corruption within construction procurement activities. Also, the same author, Aduwo et al. [77] investigate the presence of critical gray areas in the public procurement process and highlight the potential of e-procurement’s digital solutions to combat corrupt practices. Public procurement plays a vital role in developing and maintaining city infrastructure to enhance citizens’ quality of life. However, corrupt practices hinder its success. Through a survey of 759 construction stakeholders across Nigeria’s six geopolitical zones, this study identifies e-procurement technologies utilized for project announcement, information exchange, tendering, proposal submission, progress monitoring, and payment. The findings emphasize the importance of digitalization in eliminating corruption within procurement processes. Thus, this paper explores digital solutions for enhancing public procurement in the Nigerian construction sector.

Ibem et al. [79] investigate the impact of e-procurement on the user experience within the Nigerian construction industry. While e-procurement adoption is widespread in developing countries like Nigeria, its influence on construction stakeholders and their experiences remains understudied. This survey-based study includes 759 stakeholders and reveals that e-procurement tools are extensively used for information exchange and expanding tender opportunities. However, their utilization for tracking construction site progress is limited. Factors such as internet infrastructure adequacy, operational environment, technology benefits, and system accessibility directly influence user experiences, emphasizing the need for their consideration to ensure sustainable e-procurement implementation in the construction sector.

Ramkumar et al. [75] emphasize the significance of the Technology Acceptance Model (TAM) and Quality-TAM (Q-TAM) in e-procurement services. Through an analysis of data from organizational buyers, the research shows how organizational purchasers’ perceptions of procurement services are affected by information flow and logistical fulfillment. This research introduces a quality technology acceptance model that predicts organizational buyers’ intentions to continue using e-procurement services, focusing on user satisfaction within a mandated usage setting. It distinguishes itself from existing literature by exclusively focusing on user intentions of organizational buyers, rather than firm-level adoption issues. Furthermore, the application of e-procurement in SMEs is crucial for developing competitive advantages. E-procurement systems facilitate connections between SMEs and other business activities, such as supply chain integration, resulting in rapid development in a globalized world. Madzimure et al. [76] investigate the relationship between e-procurement, supplier integration, and supply chain performance in retail SMEs through case studies in South Africa. Their quantitative research approach evaluates various e-procurement components, highlighting the impact of e-design and e-negotiation on supply chain integration. Additionally, the study demonstrates that supply chain integration positively influences supply chain performance.

Mélon et al. [80] examine the impact of large-scale e-procurement adoption on institutional quality in Denmark, the Netherlands, and Portugal, comparing it with other countries. Using data from 108 countries between 1996 and 2017, the study employs a differences-in-differences policy analysis approach. The findings indicate that the effects of e-procurement reform on institutional quality are not uniform. While Denmark and the Netherlands experience substantial improvements in the rule of law and government effectiveness post-reform, the overall impact on institutional quality is less pronounced. This paper highlights the contributions of e-procurement to institutional quality, revealing variations in its effects across different countries.

Masudin et al. [81] and Susantya et al. [86] investigate the effects of e-procurement adoption in Indonesian manufacturing companies by examining the relationships between top management support, information quality, e-procurement implementation, and company performance. Through two surveys administered to staff members, the study finds
that the support of senior management and information reliability significantly influence e-procurement implementation, leading to enhanced business performance.

It is well-established that prior experience in e-procurement platforms enhances project performance. To gain deeper insights into the effectiveness of prior experience, Hong and Shao [82] explore the moderating factors that influence the impact of buyer-supplier experience in these platforms. Specifically, they examine the role of temporal distance, language difference, and routine tasks in determining the success of the prior experience. Their findings shed light on the significance of prior experience in e-procurement platforms.

Sanchez et al. [72] conducted a study to explore the impact of digital transformation (DT) on supply chain procurement (SCP) and competitive advantage (CAD). Through a survey of 221 supply chain professionals, the researchers determined that DT positively influences both SCP and CAD, with SCP mediating the relationship between DT and CAD. The findings suggest that digital procurement has the potential to revolutionize competitive markets, and the study offers preliminary recommendations for shifting from standard to smart procurement practices.

Chen et al. [83] conducted a study to explore the relationship between procurement complexity, government structure, and e-procurement adoption in local governments. Analyzing survey data from over 400 cities, the researchers found that a centralized government structure increases the likelihood of e-procurement adoption in response to procurement complexity. In contrast, governments with a coordinated structure are less likely to adopt e-procurement due to their reliance on intra-organizational collaboration and information-sharing to manage complex procurements. These findings shed light on how different government structures can effectively handle complex administrative operations and enhance the adoption of e-procurement.

Fu et al. [74] present a case study on the implementation of a green e-procurement system using a cloud model. The study focuses on private hospitals in Taiwan and highlights the challenges associated with conventional systems, including high resource requirements, regular updates of green specifications, and system crashes affecting procurement efficiency. To address these issues, the authors propose a cloud-based e-procurement system that improves efficiency and reduces information maintenance costs. The results demonstrate the successful optimization of resource allocation and timely understanding of user needs, enabling the development of tailored marketing strategies. The cloud-green e-procurement model proves beneficial for enhancing procurement activities in a sustainable manner.

E-procurement has revolutionized public procurement systems, enhancing government administration and governance [87]. Micea et al. [78] explore the impact of an integrated model of Blockchain and the Internet of Things, known as (BIoT) on achieving sustainable and smart procurement in the public sector. Additionally, Chen et al. [83] investigate the adoption of e-procurement systems in local government. They argue that the complex structure of local government procurement can be effectively addressed through the implementation of an e-procurement system. The study findings highlight the potential of different local government structures in handling complex managerial tasks and facilitating e-procurement adoption.

4.3. Big Data

Big data is an emerging and relevant topic for industrial operations. In the supply chain, the application of big data will bring benefits like higher visibility, enhanced bargaining position in negotiations, better risk management, and better decision-making. Big data helps to control spending with data analysis and reduce risks by identifying potential supply chain disruptions [93]. Therefore, it plays a significant role in enhancing the procurement process.

In a recent review essay, Lee and Mangalaraj [100] discuss the uses of big data analytics in various business functions particularly in the context of the rapid expansion of machine learning and technological infrastructure. The role of big data in supply chain management (SCM) for handling customer preferences, visibility improvements, and resilience has been
emphasized in the paper but, interestingly, from the vantage point of an interdisciplinary perspective, which will offer an increased and holistic understanding of its functions. By combining existing perspectives in big data research in SCM, namely organizational and technical, and holding together a bottom-up approach, i.e., using bibliometric analysis in classifying those studies, and a top-down approach, i.e., employing a framework to classify findings, this paper analyzes prominent theories used in the study of big data and SCM. Moreover, a focus has been given to sustainability within this research domain, which has not been given due attention in previous studies.

Zeisel et al. [101] present a conceptual architecture for implementing big data applications in the procurement function. The architecture facilitates the integration of diverse data sources, skilled teams, and big data analytics. Additionally, the authors identify and discuss a comprehensive range of both existing and innovative use cases for big data in procurement.

Moretto et al. [94] analyze the value of big data technology in supporting the procurement process and the implementation of procurement practices. Using a focus group discussion among procurement professionals and experts and analyzing four case studies supported by secondary data analysis, this work illustrates how big data technology influences different procurement processes and what kind of benefits can be expected from adopting this technology for procurement performance. Big data technology is shown to have the greatest potential impact on strategic sourcing phases, mainly in strategy configuration, reverse marketing, spend analysis, supplier evaluation, negotiation, and selection. In short, the application of the technology enables better data management and improves the quality of the business environment.

Tiwari et al. [95] illustrate the implications of big data in the procurement process of various industries and businesses and argue that the application of big data technology assists companies in making informed decisions by analyzing massive amounts of data in a short time. More specifically, the author explores the implication of big data for purchasing and supply purposes that enhance companies’ visibility in the supply market. Data gathered from interviews suggest that big data technologies enhance companies’ ability to identify new suppliers, manage risks, and analyze suppliers. In addition, predictive analytics techniques can be used in market analyses and negotiations.

Song et al. [96] discuss the significance of a big-data-driven approach for emergency drug procurement planning. In the context of uncertainty of diseases, traditional approaches to drug procurement planning are inefficient, which often causes overstocking or understocking in hospitals. Consequently, public health care services are negatively affected. Thus, the authors use a heuristic optimization algorithm based on a deep neural network to predict morbidities of acute gastrointestinal infections based on a massive amount of environmental data. Two case studies illustrate that such methodology provides quick and efficient solutions, which are better than the methods currently used in drug procurement.

Narwane et al. [102] investigate the role of big data analytics in mediating the relationship between Supply Chain 4.0 company performance and various performance parameters. The study employs a two-stage hybrid approach combining statistical assessment and an artificial neural network (ANN) algorithm, based on data obtained from 321 responses from 40 Indian industrial organizations. The findings highlight the significant impact of organizational performance characteristics, ecologically conscious procurement and sourcing, endogenous and exogenous factors, shipping and distribution, operation-related aspects, technical expertise, and collaboration on the adoption of big data analytics.

Kuo et al. [98] discuss the implementation of the smart support system of material procurement based on big data and predictive analytics in order to reduce waste and thereby make sustainable enterprises. In this system, an intelligent event-driven feedback control method is used for controlling process plans. A decision support system is also designed to reduce material usage based on usage data. Moreover, data science and predictive analytics
techniques have been applied to make better procurement decisions. The authors argue that the application of the system is highly effective in semiconductor manufacturing.

Focusing on big data’s impacts on supply chain activities, Murad et al. [99] analyzes optimizing procurement as an intermediate factor in which big data’s impacts on the supply chain’s sustainability performance could be measured. They argue that the benefits of having big data capabilities are neither visible immediately nor achievable straightforwardly, instead, they have to be sought in intermediate factors such as procurement optimization. By analyzing existing literature, they offer a conceptual framework to examine procurement optimization with big data capabilities, specifically focusing on healthcare-sustainable supply chains.

It is an already acknowledged fact that green procurement is a necessary component in any organization to attain higher environmental performance. However, this is not an easy task because of the potential risks such absence of appropriate information, tools, and training. Alnuami et al. [97] demonstrate that big data technology is a solution to this problem. Its concept can transform the traditional e-procurement system into green procurement and ensure better environmental performance. By analyzing resource orchestration theory, the authors argue that if organizations reorganize resources and capabilities in terms of the big data e-procurement method, a higher environmental performance is achievable. Empirical samples of 216 procurement professionals indicate that big data analytic capabilities provide enhanced environmental performance and sustainability.

4.4. Internet of Things

IoT provides useful capabilities for achieving better procurement with more efficient operations. IoT refers to the interconnection of information with the help of sensing and actuating devices that facilitate a platform so that information may be exchanged across systems in an integrated manner, leading to a unified framework that can be used to power cutting-edge applications [103]. Scholars have discussed the significance of IoT as an enabler, empowering companies to gain real-time data and continuous evaluation for better decision-making by identifying consumers’ consumption patterns.

Fang et al. [104] illustrate an integrated three-stage model based on IoT for the optimization of procurement, production, and product recovery. Due to increasing environmental concerns worldwide, the recovery of end-of-use products has become an important part of the manufacturing industry today. In this context, manufacturers must develop proper strategies to reduce waste, raw material usage, and production costs by recycling and refurbishing used items. The authors propose the use of IoT to address the questions of how to collect end-of-use items from customers and acquire knowledge about each item. The products can be identified with codes and monitored and tracked using wireless sensor networks. A particle swarm optimization algorithm is used, and there are three recovery options for increasing product demand in each stage of the product life cycle. IoT facilitates manufacturers to collect and share data for providing products that are functional and less expensive. By doing so, manufacturers can make a global chain comprising suppliers, factories, and recyclers, which help them assemble products at a lower cost. In this context, manufacturers are forced to select appropriate suppliers for specific components, ensuring lower procurement costs of greenhouse gas emission-contained materials.

Jemmali et al. [105] present an intelligent algorithm aimed at addressing supplier selection challenges. The proposed algorithm utilizes a set of determinants and sophisticated formulas to convert predefined preferences into quantitative measurements. These measurements enable the differentiation between suppliers and their proposals. Experimental results confirm the effectiveness of the D3S model in selecting the most suitable offer from a range of proposals provided by various vendors.

4.5. Additive Manufacturing

Additive manufacturing (AM), also called 3D printing [106], is yet another technological advancement that takes a transformative approach to industrial production by
facilitating the creation of lighter, stronger parts and systems. It employs a method of data-driven computer-aided design that has a huge potential for developing novel product concepts and enhancing the performance of existing ones. It also facilitates better design freedom and functional benefits such as weight reduction.

Revilla et al. [107] discuss the significance of AM technology and its potential to alter and disrupt a wide range of industrial sectors. AM technology is not only used for new product designs but also for redesigning production networks. The buyer uses AM technology to produce parts with data provided by suppliers. Using supplier-provided data, the client (buyer) could manufacture parts using additive manufacturing. This is one manner in which AM technology is influencing the future of business partnerships between buyers and suppliers. However, studies examining the effects of AM on industrial procurement are still limited. AM technologies potentially allow the decentralization of the manufacturing and restructuring of logistical aspects of supply chains that were never explored well.

Sgarbossa et al. [108] examine the logistical considerations and challenges associated with AM and decentralization. The study also investigates the potential of AM as a solution for strategic sourcing in procurement. Moreover, the authors explore the application of AM technologies in spare parts management and provide decision trees to assist industrial managers and practitioners in their decision-making processes.

The effects of using AM in spare parts procurement are investigated by Bhattacharyya et al. [112], in particular in terms of supply chain resilience and effective inventory management for spare parts. The results of the research show that using AM might lessen reliance on original equipment manufacturers (OEMs) for acquiring some replacement components. The study also found that using AM might save costs in production and lead times significantly.

The adoption of AM technologies has increased the freedom of design by expanding the possibility of producing unconventional geometrics. However, such decisions are complex since optimizing AM requires integrating data from several disciplines. For instance, to make unique and challenging products, there must be a proper assessment of the qualities of printed materials and their compatibility with a certain application, redesign forms with respect to AM’s limitations, and so on. Moreover, procurement and logistics evaluation must be included in this process. In this regard, Raffaeli et al. [109] investigate the adoption of AM technology in production design. The study examines the various factors involved in this decision-making process and proposes a systematic approach that guides designers through structured algorithm procedures. This approach enables designers to evaluate the suitability of AM adoption and to develop optimal designs considering the constraints of AM technology.

Muhammad et al. [110] examine the application of AM in enhancing the resilience of the automotive supply chain network and addressing disruptions. The global supply system, particularly the automotive sector, has faced significant challenges due to the COVID-19 pandemic. To assess the potential of AM in strengthening the automotive supply chain, the authors focus on the Indian automotive industry as a case study. They identify key barriers to widespread AM adoption, such as insufficient government regulations, limited management support, restricted availability of raw materials, and workforce constraints. The study also discusses mitigation strategies that leverage AM in the upstream automotive supply chain.

Chowdhury et al. [111] present an innovative optimization framework for the design and operation of an integrated AM supply chain network. This framework considers the interdependencies among flow networks, resource limitations, and costs at the process and system levels within a unified decision framework. A two-stage stochastic programming model is proposed, where the first stage focuses on minimizing facility site selection and capacity decisions before any customer demand information is known. Once demand information is available, second-stage decisions are made, including determining the opti-
mal layer thickness for AM products, production planning, post-processing, procurement, storage, and transportation.

Knofius et al. [113] conduct a comprehensive analysis of the total costs associated with consolidation using AM, encompassing logistics, manufacturing, and repair expenses. Their findings indicate that consolidation with AM often leads to higher overall costs, primarily due to a loss of flexibility. In contrast to conventionally constructed components that allow for partial replacements, consolidated components require complete replacement in the event of failure. Moreover, the perceived advantage of shorter lead times for resupplying consolidated spare parts proves to be insignificant. These conclusions highlight the necessity of considering a holistic cost perspective when evaluating the outcomes of design enhancements using AM. Neglecting such an approach may result in unintended consequences that cast doubt on the viability of design changes, even in the presence of significant functionality improvements.

4.6. Blockchain

Blockchain is yet another important I4.0 technology that has been predominantly used in procurement for making smart contracts. Smart Contracts play an essential role in procurement and they have been increasingly used in many industries due to many features, including automatic execution, non-tampering in the blockchain environment, and transparency [4]. However, blockchain technology and its recent developments in applications are moderately well explored in the literature.

In 2017, the initial scholarly publications on the application of blockchain technology in the construction industry were introduced, comprising a total of three articles. Over the span of a few years, a body of literature has emerged with an average annual expansion rate of 184%, resulting in a cumulative count of 121 documents by early 2021. To explore the topic’s growth and advancement, all 121 papers were reviewed. A literature study and scientometric analysis were used in a mixed methods approach to examine the present environment [133]. In total, 33 blockchain application categories in construction were identified and organized into seven subject areas: (1) procurement and supply chain, (2) design and construction, (3) operations and life cycle, (4) smart cities, (5) intelligent systems, (6) energy and carbon footprint, and (7) decentralized organizations.

The possibilities of blockchain technology in making a digitalized supply chain (DSC) have been explored and multiple models are experimented with in different procurement fields [114]. Dutta et al. [115] explore industrial sectors such as shipping, automotive, aviation, manufacturing energy, healthcare, etc., in which the use of blockchain technology can enhance efficiency in business process management. Similarly, another study pointed out a blockchain-enabled smart contract system has been used to mitigate unethical practices of bid shopping and peddling during the subcontractor procurement process [116].

One of the important qualities of blockchain technology is its capacity to record data in a predetermined way, in a cryptographic mode. Many enterprises employ this technology in their respective fields in order to make their procurement processes more efficient and cost-effective. In this context, Hofbauer and Sangl [117] present a comprehensive analysis of blockchain technology’s application potential in digitizing transaction processes. They delve into the underlying principles and implications of blockchain in transaction activities. Through an examination of statistical data on users’ expectations and requirements, the authors highlight how blockchain can meet these needs. By integrating theoretical foundations with practical applications, this study effectively showcases the transformative possibilities of blockchain technology in the digitalization of transaction processes.

A methodology for green procurement using blockchain and Internet of Things integration is proposed by Rane and Thakker [118]. By reviewing extensive literature and analyzing interviews conducted among procurement managers from different industries, they identify challenges in green procurement and then discuss how the integration of blockchain and IoT technologies provides capabilities to overcome procurement challenges, making a sustainable business model. The authors argue that the proposed architecture
can create a green supply chain, and such green initiatives enhance the competitiveness of the industries at the global level. Also, a successful green procurement will contribute to saving energy consumption and efficient waste disposal, thereby realizing a sustainable business model.

Government agencies and companies widely use computing solutions because of the ease of use of procurement processes. However, the security of cloud file storage has always been a threat. Pinheiro et al. [119] designed a new method to monitor the integrity of files stored in cloud storage using smart contracts in the blockchain network, symmetric encryption, and computational trust. This consists of a protocol that provides important features such as confidentiality, decentralization, audit availability, etc. The proposed method is feasible and accurate in detecting corrupted files. Therefore, it has the potential to improve the e-procurement process in various stages of a business.

Guo et al. [127] present the significance of blockchain technology in contract management that offers better security to the traditional electronic contract system. Industries have generally been adopting the e-contract system in modern times because it reduces time and human labor and improves contract management efficiency. However, since it has a centralized database-based storage schema in the e-contract system, there is a high possibility of data hacking and information draining; therefore, it raises serious security concerns. In this context, this study proposes a blockchain technology integrated contract management system. It develops a process-oriented contract management system (BE contractor) and discusses its implementation with a focus on Hangzhou (in China) power grid enterprise.

Omar et al. [128] discuss the integration of blockchain technology in the healthcare supply chain process for automating procurement contracts. Effective healthcare supply chain (HCSC) management is crucial for a better health system, especially during pandemics such as COVID-19. Although new technological advancement has been integrated for better management, the healthcare system still suffers from poor procurement processes. Contracting through Group Purchasing Organizations (GPOs), which is an important stakeholder in HCSC, is time-consuming and lacks efficiency. In this context, the authors suggest a solution in which blockchain technology is integrated into a decentralized storage system, which provides better transparency and communication with various stakeholders. In this new method, all stakeholders such as manufacturers, GPO distributors, and providers connect through the Ethereum network. In short, this paper proposes an automatic blockchain solution model for smart contracts for GPO contract processes. Similarly, Raj et al. [129] discuss the importance of blockchain-based smart contracts for supply chain transactions that help enterprises reduce problems related to payments at various stages of the supply chain process, especially when supplying is based on third-party logistic services. Considering the inefficiency and risk even in the most modern form of electronic transactions, they introduce a new platform of transaction based on an Ethereum-based smart contract that enables a centralized payment system along with decentralized authorization and information sharing possibilities between various supply chain stakeholders.

Studying the potential applications of blockchain technology in public sector E-Procurement in Bangladesh, Khalfan et al. [130] argue that many developing countries are suffering seriously in terms of the development project and identify 38 such issues in public sector issues in Bangladesh. Most of these failures are attached to a lack of a proper development project, including poor project management, poor procurement management, and lack of transparency. One of the significant reasons for this problem is the awarding of the lowest bidder during the procurement process because of the current regulatory requirements in the country. The authors observe and analyze the Oracle platform, which is the prominent E-procurement platform in Bangladesh built on blockchain technologies and cloud computing applications, and identify that the application of blockchain technologies solves 25 out of 38 issues in the procurement process. It shows the potential of blockchain technologies in handling the majority of issues in the successful implementation of public sector projects.
Kim et al. [121] discuss the significance of blockchain technology in the construction industry. One of the main advantages of this technology is the reduction of transaction costs, which is crucial to the construction industry because it consists of a high volume of transactions among various entities. Therefore, their study aims to apply this technology in the construction industry to achieve better performance. The authors conduct a survey based on a questionnaire that collects data on the construction life cycle and project management knowledge. The data are analyzed through the method of importance-performance analysis (IPA) in order to figure out the relationship between the application of these technologies and the anticipated impacts of using this technology. In the construction project lifecycle, there are three parts, including project cost, contract bidding formation, and procurement evaluation, in which blockchain technology shows high applicability and impact.

Gunasekara et al. [124] analyze the application of digital innovations such as blockchain technology within facility management. The authors observe that the facility management industry is still lagging behind in adapting new technologies for its process, compared to other industries. A framework is proposed to enable blockchain technology in the facility management procurement process. By using interviews, templates, and content analysis for collecting data, this study suggests steps for transforming into a digitalized technology-based industry. According to the authors, applying blockchain technology in different steps of procurement through a systematic framework can solve issues related to data security, integration, and transparency.

Faccia and Petratos [125] examine the application and integration of blockchain to Accounting Information Systems (AIS) and Enterprise Resource Planning (ERP). The authors argue that it can be successfully integrated and can have significant benefits. In order to overcome security and privacy limitations, facilitate integration at multiple levels, and reduce risks in auditing and management, the authors analyze e-procurement systems and operations. In short, this study illustrates the significance of the integration of blockchain techniques, decentralized finance (DeFi), and financial technology (FinTech) into AISs and ERP systems which can benefit efficiency, security, and productivity. Similarly, Prajapati et al. [126] analyze an approach for the virtual closed-loop supply chain that utilizes blockchain and IoT technology, in order to accelerate e-commerce thereby bringing forth sustainability in the circular economy.

Xu et al. [122] analyze the benefits of smart contract applications in various industries from a procurement perspective and provide a systematic literature review with 174 publications. The authors argue that smart contract applications have been widely accepted at the global level, especially in the fields of information computing technologies (ICT), public management, supply chain, energy, finance, and healthcare.

Rane and Narvel [123] propose a data-driven decision-making technology by presenting an integrated model of Blockchain-IoT technologies for enhancing project resource management (PRM). For several reasons, including fierce competition, volatile markets, innovative new business models, and the ever-increasing complexity of technologies and developments, today’s PRM methods are insufficient. In this context, the authors discuss a new formula for handling this crisis by using an integrated model of Blockchain-IoT technologies in order to provide business intelligence to advance the PRM process. Further, the authors analyze the challenges faced by the Engineering, Procurement, and Construction (EPC) industry in handling resources and argue that the integration of Blockchain and IoT technologies can provide various capabilities such as instantaneous data acquisition and self-governing coordination of resources, which can enhance the decentralization, trustworthiness, security, and transparency of transactions. These advancements can lead to an improved level of agility for EPC industries. In summary, this paper identifies a new way of utilizing Blockchain-IoT integration technologies to boost the agility of resource handling in asset-intensive industries such as EPC.

Rodríguez et al. [120] discuss the potential of emergent disruptive technologies to advance the humanitarian supply chain. While increasing the importance of humanitarian operations in the supply chain process, challenges that these operations commonly face,
such as delays, congestions, poor communication, lack of accountabilities, and advantages of disruptive technologies to counter these problems, are being discussed in various literature. However, this literature on the humanitarian supply chain lacks a framework for understanding the challenges and solutions. They fill this gap by discussing the application of three such emergent disruptive technologies in detail: Artificial intelligence, Blockchain, and 3D Printing. By analyzing a case study based on the flood of Tabasco of 2007 in Mexico, they discuss the potentials of these emergent technologies in reducing congestion in the supply chain, enhancing simultaneous collaborations of different stakeholders, decreasing lead times, and increasing transparency, traceability, and accountability of material and financial resources.

In a recent study, Nodehi et al. [131] present a comprehensive blockchain solution, called the Enterprise Blockchain Design Framework (EBDF), in order to ensure a decentralized contracting and use of store of value validated through the emergence of cryptocurrencies with multiple stakeholder ecosystem. The contention posits that the implementation of blockchain technology remains in its nascent phase, and numerous corporate blockchain initiatives falter as a result of suboptimal utilization and inadequate motivation for all parties involved, stemming from a perceived lack of necessity. In this context, they propose a comprehensive framework that is not only relevant to certain cases but creates an enterprise blockchain system that is useful to multiple industries. This is certainly a novel step with regard to blockchain technology applications in private companies.

Yadav et al. [114] discuss the optimization of procurement costs through the utilization and integration of blockchain technology. The proposed model is a mathematical formulation that utilizes Mixed Integer-Linear Programming (MILP) to incorporate the expenses incurred in the various stages of block development, including procurement, placing orders, transportation, and storage or inventory procedures. An integrated MILP model is proposed to address potential leakage from the system during the four vulnerable stages, thereby enhancing the accessibility, traceability, and immutability of information for DSC. Ultimately, the LINGO 10.0 software is employed to address procurement obstacles in the digital realm, utilizing randomized datasets. The model is subsequently subjected to validation and testing in three distinct scenarios.

Prakash et al. [134] use a phenomenological method with six experienced experts to better understand the construction industry’s readiness to use blockchain technology. Subsequently, the research emphasizes the necessary sequential procedural measures for the efficacious integration of blockchain technology in construction industry use cases. The study presented evidence of the potential benefits of utilizing blockchain technology in the construction sector to enhance productivity. This was achieved through the examination of various case studies, including payments, procurements, building information systems, and smart asset management. This study contributes to the advancement of efficient and feasible tactics for expediting its implementation.

A comprehensive systematic review of 153 distributed ledger technology (DLT) and smart contract publications relevant to the design, construction, and operation of built assets is conducted by Li et al. [132]. The findings are fully transparent, accountable, repeatable, and updatable since they were generated using the steps and techniques of a systematic review. In order to provide the necessary change and impact from the widespread adoption of DLT and smart contracts, a more comprehensive socio-technical approach to the solution is required. The results of this comprehensive study provide valuable information for academics, professionals, and public officials concerned with the evolution of DLT and applications of smart contracts in the construction industry.

Sanchez et al. [92] present a comprehensive assessment of the successful application of DLTs in public procurement governance, while also addressing potential legal challenges. By examining various proof-of-concept projects in the industry, DLTs demonstrate the potential to enhance transparency, integrity, autonomy, and speed in the procurement cycle. Although the nascent nature of blockchain-based public procurement architecture poses cer-
tain limitations, it has been observed that the use of private ledgers or public-permissioned ledgers holds greater suitability for tender procedures in the public procurement context.

Li et al. [135] explore the design and management of a distributed energy system encompassing renewable energy generation and diverse end-users across residential, commercial, and industrial sectors. A hierarchical structure is developed to facilitate the real-time peer-to-peer exchange of energy information, accounting for the varying demand flexibility among different user types through inter-sectorial interactions modeled as a non-cooperative game. Additionally, the inherent unpredictability of renewable generation is addressed using the receding horizon optimization technique. To establish a seamless, secure, and efficient distributed energy system, blockchain-enabled smart contracts and decentralized identifiers are employed.

Radanovic et al. [136] explore the potential applications of blockchain technology in the field of medicine. The authors pinpoint multiple domains in which blockchain technology can be utilized, including but not limited to digital healthcare records, medical insurance, clinical studies, medication supply systems, etc. However, the adoption of blockchain in medicine is not without challenges. The technology is still in its early stages and lacks widespread understanding, hindering the development of a clear strategic vision for its future potential. Scalability, smart contract security, and user adoption are among the current concerns that need to be addressed.

Amiri et al. [137] present a novel blockchain system architecture aimed at enhancing the supply chain of engineering, procurement, and construction (EPC) companies involved in oil and gas infrastructure projects. The study addresses the issue of information flow disruptions within the supply chain, which contribute to cost and time inefficiencies. The proposed blockchain system architecture demonstrates promising results, with a reduction of 12.4% in cost inefficiencies and a 36.5% reduction in operational lead times. This approach offers a viable solution for improving the efficiency of EPC supply chains in the oil and gas industry.

Mohd et al. [139] present a descriptive study that investigates challenges in Engineering, Procurement, and Construction (EPC) contracts within the Malaysian oil and gas industry. The research methodology involves a literature review on EPC contracts and cloud computing, as well as the findings from a pilot study. The analysis reveals that the characteristics of cloud computing when integrated with EPC contracts, empower stakeholders and enable highly automated operations. This integration improves the performance of the upstream oil and gas industry by enhancing speed, minimizing financial risks and schedule delays, and elevating the quality of work.

Niu et al. [138] examine the tradeoffs associated with adopting blockchain technology in the context of a common online retailer. The study focuses on the costs of blockchain adoption, the potential increase in market opportunities, and the enhanced competitiveness with local providers for overseas suppliers. The study endeavors to identify potential mutually beneficial outcomes that could result from the implementation of blockchain technology by the overseas supplier, through an assessment of the profitability of all stakeholders in the supply chain.

Hofbauer et al. [117] aim to achieve two scientific objectives in their research. First, they provide a comprehensive description of key features of blockchain technology to comprehend its advantages in transaction processes. Second, they present practical applications of blockchain in transaction activities, specifically in sales and procurement. The methodology employed in this study is analytical and theoretical, combining users’ expectations and requirements with statistical data to assess the compatibility between blockchain characteristics and critical needs such as efficiency, cost reduction, security, and trust. The theoretical foundation of the research enables conceptual considerations and deductive exploration of potential application possibilities.
4.7. Artificial Intelligence

In I4.0, Artificial Intelligence (AI) tools and systems have made real impacts in all aspects of production and distribution. However, its influence on the procurement process is less examined in the literature. Scholars have acknowledged the potential benefits of AI in functions such as finance, production, marketing, and sales [143], and underscores that it could be used in procurement organizations that yield solutions to many complex problems more efficiently or effectively with the help of using smart computer algorithms [147].

The applications of AI technologies by public sector organizations have been increasingly discussed and variously debated. Sloane [141] broadly discusses the application of AI technology in the public sector and measures to tackle potential risks to society while employing it. AI technologies can harm citizens and pose a risk to social life in many ways. Therefore, the existing procurement process must be revised and innovated, considering these concerns. Noordt and Misuraca [145] analyze the implications of artificial intelligence within the public sector and its impacts in strengthening governance or administrative functions in three important ways: enhancing public service delivery, improving internal management, and policy decision-making, although in some limited ways. In short, all these studies acknowledge that an increasingly AI-powered mechanism in the public sector, especially in the field of procurement, will boost better governance and efficiency in public service delivery.

The traditional compliance management for procurement’s internal auditing has been coupled with many mistakes with a lack of accuracy due to manual audit systems and faults in handling large-scale paper-based repositories. As a solution, Wang et al. [140] designed a continuous compliance awareness framework with the help of AI technology that alleviates potential risks during the earlier manual auditing, including a low level of accuracy, efficiency, accountability, high expense and laborious and time-consuming. This system automatically audits the organization’s purchases by intelligently understanding compliance policies using text extraction technologies, automated processing methods, and report rating systems. In addition, it shows 95.6% accuracy with efficiency and quality and procurement’s internal audit.

Jemmali et al. [105] discuss the application of a multi-criteria intelligent algorithm for efficient supply chain management. In the traditional model of the supply chain system, the process of choosing suitable suppliers of commodities is a difficult process due to the wide range of suppliers in the fields. The decision-making in this context will be time-consuming. The authors propose an intelligent algorithm model as a solution that employs a set of intelligent formulas by converting predefined preferences into quantitative measurements. The application results of this system show that there is a high level of success in choosing the most appropriate suppliers in a short time by using this technology. Similarly, in a recent study, Manimuthu et al. [144] propose a new design framework for smart contracts and decision-making by using Federated Learning-Artificial Intelligence (FAI). In such an automotive industry system, the cost function, excessive utilization of embedded apparatus, and other related tools will be moderated because of the automated execution and control enabled by FAI. This paper thus shows the significance of AI in decentralized blockchain with smart contracts in order to handle market risk assessment during socio-economic crisis periods.

Mahmoudi et al. [142] intend to create a novel decision-making system to address supplier selection challenges in unprecedented disruption situations. During the COVID-19 outbreak, for instance, essential and non-essential goods and services are disrupted unprecedentedly; therefore, a recovery from supply chain disruptions is necessary. In this context, this paper suggests a new innovative decision-making technology by integrating green and resilience aspects of the supply chain, which the author called “gresilience”. In this gresilient supply chain management, a two-fold decomposition of the core algorithm of the Ordinal Priority Approach (OPA). The study employs OPA and extends it to the Fuzzy OPA (OPA-F) as a solution for supplier selection problems. The proposed model can solve supply disruptions during the time of the outbreak and sustain the supply chain.
Notwithstanding these benefits, some other scholars problematized the other side of AI-powered solutions and their potential dangers and risks in the public sector. For instance, in a recent work, Nagitta et al. [146] call for a human-centered AI (HCAI) discourse in procurement systems. By conducting research among procurement practitioners in Kenya, the author argues the importance of having a customized AI-powered procurement system in the public sector with a human-centric manual process in order to tackle potential challenges of AI technologies among humans. This approach to AI is crucial in the world and many companies are adopting such a strategy in order to keep dignity and respect for humankind.

5. Discussion

The advent of I4.0 has brought about significant transformations in the procurement landscape. From the analysis of the literature, several key themes emerged, namely I4.0 or P4.0, e-procurement, big data, the Internet of Things, additive manufacturing, blockchain and smart contracts, and artificial intelligence. Each of these themes has distinct implications for procurement, and their integration can unlock numerous benefits while also presenting challenges. The application of I4.0 technologies in procurement processes is not a novel topic because copious publications have been published on the same over the last few years. However, most of the literature discussed individual applications of I4.0 technologies in the field of procurement. The review presented herein brings this systematic literature together in order to make a comprehensive picture of the P4.0 process and enhanced digitalization that it brings forth for better efficiency in supply chain management.

Digitalization in the procurement processes enables a possibility of collaboration between various procurement processes which helps to sort out challenges related to procurement like supplier-related risks, misplacing orders, and others. This review supports that the utilization of I4.0-enabling technology is expected to yield noteworthy enhancements within procurement in particular and supply chain management in general. This is attributed to the technology’s ability to enhance the efficiency and effectiveness of supply chain management, facilitate extensive supply chain integration, and improve information management. I4.0 integrates supplies, demands, sales, and manufacturing resources by using highly equipped technological innovations in the procurement process. P4.0 represents a paradigm shift in procurement practices, where digital technologies are harnessed to enable more efficient and effective processes. The studies reviewed highlight the potential of P4.0 in improving supply chain visibility, streamlining processes, enhancing collaboration, and enabling data-driven decision-making. However, the adoption of P4.0 is not without challenges, including the need for organizational change and overcoming resistance to digital transformation [39].

E-procurement emerged as a critical aspect of I4.0, enabling the automation and digitalization of procurement processes. The literature demonstrates that e-procurement systems can enhance efficiency, reduce costs, improve transparency, and facilitate supplier collaboration. Nevertheless, the success of e-procurement implementation relies on factors such as organizational readiness, supplier integration [149], data security, and user acceptance [150]. There are several I4.0 technologies that help procurement managers predict prices [52]. One of them is cloud manufacturing, which takes several factors into account when estimating prices such as production conditions, variety of offerings, production capacity, customer demands, and price-supplier selection optimization.

Big data analytics has emerged as a powerful tool in procurement, enabling organizations to extract valuable insights from vast amounts of data. The reviewed studies highlight the potential of big data analytics in demand forecasting, supplier performance evaluation, risk management, and strategic decision-making. Big data can help achieve lower procurement costs through improved knowledge of the supply processes at various stages, such as supplier appraisal and marketing through which a supplier can negotiate cost reductions. Similarly, negotiations between parties could take place without the need for a professional intervention if big data analytics approaches are used. It can also cut
down on negotiating times, thus lowering most costs [95]. However, challenges such as data quality, privacy concerns, and the need for analytical expertise need to be addressed for successful implementation [151]. In practice, big data has the potential to assess material prices by accessing the commodities’ database of each supplier’s cost structure. As a result, the best timing and price for making a purchase might be determined. Because of the important uncertainties and risks involved, selecting and assessing vendors in an e-procurement system is more difficult than in traditional procurement. In all, there are three types of hazards here: internal risks that occur within a business, supply chain risks, and external risks that occur outside the supply chain [152].

The Internet of Things has the potential to revolutionize procurement by connecting physical objects and systems to digital networks. The literature indicates that IoT-enabled procurement can enable real-time monitoring of inventory, enhance traceability, enable predictive maintenance, and support automated replenishment. Although there are different types of costs related to the supply chain, two of them are important in this context. They are the costs of purchasing raw materials and the costs of maintaining inventory in production sites [104]. Companies are utilizing the IoT by tagging their products with identification tags and linking the important data from these tags to the cloud via the Internet. As a result, these stored data can be accessed easily from anywhere on the globe, and their affiliated companies (suppliers or vendors) can be linked to them for purchases. In today’s commercial context, the IoT-supported system has become a cost-effective solution by allowing faster decision-making. However, concerns related to data security, interoperability, and scalability need to be addressed to fully leverage the potential of IoT in procurement [153].

Additive manufacturing, also known as 3D printing, has emerged as a transformative technology [106]. It offers new possibilities for product design, enabling lighter and stronger parts [107]. AM provides increased design freedom, allowing unconventional geometries to be produced [109]. Furthermore, it facilitates collaboration between buyers and suppliers, leading to redesigned production networks [107]. The adoption of AM can decentralize manufacturing and reshape supply chains [108]. However, decision-making complexities arise from material properties, compatibility, and cost considerations. Despite challenges, AM has the potential to enhance supply chain resilience and reduce dependency on original equipment manufacturers [112]. It is crucial to evaluate the trade-offs between flexibility, lead times, and overall costs when incorporating AM in design enhancements [113]. In addition to its impact on product design and supply chains, AM plays a significant role in addressing disruptions and enhancing resilience in the automotive sector. The COVID-19 pandemic highlighted the vulnerabilities of global supply chains, emphasizing the need for innovative solutions [110]. However, widespread adoption of AM faces barriers such as limited government regulations, management support, raw material availability, and workforce constraints [154]. To fully leverage the benefits of AM, a systematic and interdisciplinary approach is necessary. This approach should consider the entire cost perspective, including logistics, manufacturing, repair expenses, and trade-offs between functionality improvements and design changes [113]. By addressing these challenges and embracing a comprehensive perspective, AM has the potential to optimize supply chains, enhance industrial performance, and unlock new possibilities for future advancements [109].

Blockchain technology and smart contracts have gained huge attention as enablers of secure and transparent transactions in procurement. The literature review reveals that blockchain can enhance trust, improve traceability, streamline payment processes, and facilitate supplier verification [133]. Additionally, blockchain technology gives a permanent review succession, which permits members/actors/stakeholders to know what activity was performed by whom and when it was performed [117]. This characteristic of blockchain provides straightforwardness and lessons related to the danger of data loss with outsider frameworks [119]. Huge information can assist with controlling the dangers related to providers when a presentation pointer is characterized, which prompts perceiving proper
obtaining. Blockchain provides security, guarantees secrecy, and upgrades the information uprightness of exchanges without the outsider’s contribution. Information security is critical for private organizations too. In any event, for privately owned business providers, for instance, save and secure the examined duplicates of procurement arrangements by exchanging them straightforwardly and by utilizing electronic information exchange [122]. All things considered, there is a lot of protection from these new emerging advances. However, challenges such as scalability, regulatory considerations, and the need for industry-wide collaboration need to be addressed for widespread adoption [155]. Despite these complexities, the transformative potential of blockchain and smart contracts in revolutionizing industries and creating new business models cannot be overlooked [156].

Artificial intelligence has emerged as a powerful tool in procurement, offering capabilities such as intelligent automation, predictive analytics, and cognitive decision support. The integration of AI in procurement processes has gained attention in the literature, with studies highlighting its potential benefits in various functions and areas, including compliance management, supply chain optimization, supplier selection, and risk assessment [141]. However, it is important to consider ethical considerations, data quality, and the need for human-AI collaboration. In the public sector, AI technology has been discussed for enhancing public service delivery, improving internal management, and policy decision-making, albeit with certain limitations [145]. The existing literature also recognizes the need to address potential risks and revise procurement processes accordingly. Emphasizing a human-centric approach in AI-powered procurement systems can help tackle these challenges and ensure effective and responsible implementation [157,158].

Table 7 summarizes the drivers and challenges of Industry 4.0 technologies in procurement. Additionally, in the context of I4.0 and its integration into procurement and supply chain management, modularization plays a pivotal role. Modularization refers to the strategic approach of breaking down complex systems or processes into modular components that can be developed, managed, and optimized independently. This approach facilitates flexibility, scalability, and customization, allowing for swift adjustments and improvements in response to changing market demands [159], and by adopting modular concepts, procurement processes can become more agile and adaptable. Components of the supply chain, such as sourcing, production, and distribution, can be structured as modules, enabling streamlined management of each element. This modularity empowers organizations to efficiently respond to dynamic market shifts, mitigate risks, and optimize resource allocation. Furthermore, modularization aligns with I4.0 technologies like IoT and AI, enabling data-driven decision-making and predictive analytics in each module. Through this integration, procurement and supply chain management can achieve enhanced efficiency, reduced operational costs, improved collaboration, and rapid responsiveness to market changes, fostering a dynamic interconnected environment and optimized for greater resilience and adaptability in an ever-evolving business landscape [160].

Comparing and contrasting the studies reviewed in these thematic areas, it becomes evident that the integration of multiple I4.0 technologies can unlock synergistic effects. For example, the combination of e-procurement, big data analytics, and AI can enable organizations to make data-driven decisions, automate processes, and optimize supply chain operations. Similarly, the integration of IoT, additive manufacturing, and blockchain can create a decentralized and transparent procurement ecosystem with enhanced traceability and customization capabilities. Moreover, comparing the adoption of I4.0 technologies in various industries and contexts, such as manufacturing, services, and the public sector, reveals both similarities and differences in their application and challenges. In manufacturing, I4.0 drives operational efficiency through automated production and supply chain processes. Similarly, the services sector benefits from improved customer experiences through data-driven insights. In the public sector, I4.0 enhances transparency and accountability in procurement processes. However, challenges vary: manufacturing deals with optimizing physical processes, services navigate intangible offerings, and the public sector focuses on regulatory compliance. While all sectors face data security concerns,
manufacturing grapples with integrating IoT in complex machinery, services emphasize AI-driven personalization, and the public sector navigates policy frameworks. The paper’s comparative analysis thus highlights the need for tailored strategies in each context while emphasizing the overarching transformative potential of I4.0 technologies in procurement.

Table 7. Drivers and challenges of the technologies in procurement.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Drivers</th>
<th>Challenges</th>
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<tbody>
<tr>
<td>Industry 4.0</td>
<td>Improved supply chain visibility, Streamlined processes, Enhanced collaboration, Data-driven decision-making</td>
<td>Organizational change, Resistance to digital transformation</td>
</tr>
<tr>
<td>E-Procurement</td>
<td>Automation and digitization, Increased efficiency, Cost reduction, Improved transparency, Supplier collaboration</td>
<td>Organizational readiness, Supplier integration, Data security, User acceptance</td>
</tr>
<tr>
<td>Big Data</td>
<td>Valuable insights, Demand forecasting, Supplier performance evaluation, Risk management, Strategic decision-making</td>
<td>Data quality, Privacy concerns, Need for analytical expertise</td>
</tr>
<tr>
<td>Internet of Things</td>
<td>Real-time inventory monitoring, Enhanced traceability, Predictive maintenance, Automated replenishment</td>
<td>Data security, Interoperability, Scalability</td>
</tr>
<tr>
<td>Additive Manufacturing</td>
<td>Decentralized production, Customization, Reduced lead times, Lower costs for low-volume production, Increased design flexibility</td>
<td>Limited material options, Intellectual property issues, Need for new skill sets</td>
</tr>
<tr>
<td>Blockchain</td>
<td>Secure and transparent transactions, Enhanced trust, Improved traceability, Streamlined payment processes, Supplier verification</td>
<td>Scalability, Regulatory considerations, Need for industry-wide collaboration</td>
</tr>
<tr>
<td>Artificial Intelligence</td>
<td>Intelligent automation, Predictive analytics, Cognitive decision support, Compliance management, Supply chain optimization, Risk assessment</td>
<td>Ethical considerations, Data quality, Need for human-AI collaboration</td>
</tr>
</tbody>
</table>

However, it is important to acknowledge the limitations and challenges associated with the adoption of I4.0 technologies in procurement. The studies reviewed often focus on specific aspects or use cases, limiting the generalizability of the findings. Additionally, there are organizational, technical, and cultural barriers that need to be overcome for successful implementation [161,162].

Organizations need to carefully consider factors such as data security, privacy, interoperability, and regulatory compliance when adopting I4.0 technologies. The potential risks associated with increased reliance on digital systems, such as cyber threats and data breaches, should not be overlooked. It is essential to develop robust risk management strategies and invest in cybersecurity measures to mitigate these risks. Moreover, the human factor should not be underestimated. While I4.0 technologies offer automation and efficiency gains, they should be seen as tools to augment human capabilities rather than replace human involvement entirely. Organizations should prioritize the development
of digital skills and provide training and support to ensure the successful adoption and utilization of these technologies. From a broader perspective, the implications of I4.0 in procurement extend beyond operational improvements. The integration of digital technologies can have far-reaching effects on the procurement profession itself, including changes in job roles, skill requirements, and the nature of supplier relationships [1,163,164]. Procurement professionals need to adapt and embrace continuous learning to remain relevant in the era of I4.0.

In the realm of procurement, a range of I4.0 technologies have emerged as influential forces in different processes to enhance efficiency, visibility, predictability, and decision-making. Among them, the IoT stands out for its profound impact on supply chain management. IoT devices equipped with sensors and connectivity capabilities provide real-time data on inventory levels, product quality, and equipment performance, thereby enhancing visibility and enabling organizations to optimize their inventory management, demand forecasting, order fulfillment processes, and facilitating E-processes. Also, AI has proven to be a game-changer in procurement, empowering professionals with advanced big data analytics and decision-making capabilities. AI-powered algorithms can analyze vast amounts of data, identify patterns, and generate valuable insights on strategic sourcing, risk management, and contract management. Table 8 summarizes the potential applications in procurement functions with respect to different KPIs criteria.

Table 8. Summary of the potential applications.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Applications</th>
<th>Criteria</th>
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</thead>
</table>
| Industry 4.0        | - Enhanced operational efficiency  
                      - Improved supply chain visibility  
                      - Predictive analytics  
                      - Proactive decision-making  
                      - Support modularization | Cost savings  
                      Process automation  
                      Scalability  
                      Flexibility  
                      More product variety in a shorter lead time and lower cost |
| E-Procurement       | - Streamlined procurement processes  
                      - Enhanced supplier relationship management  
                      - Increased procurement transparency | Ease of use  
                      Integration with existing systems  
                      Security and data privacy |
| Big Data            | - Demand forecasting  
                      - Supply chain optimization  
                      - Risk management  
                      - Performance measurement and tracking | Data accuracy and quality  
                      Real-time analytics  
                      Scalability  
                      Integration with other systems |
| Internet of Things  | - Real-time asset tracking and monitoring  
                      - Condition-based maintenance  
                      - Inventory management optimization  
                      - Improved logistics and supply chain visibility  
                      - Facilitating E-Design, E-Sourcing, E-Negotiation, E-Evaluation | Connectivity and interoperability  
                      Data security  
                      Scalability  
                      Energy efficiency  
                      Lean processes |
| Additive Manufacturing | - On-demand and localized production  
                        - Customized and personalized products  
                        - Rapid prototyping and iteration  
                        - Reduced lead times and transportation costs | Design flexibility  
                        Material selection  
                        Quality control  
                        Environmental sustainability |
| Blockchain          | - Transparent and secure transactions  
                      - Supply chain traceability and verification  
                      - Simplified procurement processes | Data immutability and integrity  
                      Smart contract functionality  
                      Interoperability with existing systems |
| Artificial Intelligence | - Strategic sourcing and supplier evaluations  
                          - Contract management and compliance  
                          - Risk management and predictive analytics  
                          - Process automation and optimization | Data analysis and insights  
                          Automation and efficiency  
                          Ethical considerations  
                          Scalability and adaptability |
The paper highlights the transformative potential of I4.0 technologies in the procurement journey. The integration of e-procurement, big data analytics, IoT, additive manufacturing, blockchain, and AI can lead to enhanced efficiency, transparency, collaboration, and decision-making in procurement processes. However, the adoption of these technologies should be accompanied by careful consideration of risks, challenges, and the human element. Organizations need to develop comprehensive strategies, invest in cybersecurity, foster digital skills, and adapt to the evolving procurement landscape to fully harness the benefits of I4.0. Future research should focus on addressing the identified limitations, exploring new applications and use cases, and investigating the long-term impact of I4.0 on the procurement profession and supply chain ecosystems.

Moreover, it is important to recognize that the adoption of these technologies is not without challenges. Implementing I4.0 technologies requires significant investments in infrastructure, data management systems, and workforce training. Organizations need to address issues related to data security, privacy, and interoperability when leveraging technologies like big data and IoT. Moreover, the integration of multiple technologies may pose compatibility issues and necessitate changes in organizational structures and processes. To fully harness the potential of I4.0 technologies in procurement, organizations should develop a comprehensive strategy that aligns technology adoption with their business objectives. This strategy should consider factors such as organizational culture, change management, and stakeholder engagement. Collaboration with technology providers, industry partners, and research institutions can also facilitate knowledge sharing and accelerate the adoption and implementation process.

Future research in this area should focus on surveying and addressing the practical challenges and barriers to implementing I4.0 technologies in procurement. Empirical studies and case examples can provide valuable insights into the real-world impact of these technologies on procurement performance, cost-effectiveness, and sustainability. Additionally, exploring the ethical implications of technologies like AI and blockchain in procurement, including issues of bias, privacy, and fairness, is essential to ensure responsible and equitable adoption. The paper’s significance can be amplified by delving into specific research questions: How do individual I4.0 technologies impact different procurement stages? What are the implications of AI-driven supplier evaluation models on decision-making? Challenges like data privacy in IoT implementation and biases in AI algorithms require scrutiny. Future research should address how AI enhances contract management and how big data accuracy impacts procurement. Contributions lie in models for technology-driven supplier selection, frameworks for IoT integration, and ethical guidelines for AI and blockchain, fostering innovative, responsible procurement practices.

6. Conclusions

In this paper, the role of I4.0 in the procurement industry has been examined, focusing on its potential benefits and implications. The procurement journey has undergone significant transformations in recent years, and a crucial role has been played by the integration of I4.0 technologies. Through the employed systematic review, various aspects of I4.0 in procurement have been explored, including the impact on supply chain management, data analytics, modularization, automation, and collaboration. The literature review conducted has provided insights into the current state of research and practice in this field, with a focus on the key trends and challenges faced by organizations.

Based on the analysis and discussion presented, it can be concluded that significant opportunities exist for procurement professionals to enhance their processes and achieve greater efficiency, cost savings, and strategic value through the adoption of I4.0. The integration of advanced technologies such as the IoT, AI, and blockchain, among others, can revolutionize traditional procurement practices and enable data-driven decision-making.

One of the major benefits of I4.0 in procurement is the ability to leverage real-time data and analytics for gaining insights into supplier performance, demand patterns, and market trends. This allows for the optimization of sourcing strategies, identification of
potential risks, and enhancement of supplier relationship management. Furthermore, the automation and digitization of procurement processes streamline operations, reduce manual errors, and result in time and resource savings. Collaboration also stands as a significant aspect facilitated by I4.0 in procurement. With connected systems and platforms, seamless communication, information sharing, and effective collaboration are made possible among stakeholders across the supply chain. This leads to improved coordination, enhanced visibility, and expedited decision-making processes.

The study underscores several key implications for various stakeholders in the realm of I4.0 technologies’ integration in procurement. Manufacturers can leverage the synergistic effects of I4.0 technologies to enhance operational efficiency and automate production and supply chain processes, while vendors and suppliers stand to benefit from the transparency and accountability brought about by I4.0 in procurement processes. The services sector can utilize data-driven insights for improved customer experiences, and the public sector can enhance regulatory compliance and transparency in procurement practices. Scholars and researchers gain insights into the complex interplay of I4.0 technologies across different sectors, offering valuable knowledge to inform future studies and practical implementations. As the procurement landscape continues to evolve, it is imperative for organizations to stay abreast of the latest advancements and adapt to the changing dynamics. Embracing I4.0 is not just a choice but a necessity to thrive in a digital and interconnected world. The successful adoption of I4.0 in procurement requires a holistic approach involving a combination of technological investments, organizational change management, and continuous learning.

However, it should be noted that the implementation of I4.0 in procurement is not without challenges. Concerns regarding data privacy and security, the need for upskilling and reskilling the workforce, and the integration of legacy systems with new technologies present hurdles that organizations must address. Robust strategies must be developed to fully harness the potential of I4.0 in procurement. In conclusion, a significant paradigm shift is evident with the introduction of I4.0 in the procurement industry. Unprecedented opportunities arise for organizations to transform their procurement processes and achieve strategic objectives. Through the adoption of advanced technologies, utilization of data analytics, and fostering collaboration, procurement professionals can enhance their decision-making capabilities, optimize supply chain operations, and drive sustainable growth.

As the procurement landscape continues to evolve, it is imperative for organizations to stay abreast of the latest advancements and adapt to the changing dynamics. Embracing I4.0 is not just a choice but a necessity to thrive in a digital and interconnected world. The successful adoption of I4.0 in procurement requires a holistic approach involving a combination of technological investments, organizational change management, and continuous learning.

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