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Data-driven review of additive manufacturing on supply chains: Regionalization, key research themes and future directions

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ABSTRACT

Additive manufacturing (AM) has the potential to greatly impact supply chains in a number of positive ways, particularly in regional and remote locations. This study aimed to identify the impact and application of AM on regional supply chains (RSCs) and address the associated challenges while promoting the sustainable use of this technology. Therefore, this study implemented a streamlined evaluation text mining method that employed Latent Dirichlet Allocation (LDA)-based modeling for robust content analysis. Over the past 19 years (2004–2022), there has been a significant increase in the number of journal articles that center on AM in supply chains. Through an extensive analysis of 341 published papers, five main research themes were identified: manufacturing, environment, costs, logistics, and maintenance. The identification of a gap in research in regional locations is significant as they often face unique challenges in their supply chains, such as limited access to technology and required infrastructure and the availability of resources. These challenges may have a different impact on the implementation of AM. Further, the possible impact of using AM in the recovery of RSCs after the COVID-19 pandemic is substantial and can bring about several positive sustainable changes, including increased responsiveness to changing demands, shorter production lead times, lower material usage and waste, customizability, localized production, energy efficiency, and reduced carbon dioxide and gas emissions.

1. Introduction

The outbreak of COVID-19 has disrupted global supply chains, resulting in supply shortages, delayed transportation, and higher costs. The pandemic has affected nearly every industry, and businesses have had to rapidly adapt to changing conditions (Ha, Akbari and Au, 2023). Many businesses were caught off guard by the rapid spread of the virus and were unable to quickly adjust to changing conditions. This has led to supply chain (SC) bottlenecks, delays, and shortages of goods, which in turn has impacted economic growth and consumer confidence (Alblowi, 2022). At the same time, a significant shift in consumer spending patterns has occurred (Zwanka and Buff, 2021) – many consumers reduced spending on services and increased spending on products, especially those related to home and health (Roll et al., 2022). This shift in demand has placed new pressures on SCs, which were already struggling to keep up with the increased demand caused by the pandemic (Pujawan and Bah, 2022).

As a reaction to these challenges, many firms are seeking to improve their SC productivity by, for example, redesigning and streamlining production processes. This can involve embracing new technologies in automation such as AM (Caiado et al., 2021). Industry 4.0 signifies an interesting era in manufacturing and transportation, where advanced emerging technologies such as 3D printing, drones, artificial intelligence (AI), cloud computing, the Internet of Things (IoT), and Big Data Analytics (BDA) are integrated into production processes, creating smarter and more efficient SCs (Frank, Dalenogare, & Ayala, 2019; Hoyer, Gunawan, & Reaiche, 2021). The goal of Industry 4.0 is to create more flexible, connected, and responsive SCS that can quickly adapt to ever-changing market conditions and consumer demands (Akbari et al., 2023).

The history of 3D printing, also known as AM, dates back to the 1980s when the first 3D printing technique was introduced (Vithani et al., 2018). However, it wasn't until 2014 that this technology received significant interest, when an electric vehicle was 3D printed (Durach, Kurpjuweit and Wagner, 2017). Made using a large-scale 3D printer, this project marked a major milestone in the advancement of 3D printing machinery and demonstrated its potential for use in the automotive industry (Ngo et al., 2018). A report in 2019 stated that 3D printing technology was used to construct a Latin American village consisting of 50 houses (Siso, 2019). The walls and edges of each house were

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reportedly printed in 24 h, which is a remarkable achievement given the traditional time required for construction. The use of 3D printing in this project helped to reduce waste and allowed for the precise use of materials with minimal waste (Siso, 2019).

The materials used in 3D printing are diverse, ranging from plastic, metal, ceramic, sandstone, resin, and biomaterial to biodegradable and reusable materials (polylactic acid), and food substances (Ahmed et al. 2021; Akbari and Ha 2020). This flexibility is highly valued by Conner et al. (2014), in which the authors praised the unparalleled levels of customization in 3D printing, where each printed component/product could be unique. The use of AM in construction is in its initial stages, but it is a promising development that could revolutionize the industry. By speeding up the construction process and reducing waste, AM technology can help to lower costs and make housing more affordable for a wider range of people. Additionally, the precise and efficient process of 3D printing can help to enhance the quality and accuracy of construction, resulting in stronger, safer, and more sustainable buildings (Ngo et al., 2018).

The applications of 3D printing in the industrial setting open a world of possibilities for SC practitioners (Caviggioli and Ughetto 2019), including reducing wastage of materials (Hossain et al. 2020), enabling a circular economy (CE) (Despeisse et al. 2017; Priyadarshini et al., 2022), minimizing SC's intricacy as a result of design consolidation (Knofius et al., 2019), and reducing transportation costs and lead-times through localized manufacturing (Sasson and Johnson 2016). With such a plethora of benefits, it is not surprising that AM has been utilized in numerous industries, such as automotive, aerospace, prototyping and manufacturing, jewelry, construction, wood-furniture sector, and even in the military (Cottingham 2021; Murmura and Bravi 2018).

AM has the potential to contribute significantly to various United Nations Sustainable Development Goals (SDGs). For SDG 9, AM can drive innovation and establish new industries, particularly in manufacturing, leading to enhanced infrastructure and economic growth (Machado et al., 2019). Second, AM aligns with SDG 12 by promoting responsible consumption and production through reduced waste and on-demand manufacturing (Machado et al., 2019). For SDG 13, AM helps combat climate change by minimizing greenhouse gas emissions through decreased transportation and material usage (Nyamekye et al., 2023). For SDG 14, AM plays a role in reducing ocean plastic waste by enabling the production of biodegradable products (Garrido et al., 2020). Lastly, SDG 17 is supported by AM, as it fosters partnerships between businesses, governments, and civil society organizations to collaborate on sustainable development initiatives and accomplish the SDGs (Hegab et al., 2023). By leveraging the benefits of AM, it is possible to make progress toward achieving the SDGs and building a more sustainable and equitable world.

In regional areas, the SC plays a key role in establishing the level of sustainability in a local economy. As the traditional SC model is undergoing significant alterations, AM technology has emerged as a potentially disruptive drive that could have a substantial impact on sustainable development in these areas. To realize the advantages and benefits of AM for sustainable development in regional areas, it is crucial to consider the broader social and economic context, including access to energy, technology, and resources. Carefully evaluating the impact of AM on the local economy can ensure that this technology is used in a way that supports sustainable growth and development and reduces the adverse environmental impact.

The main aim of this study is to analyze and respond to the following research questions:

RQ1. As the supply chain is undergoing significant changes, what is the impact of AM on sustainable growth and development, particularly in regional areas??
RQ2. What is the fundamental research direction for researchers in the field who focus on the impact of AM in regional supply chains?

Answering these two research questions will provide an invaluable understanding of the sustainable application of AM in SCs, particularly in regional areas. Prior to describing the methodology, results, and discussion in this study, the subsequent sections plunge into the study background of AM in relation to regionality in SCs and sustainable development.

2. Background

2.1. Supply chains and regionalizations

SC refers to the coordination and oversight of all involved activities in the process of the production and delivery of goods, from sourcing raw materials to delivering finished products to customers (Christopher, 2016). Over the last century, the efficient management of global supply chains has become the main strategic point for any firm (König & Spinler, 2016). SC systems that cross international borders have played a key role in driving the globalization trend (Akbari et al., 2017; Akbari et al., 2022). Consequently, SCs have had to be more resilient, sophisticated, and, as a result, more costly (Akbari and Do, 2021).

The rise in uncertainty and the trend toward shorter production cycles also play a significant role in the growing trend toward regionalization in SCs (Akbari et al., 2023; Park et al. 2013). RSCs consist of interconnected suppliers, manufacturers, and distributors who primarily carry out upstream and downstream operations within their home geographical areas (Rugman et al., 2009). In general, maintaining robust and resilient RSCs requires careful planning and coordination, as well as a willingness to be more agile and flexible in ever-changing environments. At the same time, there are several issues that can arise, related to regional SCs (Chu et al. 2020), some of which include:

- Dependence on a single region or supplier: RSCs that are overly dependent on a single region or supplier can be vulnerable to disruptions, whether from natural disasters, political instability, or other factors.
- Transportation and logistics challenges: Shipping goods across long distances within a region can be challenging and expensive, particularly in areas with poor infrastructure or high levels of traffic congestion.
- Lack of diversity in suppliers: RSCs that are not diverse in terms of the types of suppliers they rely on can be vulnerable to disruptions in the event of a natural disaster or other crisis.
- Differences in regulations and standards: Different regions may have different regulations and standards, which can create compliance challenges for companies operating in multiple locations.
- Language and cultural barriers: Communication and coordination between suppliers and buyers in different regions can be hindered by language and cultural differences.
- Currency fluctuations: RSCs can also be impacted by currency fluctuations, particularly if the suppliers and buyers are operating in different countries with different currencies.

Nevertheless, there are also several benefits to operating in regional/rural areas, including access to natural resources, reduced transportation emissions, lower costs, better alignment with local regulations and standards, local economic development and job opportunities, as well as a strong sense of community (Park et al., 2013). Companies that are able to successfully navigate the challenges of rural SCs can create value for both themselves and the communities in which they operate.

Although there are limited studies in relation to RSCs (Durugbo et al., 2020), investigations of regional SCs have provided valuable insights into the operational difficulties faced by regional and rural firms in relation to socioeconomic growth (Closs and Bolumole, 2015), security procedures (Zhu et al., 2015), technological developments (Graham & Smart, 2010), and environmental and ecological measures (Chen et al., 2020).

The concept of a sustainable SC pertains to the cooperation of all members involved in the SC, while considering the three pillars of sustainability: economic viability, social responsibility, and environmental protection (Dubey et al., 2017). With the complicated nature of modern SCs and growing sensitivity to sustainability, the implementation of sustainable practices is becoming increasingly popular, especially with emerging Industry 4.0 technologies (Akbari and Hopkins, 2022).

2.2. Empowering cleaner production and sustainable development goals

The SDGs established by the United Nations in 2015 aim to eliminate poverty, protect the planet, and promote universal peace and affluence (United Nations, 2016). Achieving these goals requires sustainable practices in consumption and production. While the SDGs apply globally (Diaz-Sarachaga et al., 2018), different regions face unique challenges in their implementation. Developing regions often grapple with limited access to resources, infrastructure, and education, hampering their progress toward the SDGs. Conversely, developed regions face challenges associated with overconsumption, waste, and unsustainable production patterns, hindering environmental preservation and SDG achievements (Salvia et al., 2019).

To address these regional differences, governments and organizations must collaborate and tailor their approaches to specific needs (Alen et al., 2017). This involves investing in infrastructure and education and promoting sustainable consumption and production practices. Partnerships between government, businesses, and civil society organizations are crucial.

Cleaner production (CP) focuses on reducing energy and material usage while substituting harmful products with safer alternatives (Hens et al., 2018). It entails integrating preventive environmental strategies to enhance efficiency and minimize damage to humans and the environment (Akbari & Hopkins, 2022). CP is closely linked to the CE, which restores and recycles the value of used resources (Tseng et al., 2013). The CE, viewed as a viable business approach for sustainable development, presents a new perspective of production and consumption (McDonwall et al., 2017). Implementing the CE poses challenges for SCs, including limited information on product life cycles, product recovery, and the need for advanced technologies (Su et al., 2013). However, with advancements in digital technologies, the adoption of the CE has become more feasible than ever before (de Sousa Jabbour et al., 2018).

In the context of CP, AM offers significant potential. AM technologies enable the production of complex structures and customized products, reducing material waste and energy consumption (Prashar, Vasudev & Bhuddhi, 2022). Moreover, AM facilitates localized production, minimizing transportation needs and associated carbon emissions (Javaid et al., 2021). By incorporating AM into their production processes, companies can enhance their efforts toward cleaner production, resource efficiency, and waste reduction (Akbari & Ha, 2020). AM supports the transition toward a CE by enabling the reuse of materials and reducing the reliance on traditional manufacturing methods (Ponis et al., 2021).

By embracing AM and integrating it into sustainable development strategies, regions can drive progress towards achieving the SDGs, promote cleaner production practices, and pave the way for a more sustainable and equitable future for all.

2.3. Industry 4.0 and Additive manufacturing

Industry 4.0 highlights the fourth industrial revolution, in which digital supply chain (DSC) and smart manufacturing are made possible by the integration of cyber-physical systems (Hoyer et al., 2020). It is widely anticipated that the traditional supply system will be replaced by the DSC (see Fig. 1) (Akbari and Ha, 2020; Piccarozzi et al., 2018). Industry 4.0 is driven by several emerging technologies, including AM/3D printing, 5G networks, automated robots, AI, autonomous vehicles, BDA, IoT, cloud computing, drones, blockchain, augmented reality (AR), and virtual reality (VR) (Rüßmann et al., 2015). These advancements in technology are expected to drive the digitization of the SC, resulting in a more connected and intelligent ecosystem that utilizes platforms for efficient resource management, energy conservation, and other benefits (Schrauf and Berttram, 2016).

The implementation of digital strategies is now more crucial than ever as the world moves forward in the post-COVID-19 recovery period (Gupta et al., 2022). Of all the Industry 4.0 technologies that are emerging, AM shows great potential for future investment and adoption by SC companies (Akbari and Ha, 2020). AM (or 3D printing) involves constructing an object by inserting layer-by-layer materials, using computer-aided design data to guide the process (Dwivedi et al., 2017). AM distinguishes itself from conventional "subtractive" manufacturing technologies (Bogers et al., 2016). According to Fernandez and Coninck (2019), AM provides accurate control over the form and exterior of objects, allowing users to create complicated goods from a range of materials, including ceramic, metal, plastic, resin, sandstone, biomaterial, and food substances (Rogers et al., 2016).

According to Lux Research, a technology consulting firm based in Boston, the global market for AM is estimated to triple in size over the next ten years, reaching close to US$50 billion. The application of AM for prototyping, the most widespread use, is expected to grow from US $4.4 billion to approximately US$10 billion. Molds and tools, the second major use of 3D printing, are projected to generate the most significant value and rise from US$5.2 billion in 2020 to US$21 billion by 2030. By

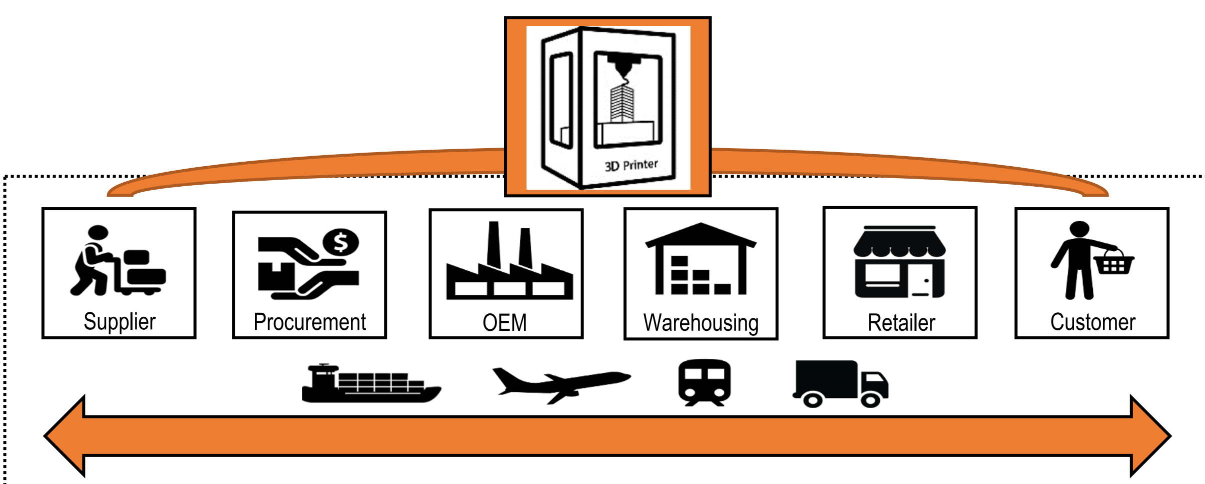

Fig. 1. AM in Supply Chains. *Source*: Adapted from Akbari and Ha (2020).

2030, the market value of 3D-printed end-use components is expected to grow sevenfold, reaching US$19 billion (Suvillan, 2020). These are just a few examples of the significant potential market impact of AM.

Offshoring manufacturing benefited SCs from the economies of scope for many years (Wagner and Walton, 2016) where companies sourced their materials, manufactured, stored, and shipped the final goods from numerous locations (Thomas and Gilbert, 2014). However, this increases lead time, and AM has a great potential to adjust this by reducing the lead time and eliminating the distribution channels (Bogers et al., 2016).

For regional and rural areas, AM has the capability to reduce waste and improve the efficiency of the SC by facilitating the local production of goods and reducing the need for long-distance transportation. This can result in lower carbon emissions, reduced dependence on non-renewable resources, and greater local control over production and distribution. However, AM also has the potential to increase the demand for resources and energy, particularly in regions that lack access to renewable energy sources. This could result in increased environmental impacts and undermine efforts to promote sustainability.

3. Methodology

The initial stage of any research paper involves conducting a literature review to survey the existing research and determine its background (Chao, 2020; Snyder, 2019). A review of literature is seen as a way to increase one's understanding of a particular subject by conducting an extensive examination of existing information (Akbari, 2018). This analysis allows the author to present a thorough examination of the existing knowledge that has been recognized in the field, providing valuable insights to the readers (Jafari, 2015, Schryen et al., 2015). According to Rousseau et al. (2008) and Tranfield et al. (2003), the assessment of available literature is considered the most crucial step of any project and research development. With this in mind, the first step in this investigation includes incorporating an evaluation of the existing literature.

This paper adopted three steps, following similar approaches by Akbari (2018), Reefke and Sundaram (2019), Seuring and Müller (2008), Nguyen et al. (2023), and Zhou et al. (2021) (see Fig. 2).

Step 1 - Literature Search and Selection: This involves a systematic process of locating and selecting relevant articles to be reviewed in the study.

Prior to conducting a literature search, we identified three sets of keywords that could encompass the synthesis of existing literature on our research topic (e.g., AM in SC).

Group 1: AM-related keywords, such as "Additive Manufacturing," and "3D Printing."
Group 2: SC-related keywords, such as "Logistics," "Transportation," "Supply chain," "Manufacturing," and "Procurement."
Group 3: SDG-related keywords, such as "Sustainability," "Green," "Regional," and "Rural."

The literature was thoroughly researched by combining keywords from the three abovementioned groups and searching through Scopus and Web of Science. The search covered the period from 2004, when the first paper was identified, to the end of 2022. The research was restricted to journal articles and only included those that contained the keywords in the title and/or abstract.

In the initial search, 640 papers were identified. This was reduced to 401 after removing duplicates. Next, all the remaining papers went through a thorough screening by the authors to check for overall relevancy and applied exclusions. In the end, 341 papers were selected for this review.

Figs. 3 and 4 display the distribution of the selected articles based on

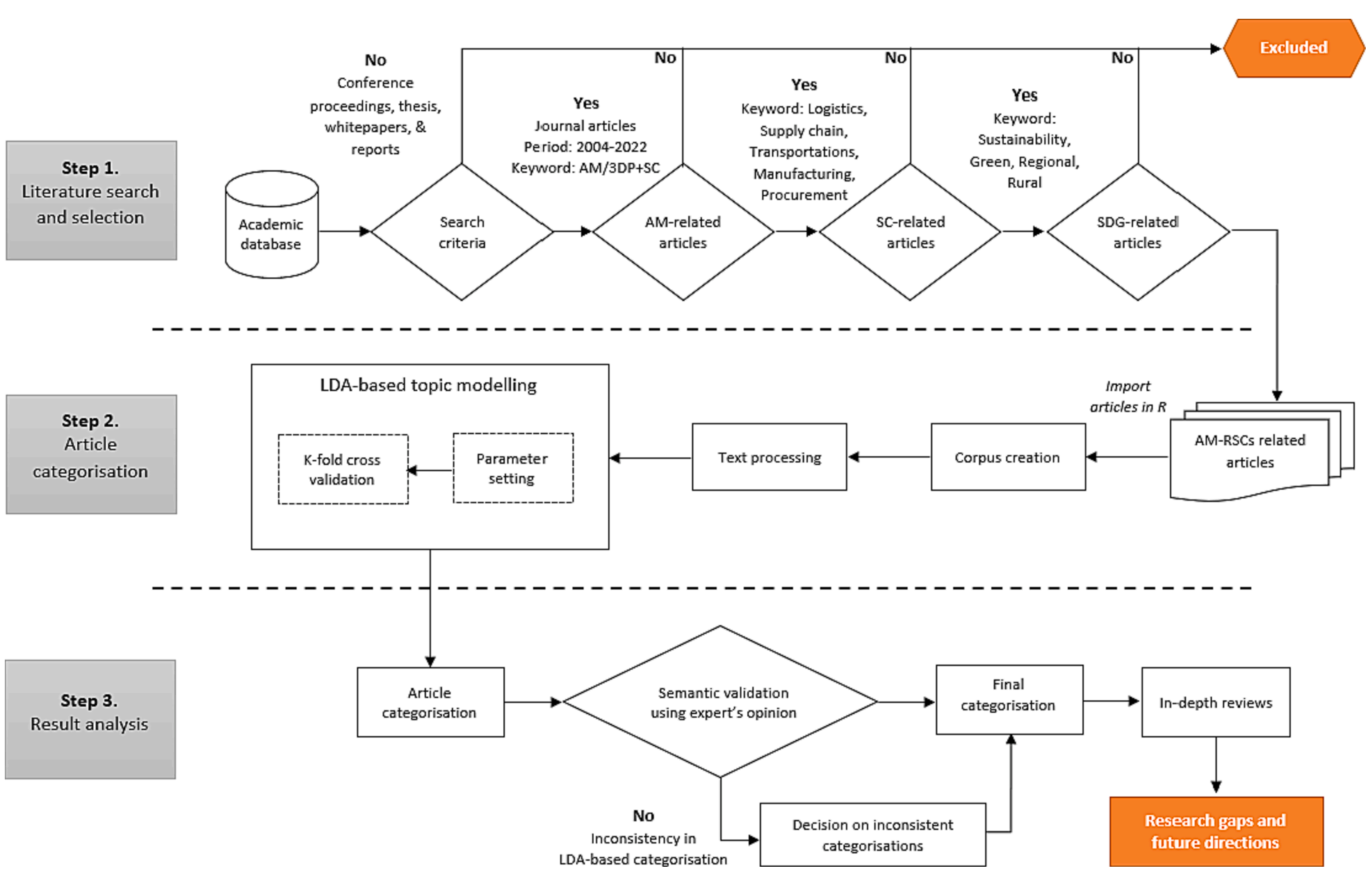

Fig. 2. The three-step systematic literature approach.

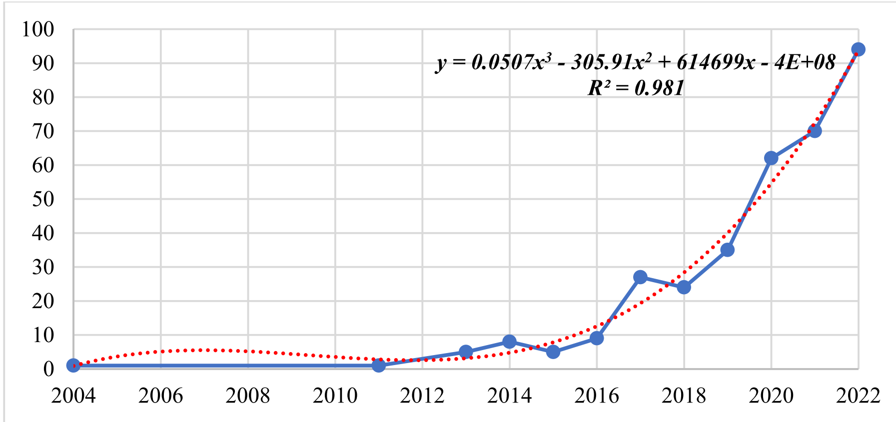

Fig. 3. Timeline Trend.

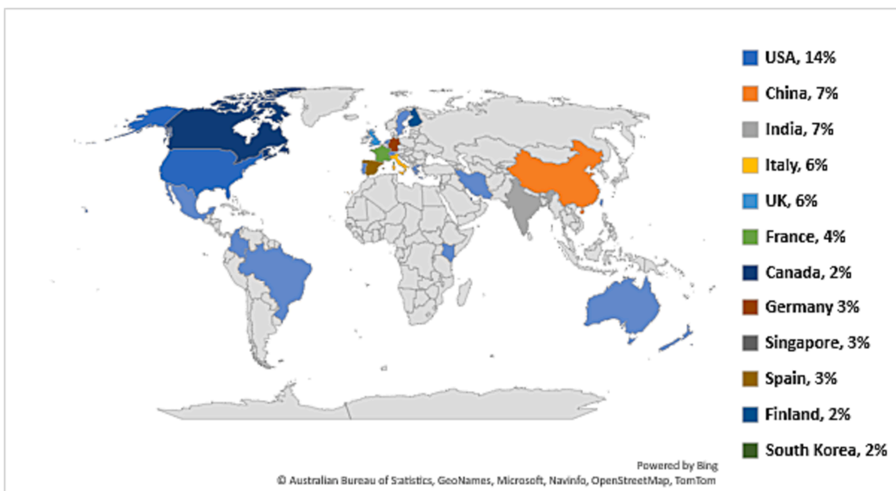

Fig. 4. Country positioning.

the year in which they were published and the journal in which they were published, respectively. A review of published works overtime showed a gradual progression, with most publications appearing in 2019 (see Fig. 3). Apart from a slight decline in 2017–2018, the publication number reached its peak in 2019.

Step 2 - Article Categorization: This employs a topic modeling technique to categorize the reviewed articles into various research categories.

Traditionally, the classification framework and text/content analysis have predominantly relied on manual approaches, where coding systems are developed through consultation with domain experts who possess extensive knowledge in the relevant field (Asmussen and Møller, 2019). The utilization of bibliometric methods, also known as bibliometric analysis, relies on expert input to establish reliable coding systems that facilitate systematic analysis of texts and content (Asmussen and Møller, 2019). However, it is important to acknowledge that human error can occur within bibliometric methods, especially during the data collection and analysis stages (Nguyen et al., 2023). Also, a significant disadvantage of this manual text/content analysis is that it can be time-consuming and requires a lot of effort to view the papers and prepare the coding sheets prior to the analysis stage. This can be discouraging for researchers and can result in wasted effort if the results are found to be unreliable.

Researchers are increasingly turning towards automated content analysis using computer-assisted text mining to replace manual coding practices because it decreases the time and cost involved and minimizes human error. This technique is underutilized in academic papers (see Table 1), despite the pressing need for a dependable and efficient literature review method that can effectively handle and analyze large and rapidly expanding amounts of research data (Duong et al., 2021). This study employs Latent Dirichlet Allocation (LDA) for topic modeling to categorize the existing literature into major research themes.

In summary, the LDA model is a widely used approach for identifying topics in a large text document collection. It operates on a hierarchical structure consisting of three layers: document layer (*D*), word layer (*N*), and topic layer (*K*). LDA assumes that each document in the corpus (*D*) can be described by a combination of *K* latent topics, with each topic defined by a Dirichlet distribution (βk) over the *V* words in the vocabulary. Every document (*d*) has its own topic distribution (θd) that is determined by a Dirichlet prior with parameter α. The LDA process uses the variables *Wdn* to represent the ηth word in document *d*, and *Zdn* to represent the topic assignment for that word. The process for generating words in LDA consists of two steps:

(1) randomly determining the topic distribution (θd) for each document in the corpus (*D*), and
(2) randomly selecting a topic (*Zdn*) from the distribution (θd) and then randomly choosing a word (*Wdn*) from that topic.

The entire process can be represented mathematically by the joint distribution of the observed and hidden variables presented here:

Table 1
Summary of existing review articles focusing on AM in SC.

Review paper	Paper focus	No. of reviewed papers	Review methodology
Ishfaq et al. (2022)	Investigated the potential uses of AM within the field of aerospace.	–	Narrative review
Monteiro et a. (2022)	Outlined various methods for increasing energy and material efficiency in metal additive manufacturing, with a particular emphasis on its application in the aerospace industry.	108	Manual coding thematic analysis
Naghshineh and Carvalho (2022)	Systematically reviewed existing literature to determine the effects of SC integration resulting from the adoption of AM.	32	Manual coding thematic analysis
Chantzis et al. (2020)	Reviewed the existing literature on the intersection of hot stamping tooling and AM.	–	Narrative review
Iqbal et al. (2020)	Explored the possibilities of using subtractive manufacturing techniques, AM techniques, and hybrid approaches that combine both in manufacturing processes.	–	Narrative review
Kunovjanek, Knofius, and Reiner (2020)	Systematically reviewed existing literature. A supply chain operations reference (SCOR) framework was developed and suggested for use.	141	Manual coding thematic analysis
Xia et al. (2020)	Explored the techniques facilitating the creation of circular metal AM by utilizing recycled feedstocks.	–	Narrative review
Verboeket and Krikke (2019)	Systematically reviewed existing literature on the impact of AM on the design of SCs.	47	Manual coding thematic analysis

$$p(\beta_k, \theta_d, Z_d, W_d) = \prod_1^K p(\beta_k) \prod_1^D 0 \times p(\theta_d) \{ \prod_1^N p(Z_{dn}|\theta_d) p(W_{dn}|\beta_k, Z_{dn}) \}$$

and concealed variable/s:

$$p(\beta_k, \theta_d, Z_d|W_d) = x = \frac{p(\beta_k, \theta_d, Z_d, W_d)}{p(W_d)}$$

According to Griffiths and Steyvers (2004), the second equation (hidden variables) in their explanation involves an intractable component that necessitates the use of an approximate inference method. Previous studies have employed two primary approaches to approximate LDA: variational algorithms (Blei, Ng & Jordan, 2003) and sample-based algorithms (Griffiths & Steyvers, 2004). For this particular investigation, the Gibbs sampling method was utilized to estimate the probability distribution of topics within a collection of textual documents. Gibbs sampling method is a Markov chain Monte Carlo algorithm that has proven to be more efficient in handling large-scale document sets. It is a Markov Chain Monte Carlo (MCMC) technique employed to generate a series of samples from a given probability distribution (Grün & Hornik, 2011). Additionally, K-fold cross-validation was employed as a technique to evaluate the performance of the implemented model.

Step 3 - Results Analysis: This entails a comprehensive examination of each research theme and insight to contextualize and reaffirm the identified themes, uncovering areas for future research centered on the existing gaps. To validate the themes, we gathered feedback from four industry experts with 3–5 years of experience in the field of AM. The experts included Expert A (Architect & Designer), Expert B (Managing Director), Expert C (Co-founder & CEO), and Expert D (Researcher and Educator). Their insights and expertise were utilized in the post-validation process of the identified themes.

After a complete review of existing literature focusing on AM in RSCs, we identified that there were no studies focusing on rural and regional areas. As the focus on the United Nation's SDGs grows, it is timely and desirable to conduct a comprehensive examination of the relevant literature especially focused on RSCs. Therefore, as the final step in this study, we present significant findings and gaps, and limitations and future research directions.

4. Descriptive analysis

4.1. Timeline trend

Fig. 3 illustrates the temporal pattern of the chosen articles. Analyzing the publications over time reveals a steady increase, with the majority of articles being published in 2019 (see Fig. 3). Although there is a slight downturn in 2017–2018, the peak in 2019 clearly indicates a significant surge in research activities within this domain.

4.2. Country positioning and industry involvement

The most frequently engaged country in the selected articles is the USA with 26 contributions, as shown in Fig. 4. The next significant contributors are India and China, each with 15 articles, followed by the UK and Italy with 14 each, France with 10, and Spain, Singapore, Germany, and Canada with 9 each.

Fig. 5 illustrates the distribution of articles across different industries. Among these industries, the manufacturing industry garnered the highest attention, accounting for 56% of the categorized articles. The supply chain industry ranked second with 12% of the articles, while the construction industry followed closely with 9%. The fashion and textile sector represented 4% of the articles, while recycling, logistics, transportation, and healthcare industries each accounted for 3%. The aerospace and bio-materials industries both received 2% of the attention.

It is noteworthy that several industries received relatively limited attention, with less than 2% of the published papers. These industries include biomass, automotive, spare parts, and others. This observation highlights a potential research gap and the need for further exploration and scholarly contributions in these areas.

4.3. Distribution by journals and publishers

The illustration in Fig. 6 shows the distribution of publishers, with Elsevier having the largest number of publications at 152. The second and third top publishers were Springer and MDPI, with 35 and 33 papers, respectively. There were 42 publishers who had fewer than 2 published papers.

This study reveals that the *Additive Manufacturing* journal had the largest number of published papers, with a total of 30 (see Fig. 7). It was followed closely by the *International Journal of Advance Manufacturing Technology*, which published 23 papers, and *Journal of Cleaner Production*, which published 22 papers.

4.4. Research method

According to Malviya and Kant (2015), there are five main categories of research methods: (1) desk qualitative, which includes conceptual models, (2) desk quantitative, which includes mathematical models, (3) empirical qualitative, which includes case studies, (4) empirical quantitative, which includes surveys/questionnaires and experiments, and

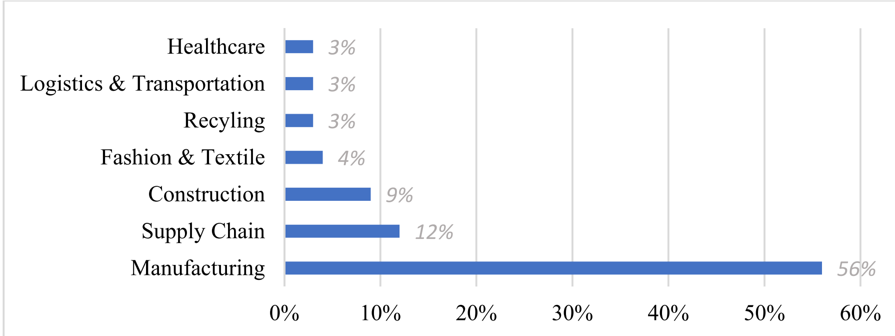

Fig. 5. Industry involvement.

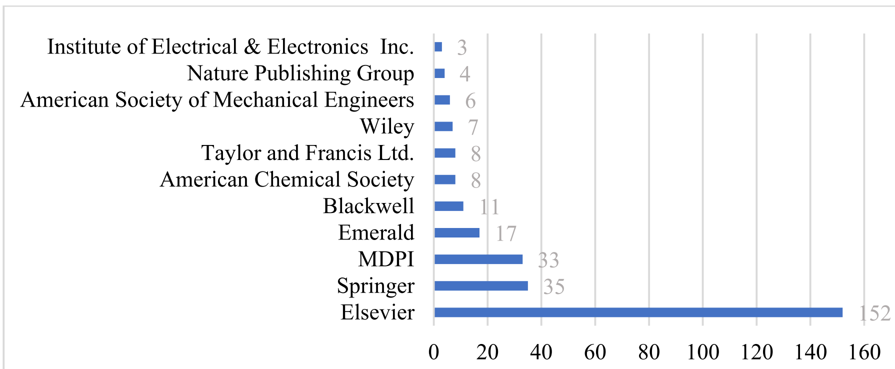

Fig. 6. Distribution by publishers.

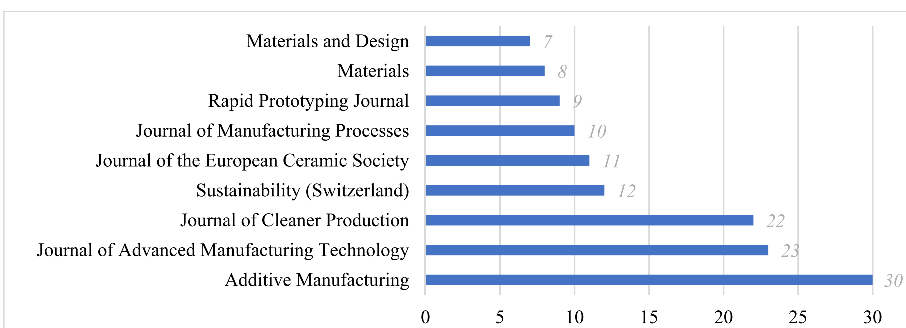

Fig. 7. Distribution by Journals.

(5) empirical triangulation or multi/mixed methods. The data shown in Fig. 8 indicates that desk qualitative was the most frequently used method, accounting for 37% of the published papers, followed by empirical triangulation at 32%, desk quantitative at 16%, empirical quantitative at 8%, and empirical qualitative at 7%.

5. In-depth review of research themes

5.1. Theme 1: Manufacturing-oriented

In the last few years, AM has grown into a topic of significant interest among both academic and industry professionals. A number of commonly employed AM methods exist in manufacturing. For example, fused deposition modelling and stereolithography for plastic printing, and direct metal laser sintering and electron beam melting for metal printing (Liu et al., 2018).

In the last few decades, topology optimization that is geared toward manufacturing has been widely researched, particularly in the context of common manufacturing procedures, including machining, injection molding, and casting (Liu et al., 2018). The collaboration between design and manufacturing engineers has resulted in numerous close-to-optimal and easily producible design solutions, to the benefit of both parties. Topology optimization is a complex mechanical design technique that allows for the determination of the optimal structure configuration through the rational distribution of materials while meeting specific load conditions, performance requirements, and constraints (Sigmund and Maute, 2013). Unlike sizing and shape optimization, topology optimization does not depend on the preliminary configuration and has a wider design scope, making it a popular choice for the design of high-performance, lightweight, and multifunctional structures in various fields.

On the other hand, AM offers the capability to manufacture complex structures, especially those enhanced through topology optimization. With no need for extra tools, molds, or complicated techniques, AM is highly flexible and ideal for intricate shapes, reducing production costs and shortening the production process, particularly for quick

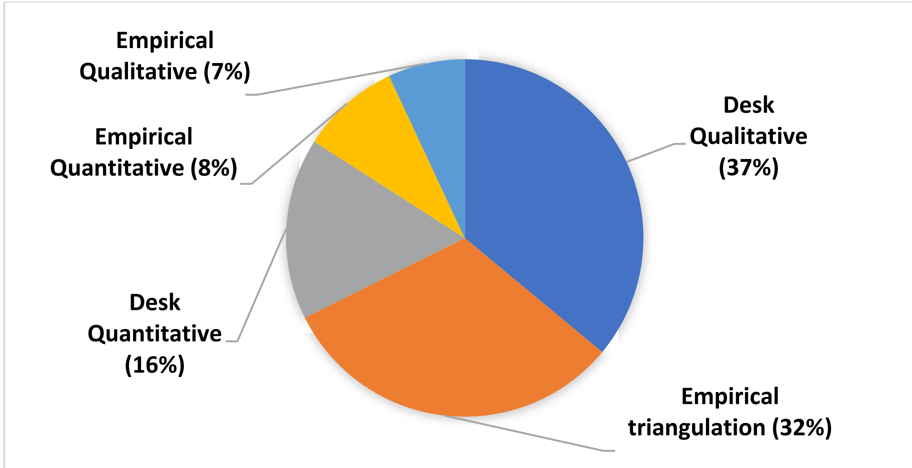

Fig. 8. Research Methods.

prototyping and small-scale manufacture (Zhu, et al., 2021). Additionally, the potential for complex configurations through AM also stimulates the integral structure design, reducing the number of components and steps to assemble.

Over the years, various AM techniques have emerged, such as stereolithography (Bendsøe and Kikuchi, 1988), selective laser sintering (SLS) (Zheng et al., 2017), selective laser melting (SLM) (Butler, 2011), and fused deposition modelling (Kruth et al., 2004). AM materials range from metals and polymers to composites and biomaterials, and parts can range from micro-nano components to large structures several meters in size (Zhu, et al., 2021). With its personalized manufacturing capabilities, AM has revolutionized the limitations of traditional methods and made a substantial impact on the advancement of manufacturing, with extensive applications in areas such as aerospace, medicine, mechatronics, and civil engineering (Jankovic and Barari, 2019; Jewett and Carstensen, 2019; Zhu et al., 2016).

For topology-optimized structures, AM supports engineers to concentrate on creating lightweight and high-performance constructs, free from the constraints of conventional manufacturing techniques. The integration of AM and topology optimization is a key approach to realizing a match between manufacturing and structural design. An example of topology optimization in action is the interesting layout of the top edge droop nose ribs for the Airbus 380, which resulted in a lighter structure that met all mechanical performance specifications (Zhu et al., 2016).

Additionally, advances in AM have facilitated the creation of cellular materials whose mechanical properties are determined by their microscale topologies (Loh et al., 2018). These materials, known as architected materials (Osanov and Guest, 2016) or *meta*-materials (Zadpoor, 2016), can be designed and created with extremely specific or exceptional physical properties.

5.2. Theme 2: Environmental-oriented

Among the various methods for handling end-of-life products and materials, only three contribute to CP: 1 recycling, 2) reusing, and 3) remanufacturing and repairing (Juraschek et al., 2017; Ponis et al., 2021).

5.2.1. Recycling

Recycling is a process that involves collecting, processing, and reusing discarded materials to reduce waste, conserve natural resources, and decrease the environmental impact of manufacturing and consumption (Kumar et al., 2020). Recycling occurs when a product is no longer useful and would otherwise be thrown away as garbage (Wu and Wu, 2019). The process of recycling starts with the collection of waste materials, which can include paper, plastic, glass, metal, and electronics. These materials are then sorted, cleaned, and processed to be converted into new products.

Recycling is driven by many factors, including economic considerations, environmental awareness, and regulations. It is seen as an important component of a sustainable waste management strategy, as it helps to reduce the volume of waste that is forwarded to landfill, protects natural resources, decreases greenhouse gas emissions, and creates jobs. Overall, recycling is a fundamental component of a larger sustainable development strategy that seeks to offset the triple bottom line (economic, social, and environmental) impacts of human activities. By adopting recycling practices, individuals, organizations, and governments can step up collectively to create a cleaner and sustainable world for the future.

An exciting new area in technology with a lot of potential for creating innovative ways to recycle plastic waste is the idea of distributed recycling for AM within a CE framework (Dertinger et al., 2020). Historically, recycling has mainly been done in large, centralized facilities to obtain benefits from economies of scale (Zhong and Pearce, 2018). With AM, discarded plastics can now be transformed into material for 3D printing, instead of sent to recycling facilities or dumped in landfill (Sanchez et al., 2017). This has many benefits, including reducing greenhouse gas emissions and carbon footprint, and generating energy savings equivalent to one billion MJ per year (Lanzotti et al. 2019).

5.2.2. Reuse

When designing products, it is crucial to consideration how they will be disposed of after use, specifically in terms of recycling and reuse. This means that the choice of materials used in product design should be based on the potential for the waste to be treated as raw material to create and design new manufactured goods (Giurco et al. 2014). As recognition of AM has increases, the demand for metal powder as raw material has also risen, emphasizing the importance of recycling and reuse (Gorji et al., 2020). The use of recycled metal powder in part productions through AM techniques is a developing field that is gaining attention among scientists (Popov et al., 2018). Although recycling metal powder in AM helps to reduce costs, processing time, energy consumption, and waste materials, it also raises concerns about the impact on the powder quality and, in turn, the properties of the finished goods (Popov et al., 2018). Ideally, recycled metal powder could be used repeatedly without any loss in quality (Peeters et al., 2019).

There are various methods for recycling waste powder which can result in economic advantages because it is less expensive compared to acquiring fresh raw materials (Melugiri-Shankaramurthy et al. 2019).

Maintaining the quality of the waste powder is crucial as it can affect the final product, therefore techniques to keep its quality throughout its use are necessary (Peeters et al., 2019). By mixing the waste powder with new, unused powder at a minimum of 30–50%, it can be reused for several more manufacturing processes of high-quality products before becoming unrecoverable waste (Kumar and Czekanski, 2017).

5.2.3. Remanufacturing and repair

Remanufacturing, one of the key aspects of CE, retrieves the product's value that is no longer in use and would otherwise go to waste. This process is known as remanufacturing, which involves the reconstruction of a product to its original specifications using a mixture of reused, repaired, and new components (Lahrour and Brissaud, 2018). Skilled workers disassemble, clean, examine, refurbish, reassemble, and evaluate/test the item, resulting in a product that's comparable in quality to a new one.

The ability to create new lifetime to end-of-life products is a significant driver for AM, which allows for the creation of unique geometries and optimization of parts through a redesign (Oros Daraban et al., 2019). The process of remanufacturing often involves subtractive manufacturing, in which unwanted material is removed and new material is included to accomplish the desired geometries. This results in either an upgrade of the product with new functionality or the repair of a damaged part (Liu et al., 2020).

Researchers have been highly interested in the application of efficient production methods aimed at prolonging a product's life cycle over repair (Oros Daraban et al., 2019). While AM has primarily been utilized for prototyping, its design in repair, particularly through 3D printing of replacement parts, is growing (Wilkinson & Cope, 2015). The distinction between repair and remanufacturing is that repair involves identifying and fixing the problem causing the failure of a part, while remanufacturing requires various procedures that make the part indistinguishable from a new one, essentially restarting its life cycle (Reames, 2021). The capacity to quickly fix an item instead of discarding it in landfill helps to counter the creation of waste and depletion of resources, thus advancing the principles of CE (Wilkinson & Cope, 2015).

5.3. Theme 3: Costs-oriented

AM allows for a decentralized manufacturing method, which can lead to lower transportation and packaging expenses compared to traditional SCs (Laplume et al., 2016; Kunovjanek et al., 2022). This is achievable because the low cost of AM setup enables jobs to be allocated, based on demand, to the most suitable facility without lengthy changeover times (Weller et al., 2015). Nevertheless, Chan et al. (2018) argued that distributed manufacturing might result in higher costs in terms of licensing and billing, and extensive quality control which may be an added burden (Westerweel et al., 2018).

The potential of AM for higher volume productions has always been a concern, due to the lack of economies of scale (Weller et al., 2015; Zhang et al., 2017). Nevertheless, advancements in speedy printing and reducing investment costs may make AM more feasible for future increases in volumes (Wagner and Walton, 2016). In addition, optimization in algorithms has the potential to decrease unit costs by utilizing more efficient production of spare parts using AM (Li et al., 2017).

Shorter lead-times produced by AM can also reduce cost of inventories during the course of the product life cycle and benefit the entire product development as well as reduce cycle-times and setup costs (Ghadge et al., 2018). Consolidation, or integrating multiple parts into one, can also decrease assembly phases and related costs (Ben-Ner and Siemsen, 2017). At present, the high costs of AM and the uncertainty around its development are still the predominant issues (Cohen, 2014). In today's fast, ever-changing environment, investment in AM can be expensive and risky for many firms (Garmulewicz et al., 2018). Improving design, such as reducing the weight of products or increasing and improving functionality, may also lower costs during the production stage (Zanoni et al., 2019).

5.4. Theme 4: Logistics-oriented

Distributed AM facilities that have general purposes enable the concentration of production for various parts that are low in volume, but highly customized and urgently needed, even if they are located in remote areas (Ratnayake, 2019). As a result, the SC throughput can be increased. On one hand, increasing the flexibility of the distributed AM networks will lead to more complexity in SCs (Chowdhury et al., 2019). On the other hand, administrative efforts can be reduced by simplifying SC and process integration (Do, 2017).

AM enables the production of lighter parts, which can reduce the weight of vehicles and thus improve fuel efficiency (Sasson and Johnson, 2016). AM also supports the creation of complex components that are challenging or difficult to make using traditional manufacturing practices. This could lead to improved performance and functionality of transportation vehicles. Additionally, AM facilitates the production of parts on demand, reducing the need for large inventories and minimizing transportation and storage costs. AM can also support the repair and replacement of parts, reducing the downtime of transportation vehicles and minimizing the need for spare parts inventory. Finally, the lead time for part production will be decreased, which can be especially critical in the transportation industry, where time is often of the essence.

5.5. Theme 5: Maintenance-oriented

Maintenance is a crucial part of the SC because it ensures the reliability, availability, and performance of equipment, machinery, and facilities (Kunovjanek et al., 2022). Equipment or machinery failure will result in delays, downtime, and increased costs, affecting the overall efficiency and effectiveness of the SC. Proper maintenance planning and execution can also support the optimization of maintenance resources, reduce maintenance costs, and improve equipment lifespan. Unscheduled maintenance activities can disrupt operations, leading to backlogs in orders, delays in deliveries, and lost revenue. Moreover, equipment failures can compromise the safety of workers, and the quality and integrity of products.

AM can provide several benefits in the maintenance of equipment and machinery. AM enables the creation of spare parts (Ghuge et al., 2022) that may not be easily available in the market, which can help to reduce equipment downtime. In some cases, it may even be possible to produce a spare part on-site (Li et al., 2019) using a portable AM machine, eliminating the need to order the part and wait for it to be shipped. This could potentially streamline demand forecasting and planning, expanding system accessibility, and SC efficiency. As a result, downtime risks are expected to be minimized, and this benefit could even be enhanced by repairing spare parts with AM technology (Muir and Haddud, 2017).

Moreover, the implementation of virtual spare parts inventory management could help to reduce stock-out risks and inventory obsolescence. Industry practitioners have expressed a strong desire for a digital warehouse and/or centralized spare parts system, to accelerate purchasing and procurement processes (Chekurov et al., 2018). Further, Ballardini et al. (2018) suggested that a centralized spare parts system can also contribute to improving the overall process of spare parts management, alongside a proper implementation of a legal framework.

6. Discussion

In the current world where globalization, access to knowledge, and networking play major roles, regions, and cities have become increasingly important as the interlinked centers for the production of economic, social, and cultural activities, and as places for the implementation of innovative economic and territorial governance policies. Evolutionary views on regional growth and diversification place significance on local experience, due to the influence of past experiences and technological change on learning. There has been a significant focus on understanding the range of local capabilities and how they impact the types of new activities that can be developed. This has been explored in the works of Castaldi et al. (2015), Frenken et al. (2007), Immarino (2005), Nefket et al. (2011), and Boschma et al. (2017).

In the context of RSCs, emerging technologies are creating new opportunities for companies to streamline their production processes and enhance the efficiency of their SCs. For example, the use of sensors, smart machines, and advanced analytics can help companies better track their production processes and identify opportunities for improvement. Additionally, Industry 4.0 is enabling companies to collaborate more effectively with suppliers and customers, leading to more flexible and responsive SCs.

AM offers numerous advantages for RSCs. First, it enhances flexibility by enabling the production of customized products in small batches, reducing the reliance on large-scale production runs (Ford and Despeisse, 2016). This improves the SC's adaptability and responsiveness. Second, AM reduces lead times by manufacturing parts and products on demand, resulting in quicker time-to-market and mitigating inventory obsolescence risks (Bogers et al., 2016). Moreover, it lowers costs by minimizing tooling, fixtures, shipping, and storage requirements (Thomas, 2016). AM also promotes sustainability and CP by enabling local production, reducing long-distance transportation, and decreasing environmental impacts. Additionally, AM facilitates collaboration through easy sharing of designs and prototypes among suppliers, customers, and stakeholders. It also reduces waste by producing only necessary parts, improves resource efficiency, increases recycling opportunities, and lowers energy consumption (Chen et al., 2020; Thomas, 2016).

However, RSCs face significant challenges in adopting AM. Limited access to expensive technology and expertise (Park et al., 2013), concerns about intellectual property theft (Ngo et al., 2018), quality control issues with complex geometries (Koufteros et al., 2005), limited material options (Fernandez and Coninck, 2019), evolving regulations (Chu et al., 2020), and the shortage of skilled workforce (Akbari and Ha, 2020) pose barriers to implementation. Overcoming these challenges necessitates collaboration among RSC participants, government entities, and industry organizations to develop supportive policies, training programs, and infrastructure that facilitate AM adoption.

6.1. Research themes

Theme 1: In the context of RSCs, the theme of manufacturing orientation becomes crucial. With the advent of emerging technologies such as AM and Industry 4.0, RSCs can enhance their manufacturing processes. By incorporating sensors, smart machines, and advanced analytics, companies can track production processes and identify areas for improvement. AM (Shrouf, Ordieres, & Miragliotta, 2014) in particular, offers manufacturing-oriented benefits for RSCs. It enables firms to produce small batches of custom-made products, reducing the reliance on large-scale production runs. This flexibility allows RSCs to adapt to changing demands and optimize their manufacturing operations effectively.

Theme 2: With concerns about sustainability and reducing ecological footprints, RSCs need to consider environmental implications. AM plays a role in addressing these concerns. By producing parts and products closer to customers, AM contributes to CP by reducing the need for long-distance transportation, resulting in decreased greenhouse gas emissions and other environmental impacts. Moreover, AM enables the production of parts with complicated shapes and structures, using fewer raw materials compared to traditional manufacturing methods. This resource efficiency contributes to the environmental sustainability of RSCs.

Theme 3: Cost efficiency is a significant consideration for RSCs. AM provides opportunities for cost reduction and improved competitiveness. By eliminating the need for tooling and fixtures, AM reduces costs associated with traditional manufacturing processes (Javaid et al., 2022). Additionally, AM minimizes shipping and storage requirements, further decreasing expenses. The ability to produce parts on demand helps reduce lead times, improving time-to-market and minimizing the risk of inventory obsolescence (Bogers et al., 2016). Moreover, by reducing the reliance on long-distance transportation, AM contributes to cost savings by lowering transportation expenses.

Theme 4: Logistics plays a vital role in the smooth operation of RSCs. Efficient coordination and collaboration across the supply chain are essential for the timely delivery of goods. In RSCs, various stakeholders, including suppliers, manufacturers, distributors, and retailers, must work together seamlessly to achieve optimal logistics outcomes. By establishing robust communication channels and sharing real-time information, RSCs can enhance their ability to plan, execute, and monitor the movement of goods. This coordination enables them to align their activities, such as production, inventory management, and transportation, to meet customer demand efficiently. AM can improve logistics-oriented aspects in RSCs. By enabling easier sharing of designs and prototypes, AM facilitates collaboration among suppliers, customers, and other stakeholders. This streamlined communication enhances logistics operations by reducing errors and delays. Additionally, AM's ability to produce parts on demand contributes to just-in-time inventory management, optimizing logistics processes within RSCs.

Theme 5: Maintenance is a critical aspect of ensuring the smooth functioning of manufacturing operations within RSCs. AM brings maintenance-oriented benefits to RSCs. With AM, companies can produce the exact parts and products needed, minimizing waste at the manufacturing stage (Ghuge et al., 2022). The ability to recycle used parts and materials through AM simplifies the maintenance and replacement process. Further, AM's reduced energy use compared to traditional manufacturing methods contributes to efficient maintenance of machinery and equipment, minimizing energy consumption and associated costs.

6.2. Affirmation of research themes

In examining the intricate landscape of AM within RSCs, it is vital to integrate a diverse array of perspectives that provide valuable insights into the identified themes.

Expert A focused on the cost-oriented perspective, as the theme of cost efficiency stands out as crucial for RSCs. The expert mentioned that the emergence of AM and Industry 4.0 technologies presents opportunities for RSCs to enhance their manufacturing processes. AM, in particular, offers cost-related benefits by eliminating the need for tooling and fixtures, thereby reducing expenses associated with traditional manufacturing processes. For example, traditional manufacturing processes often require expensive molds, jigs, and fixtures to create parts, which can significantly increase production costs. With AM, products can be directly fabricated from digital designs without the need for these costly tooling elements. Additionally, AM minimizes shipping and storage requirements, resulting in further cost savings. The ability to produce parts on demand also contributes to reducing lead times, improving time-to-market, and mitigating inventory obsolescence risks. Moreover, the reduced reliance on long-distance transportation in AM leads to cost savings by lowering transportation expenses. Therefore, cost efficiency is a critical consideration for RSCs, and AM provides opportunities for cost reduction and improved competitiveness.

Expert B's view was aligned with the manufacturing-oriented theme. In the context of RSCs, manufacturing orientation becomes crucial for optimizing operations. The integration of emerging technologies like AM and Industry 4.0 can greatly enhance manufacturing processes in RSCs. By leveraging sensors, smart machines, and advanced analytics, companies are capable of effectively tracking production processes and identifying areas for improvement. AM offers specific manufacturing-related advantages, such as the ability to produce customized products in small batches. This flexibility allows RSCs to adapt to changing demands and optimize their manufacturing operations effectively. By utilizing AM, RSCs overcome challenges related to lead times, adaptability, and responsiveness in the manufacturing domain, thus enhancing overall manufacturing capabilities.

Expert C mentioned that manufacturing plays a vital role in RSCs and adopting Industry 4.0 technologies greatly improves the efficiency of their operations. AM, in particular, offers numerous advantages for RSCs in terms of flexibility, lead time reduction, cost savings, and sustainability. The ability to produce custom-made products in small batches through AM improves the adaptability and responsiveness of RSCs. This capability proved to be beneficial, especially when dealing with customers who required unique and personalized products. By utilizing AM, they were able to meet these demands efficiently, without the need for costly and time-consuming retooling. Furthermore, AM reduces lead times by manufacturing parts and products on demand, resulting in quicker time-to-market and mitigating inventory obsolescence risks. Instead of relying on traditional manufacturing processes that involved maintaining large inventories, they began manufacturing parts and products on demand through AM. This resulted in quicker time-to-market, allowing them to respond faster to market changes and customer demands. As a result, the company managed to mitigate inventory obsolescence risks, ensuring that products remained relevant and in demand throughout their production cycle. Further, collaboration is also facilitated through AM by enabling easy sharing of designs and prototypes among suppliers, customers, and stakeholders. Overall, manufacturing-focused considerations are crucial for RSCs, and AM presents substantial opportunities for improvement in this domain. Simultaneously, implementing AM in RSCs presents challenges, such as limited access to technology and expertise, intellectual property concerns, quality control for complex geometries, limited material options, evolving regulations, and a shortage of skilled workforce.

According to Expert D, AM holds significant potential for manufacturers and businesses in RSCs. The advancements in 3D printing technologies are driving a transformation in product design, manufacturing, and local distribution. Decentralized production is a key advantage of AM, enabling on-demand manufacturing of parts closer to end-users. This shift reduces lead times and shipping costs, allowing businesses to establish agile and sustainable RSCs. For example, when a machinery part is needed, instead of waiting for weeks for it to be manufactured and shipped from a centralized factory, the company can simply 3D print the required part on-site or at a nearby 3D printing facility. This on-demand manufacturing capability allows the company to quickly provide spare parts to their customers. However, integrating 3D printing poses challenges, such as quality control, material standardization, and regulatory compliance. Collaboration among industry stakeholders, academia, and government bodies is crucial to establish best practices and foster a strong ecosystem for AM in RSCs. To fully capitalize on the benefits, businesses must invest in workforce training and awareness programs. Educating the workforce about the capabilities of 3D printing will enable them to embrace new manufacturing approaches and adapt to the changing landscape, further enhancing the region's manufacturing capabilities.

6.3. Summary framework

Fig. 9 summarizes the reviewed literature. It highlights the role of AM and the benefits this technology offers for driving sustainability, especially for RSCs.

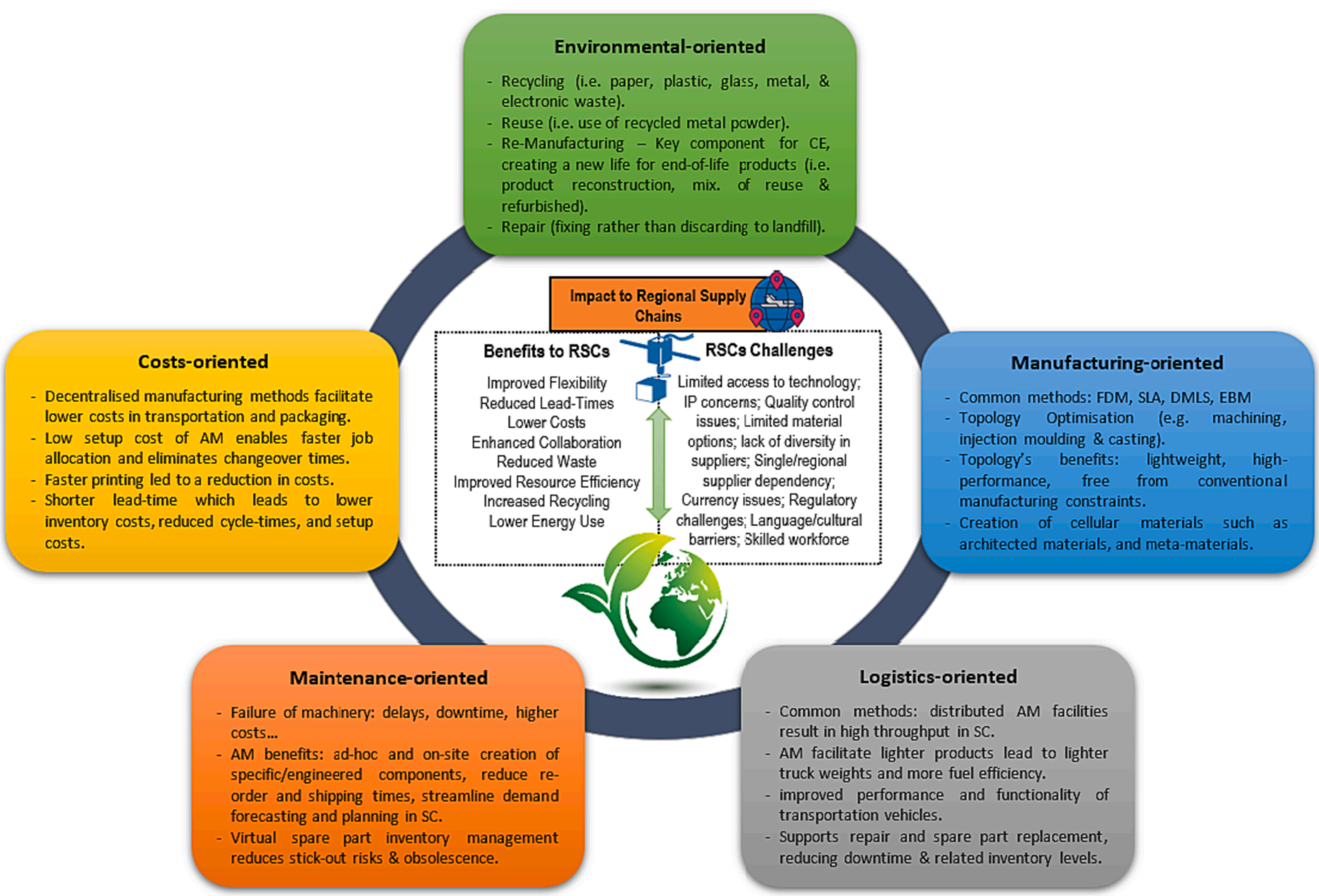

Fig. 9. Summary Framework.

6.4. Managerial implications

AM presents a range of managerial implications for organizations operating in RSCs. Addressing these implications is essential for organizations to effectively integrate AM into their operations and to realize the full benefits of this technology.

- *Supply Chain Design:* AM can transform the way SCs are managed. For example, it enables companies to produce parts and components on demand, reducing lead times and the need for large inventories. This can result in a more agile and responsive SC.
- *Sourcing Strategies:* AM can impact sourcing strategies as companies can produce components locally, reducing the need for long-distance transportation. This can lead to lower transportation costs and reduced environmental impacts.
- *Quality Control:* The quality of parts and components produced through AM can be more consistent and reliable than those produced through traditional manufacturing methods. This can improve product quality and decrease the risk of defects and returns.
- *Competition:* AM can disrupt traditional manufacturing processes and create new competitive opportunities for organizations. Companies that adopt AM can gain a competitive advantage by being able to produce customized products quickly and cost-effectively.
- *Skills and Talent:* The adoption of AM requires new skills and talent, particularly in the areas of design and engineering. Organizations need to invest in training and development to make certain that their employees have the skills needed to effectively implement and manage AM processes.
- *Regulation:* AM can raise regulatory and safety concerns, particularly in the areas of product safety and environmental protection. Organizations need to be aware of these concerns and ensure that their AM processes comply with relevant regulations and standards.

To effectively implement AM in RSCs, managers should consider the following:

(a) Assess the feasibility of implementing AM in their SC. This includes evaluating the technical capabilities, costs, and benefits of the technology and considering any regulatory or industry-specific requirements.
(b) Develop a strategic plan for implementing AM, including identifying key goals, defining the project scope, and deciding on the resources required. The plan should also outline the steps required to integrate AM into the existing SC processes and systems.
(c) Invest in the necessary equipment and infrastructure to support AM, such as 3D printers and material storage facilities. They should also consider the ongoing maintenance and support requirements of the equipment to ensure it operates effectively and efficiently.
(d) Provide training and development opportunities for employees to ensure that they have the necessary skills and knowledge to effectively operate and manage AM processes. This includes providing training in design, engineering, and quality control processes.
(e) Continually evaluate and improve AM processes to ensure that they are optimized for efficiency and quality. This includes regularly monitoring performance metrics, such as lead times and production costs, and making adjustments as necessary.
(f) Collaborate with SC partners, including suppliers and customers, to ensure that AM processes are integrated effectively into the broader SC. This may involve developing new SC agreements, modifying existing processes, and sharing information and best practices.
(g) Monitor regulatory compliance to ensure that AM processes comply with relevant regulations and standards, particularly in the areas of product safety and environmental protection.

Overall, the impact of AM on RSCs is likely to be significant, as it offers companies new opportunities to improve their efficiency, competitiveness, and responsiveness. Also, the development of AM and environmentally sustainable growth paths for regions has become a pressing concern for both policymakers and academics who are focused on promoting sustainable regional revitalization (Ramirez, 2020). Policymakers and business leaders must be aware of these developments and take steps to ensure that their regions are well positioned to take advantage of the opportunities presented by AM.

6.5. Implications for policymakers in regional government and society

Policymakers at the regional government and societal levels could play a key role in advancing the sustainable adoption of AM technology within RSCs.

Regional locations face unique challenges in their SCs, such as limited access to technology and required infrastructure and the availability of resources. This highlights the need for policymakers to focus on investing in infrastructure and providing resources to enable the implementation of AM technology in regional supply chains. Policymakers could, for example, provide incentives for businesses to invest in AM technology, create a supportive regulatory environment, and develop training programs to enhance the skills of local workforces.

Additionally, the study highlights the possible influence of implementing AM technology in the recuperation of RSCs following the COVID-19 pandemic. Policymakers could consider the use of AM technology as a means of enhancing the resilience of RSCs, enabling them to be more responsive to changing demands and reducing lead times. In addition, AM technology could enable localized production, reducing the need for long-distance transportation and associated carbon emissions. Policymakers could promote the use of AM technology as a means of creating more sustainable and resilient RSCs.

By investing in infrastructure, providing resources, and promoting the benefits of AM technology, policymakers could help to unlock the potential of this emerging technology and drive positive change in RSCs.

7. Conclusion

The process of AM involves converting digital information into a physical object (Rengier et al., 2010), and experts predict that it will cause a major disruption to SC operations in the near future (Rehnberg and Ponte, 2018). The current technological disruption, along with pandemics, war, climate change, and demand instability, have a major force on global SCs, but AM has the potential to transform it. By utilizing local sourcing and RSCs, AM can create a new, localized system, replacing the established global SC. Furthermore, AM allows for a direct connection between design, production, and marketing. This can result in a globally linked but locally centered SC network. The widespread implementation of AM will enable businesses to be more flexible and produce new products. This technology has the potential to lead to an increase in product innovation through more flexible design processes. Over time, the extensive acceptance of AM could lead to the end of large, complex production factories and change traditional production systems. Therefore, studying past AM trends in RSCs is crucial in maximizing the benefits of this new and growing trend.

This study provides a synopsis of 19 years of research on AM in RSCs. The purpose of this paper was to characterize the trends, opportunities, and future possibilities of AM in RSCs by examining various aspects such as the timeline, publishers, journals, research methods, location of the study, areas of focus, and current themes. The objective was to clarify the different perspectives and to outline future directions for research in this field.

7.1. Summary of significant findings and gaps

- Most of the research was published by Elsevier, Springer, and MDPI.
- The most frequently published journals were *Additive Manufacturing*, *International Journal of Advanced Manufacturing Technology*, and *Journal of Cleaner Production.*
- The research design revealed that 69% of published papers are either desk qualitative, or empirical triangulation.
- Most of the published papers in AM initiated from developed countries; more research is required in developing countries and emerging markets. It is noteworthy that there was no identified research focus on regional or rural areas. Future research should focus on these areas.
- A particular gap for future research was observed where published papers dropped significantly in 2017–2018.

7.2. Limitations and future research directions

This research focused on AM in RSCs, collecting information related to research design, and using several data sources and analytics techniques. It was limited to keywords in journal articles and publishers. Additional focus with respect to other databases and/or publishers, books, book chapters, conference papers, and PhD and master's theses for future research would be beneficial.

There are several key limitations and future research directions that need to be considered:

- AM is still limited in terms of the materials it can process and the complexity of the parts it can produce. Further study is required to broaden the scope of AM and create new materials and printing techniques that can produce better quality components.
- AM is still more expensive than traditional manufacturing methods, particularly for large-scale production. Further study is required to identify methods for lowering the expense of AM and making it more economical and accessible for companies.
- Implementing AM requires specialized skills and knowledge, and there is a shortage of trained professionals in this field. Research is required to create educational programs and to draw in and keep skilled individuals in the industry.
- AM raises regulatory and safety concerns, particularly in the areas of product safety and environmental protection. Therefore, research in developing standards and regulations for AM is needed to ensure that AM processes comply with these regulations.
- Integrating AM into existing SC processes and systems can be challenging. There is a need for research to develop best practices and tools for effective integration.
- The environmental impact of AM, especially energy consumption and waste generation, needs to be studied and addressed. Future research is required to develop sustainable and environmentally friendly AM processes.
- Managing and analyzing large amounts of data generated by AM processes can be challenging. Further research is needed to develop data management systems and analytics tools to establish effective decision-making in implementing AM.
- To gain a more comprehensive understanding of the topic, it is recommended that the five identified themes be further examined across diverse industries and countries. This approach will provide valuable insights into how these themes manifest in and impact different contexts, enhancing our overall comprehension of the subject matter.
- Finally, it is critical to be concerned about the regional perspective and possible applications of AM for the post-COVID-19 recovery period in global SCs, as there is currently no record of research in this area.

CRediT authorship contribution statement

Mohammadreza Akbari: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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