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Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: A circular manufacturing perspective

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Abstract

As a concern with manufacturing industries, circular economy (CE) practices—often labeled “circular manufacturing (CM)”—are industrial tasks through which several circular economy principles have been integrated. Among these circular manufacturing strategies, “3R” (recycle, refurbish/remanufacture, and reuse/redistribute) is the key strategy that assists the manufacturing industry with closing the loop for sustainability. An effective inclusion and management of 3R lead a firm to a greater likelihood of successfully integrating CE and CM. In recent years, remanufacturing has gained greater prominence, especially with the emergence of technology, including cyber-physical systems. These technologies assist the remanufacturing firm with efficient take-back systems through tracking. However, data transferred through these technologies among value chain partners in remanufacturing are not reliable. Due to the lack of trust and transparency, value chain partners are hesitant to participate in remanufacturing supply chains. To address the limitation of technologies in remanufacturing, blockchain has been introduced to secure the data. Despite the advantages of blockchain technology, practitioners face difficulties in integrating these blockchain technologies into the remanufacturing context. Several earlier studies addressed the challenges of implementing blockchain, but no earlier studies have specifically examined remanufacturing industries, which are entirely different from forward supply chain industries. Concerning the fact, this study identifies the barriers that exist with the implementation of blockchain technology in the application of the remanufacturing sector. A framework has been proposed and validated in a Danish automotive parts remanufacturing company. Multi-criteria decision-making method has been used to identify the effective and most influential barriers among common barriers. Results reveal that “scaling of technology” (**B6**) is the key barrier of BCT implementation in remanufacturing context. This study concludes with useful discussions based on the results along with the recommendations to eradicate those influential barriers and their respective impacts on SDGs (SDG4, SDG8, SDG9, and SDG17). Finally, this study sheds light on future enhancements on the integration of

blockchain technology in remanufacturing to reap several benefits of circular manufacturing.

KEYWORDS
blockchain technology, circular manufacturing, remanufacturing, sustainable development goals

1 | INTRODUCTION

Digitalization and modernization have enhanced the contributions of manufacturing sectors in the global economy. Parallel to the multifold growth of global manufacturing sectors, the manufacturing sectors often faces pressures from various stakeholders for the negative impact on sustainable development. Manufacturing industries are becoming more aware that solely pursuing economic benefits will not help them to sustain in the business marketplace; instead, demonstrating authentic concern with the environment and society provides a competitive advantage. Several scholars confirm that the circular economy is the biggest driver for sustainable development (Abou Taleb & Al Farooque, 2021; Allen et al., 2021; Demartini et al., 2022; Geissdoerfer et al., 2017), so manufacturing industries seek to integrate circular economy practices in their operations to achieve sustainable development. Several scholars explored the potential of CE principles in other domains of supply chain management (de Souza et al., 2021; Govindan et al., 2020; Kannan et al., 2020; Mina et al., 2021; Nag et al., 2021). The potential of CE principles in manufacturing processes is recognized as circular manufacturing (CM) (Acerbi & Taisch, 2020). CM upholds with three key principles of CE as defined by MacArthur Foundation (2015): (i) preserve the capital, (ii) optimize the resources, and (iii) enhance the effectiveness. It has also been suggested that these three principles can be implemented through closing the loop with recycle, refurbish/remanufacture, reuse/redistribute, and maintain/prolong. The effectiveness of CM is directly proportional to inner loops of CM (maintenance and reuse), despite the fact that comparatively less attention has been received on inner loops. In contrast, however, several attempts have been made with the farthest loop of CM, "recycle." This study considers such an inner loop of CM, "remanufacturing," as a research area.

Several studies (Feng et al., 2021; Wang et al., 2020; Yuan et al., 2020) indicate the effectiveness of remanufacturing in achieving circular economy principles. Some studies (Hatcher et al., 2011; San-Francisco et al., 2020; Zhao et al., 2019) even argue that remanufacturing is an effective and guaranteed way to address sustainable issues and to develop economic, environmental, and social benefits. Remanufacturing is not a new phenomenon. Lund and Mundial (1984) defined the decade old practice as "an industrial process in which worn out products are restored to like new condition." Remanufacturing is a strategy that involves replacing, reusing, and refurbishing the components of end of life items to recover their residual values (Wang & Hazen, 2016). For instance, in terms of resources, 16 million crude oil barrels can be saved as a global energy savings (Sundin & Lee, 2012; Yuan et al., 2020), and by 2030, 90 billion euros can be added to EU economy (Hollins, 2018; Kerin & Pham, 2020) with the application of remanufacturing. With remanufacturing gaining prominence worldwide, governments are keen to introduce remanufacturing policies to motivate value chain actors to become more involved. In contrast to earlier days, consumer willingness to purchase remanufactured products is increasing but not yet assured. Stakeholders, including consumers, are pushing firms to close their loop with remanufacturing (Hazen et al., 2017; Wang et al., 2020). Owing to such pressures, many of the biggest companies are employing third parties to handle the remanufacturing of their end of life (EOL) products.

Despite the advantages of remanufacturing, several studies (Copani & Behnam, 2018; Gåvertsson et al., 2020; Zhou et al., 2021) confirm that remanufacturing is not yet fully implemented nor has it reached its full potential. Several challenges have been identified in the mentioned studies for this ineffective implementation of remanufacturing; one of the predominant challenges identifies customer acceptance and operational challenges of reverse supply chain as key barriers. More recently, some operational challenges of reverse supply chains/reverse logistics have been addressed through the introduction of Industry 4.0 technologies. With the assistance of real time data availability and management through sensors and actuators (Dev et al., 2020), operational resources can be shared online through reverse supply chains of remanufacturing, thereby reducing the operational challenges inherited by the remanufacturing value chain actors. In addition, sustainable issues can be addressed through proper sustainability strategies linked to technological development (Gunasekaran et al., 2014). Researchers and practitioners have started to integrate technologies in remanufacturing context to address the operational challenges and to ease the transformation to sustainability (Kamble et al., 2018; Okorie et al., 2021). For instance, Kerin and Pham (2020) reviewed the integration of technologies in remanufacturing and their relationship with CE through smart remanufacturing. This study details the applications of technologies and every operation of remanufacturing along with sustainability benefits. Although these technologies address operational challenges, another key challenge of remanufacturing was left unattended: "market acceptance." If customers are still hesitant to buy the remanufactured products due to a feared lack of reliability, the value chain actors will be reluctant to share data. These risks increase with technologies (IoT, Big data, and so on.) in which *n* number of datasets are exchanged. To ensure the trust and transparency in this technology era among value chain actors and stakeholders, blockchain technology has been used in many applications.

Blockchain technology (BCT) was first introduced in the Bitcoin application by Satoshi Nakamoto, and it has been used under various fields of applications (Nakamoto, 2008). BCT assists an organization to share its information more securely in a decentralized environment. Hence, when combined with other technologies, BCT can address the lack of trust and transparency barrier that concerns value chain actors; the technology can improve circular manufacturing through remanufacturing. Contrary to these findings, very few studies have explored the application of blockchain in remanufacturing context. Li et al. (2021) is one study that discusses the application of blockchain with remanufacturing process planning. But remanufacturing has received significantly less attention with BCT despite its potential to overcome barriers. Hence, this study sought to address two key research questions:

RQ1. What common barriers exist in the initial stages of integrating BCT in remanufacturing for achieving CM?

RQ2. What is the influential barrier which hinders the implementation of BCT in remanufacturing for achieving CM?

While several studies examine the barrier analysis of BCT implementation, no earlier study reports on a specific application of remanufacturing. This study proposes a research framework to identify and analyze the influential barriers of BCT in remanufacturing for achieving CM. A multi-criteria method has been used for this analysis, namely, Decision Making Trial and Evaluation Laboratory (DEMATEL). The proposed framework has been validated in a Danish automotive parts remanufacturing company. With the replies of the case decision makers, the barriers are analyzed. The key implications of this study include as a pioneering work on analyzing the barriers of BCT in a remanufacturing context with a European perspective. The results are explored and exploited to provide a breakthrough innovation at the practitioner's level of achieving circular manufacturing through remanufacturing. As a result, this study serves several key contributions:

- The impact of remanufacturing with the implementation of CM has been explored.
- Common barriers of BCT with the concern of Danish auto parts remanufacturing context were identified.
- Key barriers have been identified and their interrelationships were tested.
- Implications and recommendations considering practitioner's perspectives were provided.

The remaining sections of the paper are as follows: Section 2 discusses state-of-the-art research with various concerns and dimensions, including Industry 4.0, CE, BCT, and remanufacturing. Section 3 deals with the methodologies used for analyzing the barriers. The case illustration and proposed framework are presented in Section 4. Section 5 details the results and its corresponding discussions and recommendations to eradicate the barriers. Finally, Section 6 concludes with key findings, limitations, and scope for future enhancements.

2 | LITERATURE REVIEW

This section discusses the state-of-the-art research selections for the considered phenomenon, including CE, Industry 4.0, BCT, and remanufacturing. Whereas several studies have been published in all considered research areas, the current work reviews only the most relevant, recent, and highly acclaimed papers.

2.1 | Circular economy and remanufacturing

As discussed in the earlier sections, there are positive correlations between CE and remanufacturing, so studies have explored this relationship to achieve CE through remanufacturing. Both remanufacturing and CE are frequently examined as individual topics, but much fewer studies combine the two topics into one perspective. A classification of studies that link remanufacturing with CE reveals six broad categories: (i) closed supply chain and logistics, (ii) consumer intentions, (iii) policy, (iv) life cycle assessments, (v) concepts and factors, and (vi) business models.

Among these classifications, a majority of studies focus on the relationship of CE with remanufacturing and consider the closed loop supply chain and logistics. For instance, Feng et al. (2021) discuss third-party remanufacturers' strategies such as authorization and outsourcing and how these strategies relate the CE to closed loop supply chains. Dominguez et al. (2020) understand the dynamic benefits of remanufacturing with different scenarios on CE through closed loop supply chains. Alamerew and Brissaud (2020) study electric vehicle recovery by addressing the issues of reverse supply chains in the concern of transition towards CE. Next to the closed loop supply chains and logistics, the second most commonly discussed topic concerns customer intentions towards remanufactured products. For instance, Wang et al. (2020) explain the relationship between the customers' intention with their knowledge of the product and the process of a remanufactured laptop. This study considers 906 Chinese laptop owners in order to explore the relationship with the assistance of structural equation modeling. Chen, Wang, et al. (2020) conducted an experimental study on customer intentions towards the remanufactured products with the Chinese context. Pisitsankkhakarn and Vassanadumrongdee (2020) studied Thailand's consumer perspective on remanufactured automotive parts to enhance the CE, in which a quantitative survey was used to collect data and structural equation modeling was used to analyze it.

Few studies discussed the policies for remanufacturing to achieve CE. Yuan et al. (2020) reviewed the existing policies for achieving CE through remanufacturing in the Chinese context. This study conducts a comprehensive review on national law, regulations, and documents of state councils for understanding Chinese policy system for remanufacturing. CE mostly focuses on end-of-life products, so few studies relate life cycle assessments for achieving CE through remanufacturing. San-Francisco et al. (2020) studied the life cycle assessments with the perspective of remanufacturing. Different methods have been studied along with their perspectives on recovery. Wahab et al. (2018) studied the issues involved in the design of remanufacturing with the application of life cycle assessments in marine and offshore components under the concern of CE. There are more general studies of remanufacturing in relation to CE under the concern of business models, success factors, and so on. For instance, Singhal et al. (2020) studied the critical success factors of remanufacturing for achieving circular economy, a study in which fuzzy DEMATEL was used as a solution methodology. Copani and Behnam (2018) proposed a novel sustainable business model with the concern of remanufacturing to promote circular economy. The proposed business model is intended to upgrade the existing product service systems in remanufacturing.

2.2 | Industry 4.0 and remanufacturing

Industry 4.0 and remanufacturing are both relatively new phenomena, and both are growing aggressively over the past years. Due to the youthfulness of these topics, very few studies have been published that consider technologies in remanufacturing applications. Some studies discuss opportunities and the potential of technologies in the application of remanufacturing. For instance, Kerin and Pham (2020) reviewed the smart remanufacturing in which the significance of integrating technologies with remanufacturing was discussed. Kerin and Pham (2019) reviewed Industry 4.0 technologies in remanufacturing application to determine which trends and gaps exist in the subject research area. Wang and Wang (2019) studied the application of waste electrical and electronic equipment (WEEE) recycling, recovery, and remanufacturing under Industry 4.0 environment; their study focused on the application of a digital twin in the WEEE sector and further explored its integration with Industry 4.0. Zahoor et al. (2019) completed a case study in the context of Pakistan with the perspective of smart remanufacturing regarding small and medium scale enterprises (SMEs). Yang et al. (2018) discussed the existing opportunities of Industry 4.0 to develop smart remanufacturing. Butzer et al. (2016) attempted to identify the different approaches that exist within the application of Industry 4.0 in remanufacturing context; this author discussed the challenges of Industry 4.0 and remanufacturing individually. There are few studies which utilized specific technology in remanufacturing application, for instance, simulation (Goodall et al., 2019; Okorie et al., 2020), automated guided vehicles (Groß et al., 2020), virtual 3D models (Siddiqi et al., 2019), additive remanufacturing (French et al., 2018), and robots (Huang et al., 2019).

2.3 | Blockchain technology

After the introduction of Bitcoin in 2008, academic articles began to look beyond its applications in Bitcoin and finance. The global focus on BCT started in 2015. According to the SCOPUS database, only seven articles were published on BCT in 2015, and this number has increased to over 2000 and counting in 2020. This clearly shows the strong trend of BCT in research and its significance. Now, there are some 4,526 papers published under BCT with the concern of various research topics. This study examines the barriers of blockchain technology, so it is necessary to understand the existing barrier analysis of blockchain. With this search term, TITLE-ABS-KEY (blockchain AND barriers) AND (LIMIT-TO [DOCTYPE, "ar"] OR LIMIT-TO [DOCTYPE, "re"]) AND (LIMIT-TO [LANGUAGE, "English"]), a total of 91 documents are obtained. Among these, only 10 documents discuss the barriers of blockchain technology. A detailed summary of these documents is presented in Table 1.

2.4 | Gap analysis and research highlights

Several research gaps can be discerned from the above literature review. The gaps have been discussed below:

- To best of our knowledge, no previous study has sought to identify or analyze the barriers of BCT implementation in remanufacturing context for achieving circular manufacturing.
- From the review, only one study has been found related to blockchain, remanufacturing, and circular manufacturing.
- Most of the remanufacturing studies are from Chinese context, and there is no evidence on Danish context with smart remanufacturing within the context of circular manufacturing.

3 | METHODOLOGY

This study utilized semi-structured interviews and a multi criteria decision making (MCDM) method as the solution methodology. There are several successful instances of MCDM in different applications when ranking and analyzing multiple criteria are involved. Accordingly, this study considers MCDM method for ranking and analyzing the common barriers of BCT implementation in remanufacturing, namely, DEMATEL. The semi-structured interviews are used to rank the barriers, and DEMATEL is employed to understand the influence among the identified top-ranking barriers. A detailed discussion on the methodology follows.

3.1 | DEMATEL

DEMATEL is the second tool considered for this study to analyze the interrelationship among the top ranked barriers of BCT implementation in remanufacturing. Unlike BWM, it is not a new tool; DEMATEL was pioneered back in 1973 by Gabus and Fontela, and since its introduction, several studies have utilized DEMATEL in their applications. The efficiency of DEMATEL to successfully handle tough decision-making problems has been tested in different fields of application by several researchers (Chen, Wang, et al., 2020; Du & Li, 2021; Ferreira et al., 2022; Kannan, 2021; Khan et al., 2020; Singh et al., 2020). Because DEMATEL can identify the relationship among variables with little or uncertain data, its results can provide decision makers with a diagraph that divides the considered criteria into cause and effect groups for better understanding. Due to these extensive benefits, many studies that intend to analyze influences among barriers consider DEMATEL as an ideal solution methodology. As Table 1 demonstrates, some of the existing studies on the analysis of barriers of BCT implementation included DEMATEL as their solution methodology. Based on its reliability as a tool for barrier analysis, this study considers DEMATEL as a second part of its solution methodology.

Steps involved in DEMATEL (adapted from Govindan et al., 2020):

Step 1: Initial relationship matrix *A*

In this step, the initial relationship matrix among considered criteria has been set up as shown in Equation 1. This usually ranges from 0 to 4, where "0" stands for *no influence* and "4" stands for *high influence*.

$$\tilde{A} = \begin{bmatrix} 0 & a12 & a13 & .... & a1(n-1) & a1n \\ a21 & 0 & a23 & .... & a2(n-1) & a2n \\ .... & .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... & .... \\ a(n-1)1 & a(n-1)2 & a(n-2)3 & .... & 0 & a(n-1)n \\ an1 & an2 & an3 & .... & an(n-1) & 0 \end{bmatrix} \quad (1)$$

Step 2: Normalized direct relationship matrix *X*

The normalization of the obtained initial relationship matrix will be obtained with the assistance of the Equations 2 and 3.

$$K = \frac{1}{max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (2)$$

TABLE 1 Existing studies that deal with the barriers of BCT in remanufacturing for achieving CM

S. No.	Source	Problem description	Field of application
1	Kouhizadeh et al. (2021)	Investigated the barriers of blockchain technology in sustainable supply chain through the application of DEMATEL.	Supply chain
2	Lohmer and Lasch (2020)	Studied the barriers of blockchain in the application of operations management and manufacturing context through literature review and semi-structured interview.	Operations management and manufacturing
3	Yadav et al. (2020)	Explored the barriers of BCT in Indian agricultural supply chain through Interpretive Structural Modeling (ISM) and DEMATEL with the replies of agro organizations and stakeholders.	Agricultural supply chain
4	Ozturk and Yildizbasi (2020)	Studied the BCT integration barriers in the application of supply chain management using MCDM methods.	Supply chain management
5	Upadhyay (2020)	Discussed the challenges, opportunities and applications of BCT through systematic literature review.	General
6	Farooque et al. (2020)	Prioritized the important barriers of BCT with the application of life cycle assessment with Chinese context through DEMATEL.	Life cycle assessment
7	Durneva et al. (2020)	Studied the challenges, state of the art and future possibilities of BCT applications through systematic literature review.	Patient care
8	Biswas and Gupta (2019)	Investigated the barriers of BCT adaption in various industries and service sectors through DEMATEL.	Industry and service sectors
9	Yang et al. (2019)	Discussed the barriers that exist with the integration of BCT and edge computing.	Edge computing
10	Andoni et al. (2019)	Explored various challenges and opportunities of BCT with the application of energy sector for which 140 BCT research projects have been analyzed.	Energy sector

$$X = K \times A \tag{3}$$

Step 3: Total influence matrix *T*

Based on the normalized direct relationship matrix "X," the total influence matrix has been set up through Equation 4, in which "T" denotes total influence matrix and "I" denotes identity matrix.

$$\boldsymbol{T} = \boldsymbol{X} + \boldsymbol{X}^2 + \ldots + \boldsymbol{X}^h = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}, \text{when} \lim_{h \to \infty} \boldsymbol{X}^h = [0]_{n \times n}. \tag{4}$$

Explanation,

$$\begin{aligned} \boldsymbol{T} &= \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^h \\ &= \boldsymbol{X}\left(\boldsymbol{I} + \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^{h-1}\right)(\boldsymbol{I} - \boldsymbol{X})(\boldsymbol{I} - \boldsymbol{X})^{-1} \\ &= \boldsymbol{X}\left(\boldsymbol{I} - \boldsymbol{X}^h\right)(\boldsymbol{I} - \boldsymbol{X})^{-1}. \end{aligned}$$

Then,

$$T = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}, \text{when} h \to \infty.$$

Step 4: Sum of rows and columns

r and s denote the sum of rows and columns. It is obtained through Equations 5 and 6.

$$\boldsymbol{r} = [r_i]_{n \times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1}, \quad \boldsymbol{s} = [s_j]_{n \times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1 \times n}, \tag{5}$$

$$\boldsymbol{T} = [t_{ij}], \quad i,j = 1,2,\ldots,n. \tag{6}$$

Step 5: Causal influence diagraph

The final stepN of DEMATEL is to set up a causal influence diagraph based on the sum of rows r and sum of columns s. In this diagraph, $r + s$ will be the x axis, and $r - s$ will be the y axis, Then, based on the criteria, factors will be grouped and their interrelationships observed.

4 | CASE ILLUSTRATION AND PROPOSED FRAMEWORK

4.1 | Case illustration

Among several sectors of remanufacturing applications, auto parts remanufacturing plays a key role in the global economy. It has been estimated that auto parts remanufacturing will grow to 30 billion USD by 2025 (prnewswire.com). According to the Automotive Parts Remanufacturers Association (APRA), remanufactured engines require only 50% of energy and 67% of labor when compared to its original equipment engine manufacturing. This exponential economic and resource advantage proves the need for effectiveness in auto parts remanufacturing. From the literature review, the majority of auto parts remanufacturing studies examine the Chinese context, with very few studies dedicated to the EU. Culture plays a big role in the implementation of remanufacturing in terms of customer intention, rules, stakeholder interest, and other factors. This study considers Denmark as a case context, which is one of the fast-growing auto markets in Europe. According to The Local.dk (2019), an increase in sales of expensive cars (above 80,000 dkk) in Denmark accounts for 7 billion euros in 2018, which records a 7% growth over the previous year. The increased consumption pattern will eventually end with a large number of end-of-life vehicles which must be managed effectively through remanufacturing to recover their value. However, as discussed earlier, the Danish remanufacturing sector faces challenges to achieve circular manufacturing because of lack of trust and transparency among value chain actors. To increase trust and transparency, studies suggested the integration of blockchain, and this study examines that integration at a Danish case company, an auto parts remanufacturer. This company has worked in remanufacturing since 1980s, beginning their career with the remanufacturing of brake calipers. Slowly, the company started to grow in different regions including European and South Korea. Now, the company is the largest in Europe with their remanufacturing and newly manufactured brake calipers. In order to increase their remanufacturing efficiency and to have a better relationship with value chain actors, including consumers, this company intends to integrate blockchain in their remanufacturing operations.

Our research team approached several remanufacturing companies in European context with the concerned research proposal. Twelve invitations were sent, and four replies were received. This case company was selected because their need exactly coincides with the core idea of the present research proposal. To identify and analyze the barriers involved in the implementation of remanufacturing, a four-phase research framework has been proposed, and the same has been applied in the case company.

4.2 | Proposed framework

This framework consists of four phases: collecting the common barriers, ranking among collected barriers, applying DEMATEL, and determining the implications of the results. Figure 1 shows the proposed framework for this study. The application of the proposed framework is as follows.

4.2.1 | Phase I: Identification of common barriers

In Phase I, the common barriers of implementation of blockchain technology in remanufacturing have been collected in a two-step process,

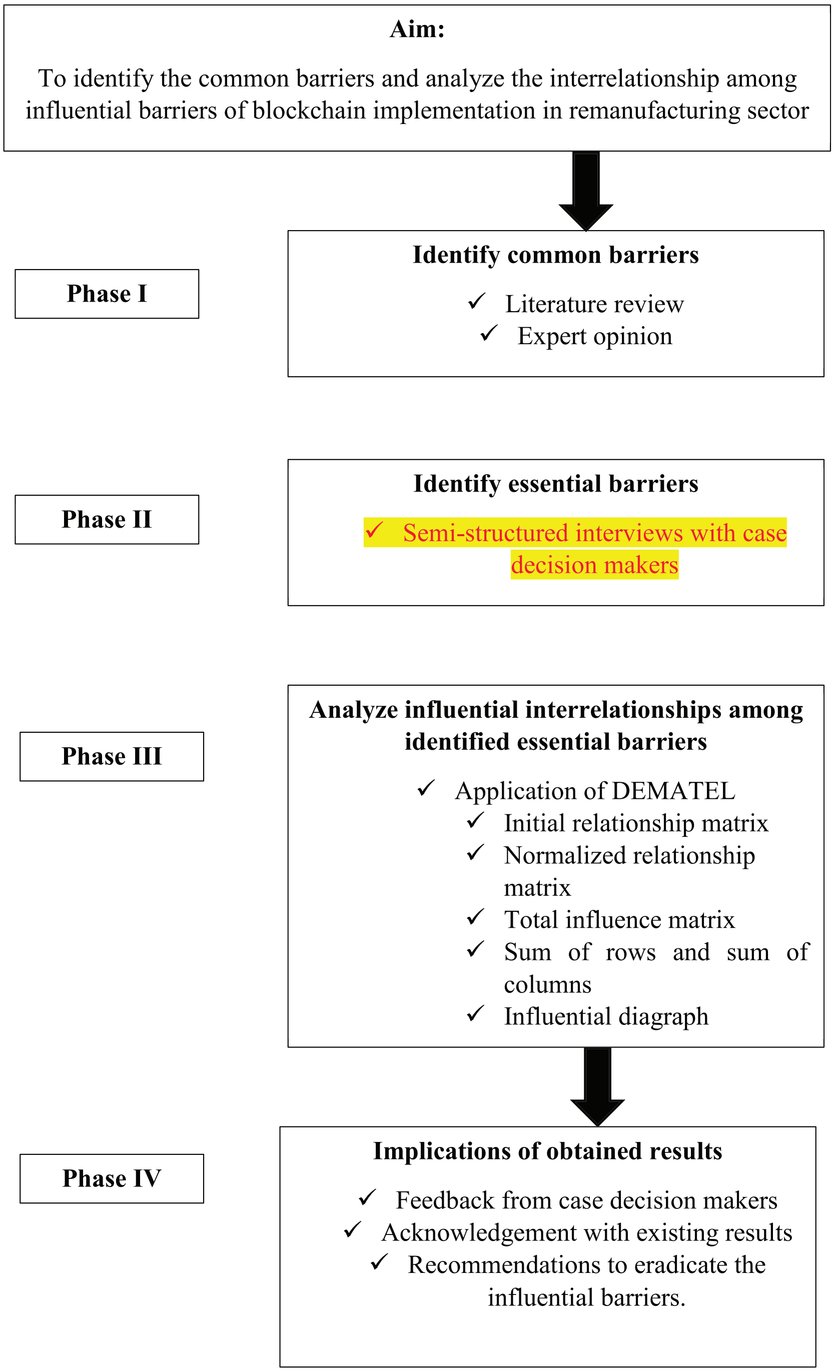

FIGURE 1 Proposed research framework for analyzing the barriers of BCT implementation in remanufacturing [Colour figure can be viewed at wileyonlinelibrary.com]

namely, a state-of-the-art literature review and input from expert opinions. The state-of-the-art review includes a systematic review on barriers involving the search terms "barriers," "challenges," "blockchain," "remanufacturing," "circular economy," and "circular manufacturing." The database for the literature review has been limited with SCOPUS and Web of Science. Once the initial set of barriers was collected, then the next step was introduced, obtaining experts' opinions. A 1-day online workshop was conducted by inviting the academicians and practitioners who are actively engaged in the integration of blockchain technology in remanufacturing practices. The collected barriers were circulated among the participants a week before the workshop, along with their definitions. At the end of the workshop, based on the suggestions from the participants, a list of common barriers of BCT implementation in remanufacturing was finalized. This information is shown in Table 2.

4.2.2 | Phase II: Ranking among collected common barriers

After the identification of common barriers of BCT implementation in remanufacturing in Phase I, in this phase, the ranking for collected

TABLE 2 List of collected common barriers of BCT implementation in remanufacturing for achieving CM

S. No.	Barriers	Explanation	Source
B1	Lack of legal security	Practitioners often ask to what extent the contracts and data were secured in remanufacturing operations. Despite the reliability in data, there is a lack of legal security in managing the information.	Durneva et al., 2020; Kouhizadeh et al., 2021; Öztürk & Yildizbaşi, 2020; Yang et al., 2018
B2	Lack of corporate governance	Corporate governance is the in-house management of activities, and in some cases, there is a lack of corporate governance which leads to ineffective implementation of blockchain in remanufacturing.	Durneva et al., 2020; Hazen et al., 2017; Kerin & Pham, 2020; Yadav et al., 2020; Tan et al., 2020
B3	Lack of business model and road map	While blockchain has received greater attention in recent years, it is still in an infant stage. Hence, the causes and effects of the implementation are not yet analyzed. It is primarily due to the lack of roadmap or business models devoted to the blockchain based remanufacturing.	Durneva et al., 2020; Hazen et al., 2017; Wang & Wang, 2019; Yadav et al., 2020
B4	Lack of legislation	Multi-stakeholder influence is essential on any new strategy, and this multi-stakeholder group includes the government. There is a need for legislation with the concern of blockchain in the application of remanufacturing. Remanufacturing includes more tedious processes from different value chain actors, so general legislation is a tough task for policy makers.	Durneva et al., 2020; Hazen et al., 2017; Kouhizadeh et al., 2021; Öztürk & Yildizbaşi, 2020; Sundin & Lee, 2012; Tan et al., 2020; Qiao & Su, 2021
B5	Lack of standardization and generalization	Remanufacturing involves more value chain partners which include multi-tier and informal aspects. Hence, it is tough to generalize and standardize the implementation of blockchain throughout the value chain; that difficulty affects the total effectiveness of remanufacturing.	Durneva et al., 2020; Farooque et al., 2020; Upadhyay, 2020; Yadav et al., 2020; Tan et al., 2020
B6	Scaling of technology	Earlier applications establish that there is a huge problem of blockchain in scalability. For instance, Visa can perform 65,000+ transactions per second, while Ethereum can perform roughly 15 transactions per second (TPS) (Cryptoslate, 2019)	Durneva et al., 2020; Kerin & Pham, 2020; Öztürk & Yildizbaşi, 2020; Upadhyay, 2020; Wang & Wang, 2019; S. Yang et al., 2018; Patil et al., 2020
B7	Issues with data privacy (under GDPR)	In recent years, data theft has emerged as a major crime. Even big organizations have been accused with the misuse of user data. In this concern, data stored in the blockchain within the decentralized environment can be used by anyone among the accepted parties. This access might cause issues with data privacy of the blockchain users.	Durneva et al., 2020; Goodall et al., 2019; Kouhizadeh et al., 2021; Upadhyay, 2020; Wang & Wang, 2019; Yang et al., 2018
B8	Operational challenges	Several challenges exist within the implication of BCT in remanufacturing which are called operational challenges. These challenges include performance monitoring, uncertainty, and so on.	Durneva et al., 2020; Farooque et al., 2020; Kouhizadeh et al., 2021; Öztürk & Yildizbaşi, 2020; Sundin & Lee, 2012; Upadhyay, 2020; Yang et al., 2018
B9	Adoption slowdown	Due to intervention of Industry 4.0 technologies such as RFID sensors, a high (and uncertain) volume of records needs to be managed by blockchain in a remanufacturing context. This makes the system slow down.	Durneva et al., 2020; Kouhizadeh et al., 2021; Tan et al., 2020

TABLE 2 (Continued)

S. No.	Barriers	Explanation	Source
B10	Lack of knowledge on cost and resources to implement	This barrier is one of the common barriers of any new implemented strategy/ technology. Due to very limited real life examples and studies, it is tough to explore the capabilities needed for BCT implementation in remanufacturing.	Durneva et al., 2020; Kerin & Pham, 2020; Siddiqi et al., 2019; Yadav et al., 2020
B11	Difficulties in selection of sharing data	Primarily, this barrier reflects difficulty in having to decide which data should be shared and who should be given access.	Durneva et al., 2020; Goodall et al., 2019; Öztürk & Yildizbaşi, 2020; Upadhyay, 2020; Wang & Wang, 2019
B12	Lack of awareness on blockchain risk	As discussed earlier, because blockchain is in its early stages, it is difficult to balance blockchain's benefits with its negative sides, especially with application of remanufacturing. Remanufacturing sectors are growing rapidly, so unaccounted risks from blockchain could damage this trend and could negatively impact a customer's intention to purchase remanufactured products.	Durneva et al., 2020; Farooque et al., 2020; Kouhizadeh et al., 2021; Lohmer & Lasch, 2020; Upadhyay, 2020; Tan et al., 2020
B13	Lack of value chain actor's engagement	Unlike manufacturing, remanufacturing may have hundreds of value chain partners with the recent help of technologies to return the used product.	Durneva et al., 2020; Farooque et al., 2020; Hazen et al., 2017; Lohmer & Lasch, 2020; Okorie et al., 2020; Öztürk & Yildizbaşi, 2020; Sundin & Lee, 2012
B14	Fear of fraudulent activity	Hackers are increasing in numbers. Previously, some instances of hacking in smart contracts have occurred.	Upadhyay, 2020; Wang & Wang, 2019
B15	Lack of tools and apps for block chain integration in remanufacturing	Unlike other technologies, there is a lack of tools and apps for BCT in remanufacturing operations. They are needed to increase the ease and convenience among users.	Durneva et al., 2020; Kerin & Pham, 2020; Lohmer & Lasch, 2020
B16	Lack of stakeholder awareness	This is the general cause for all new strategies. Most stakeholders are not aware of the modern technological development in the market which may hamper the implementation of blockchain in remanufacturing.	Durneva et al., 2020; Farooque et al., 2020; Hazen et al., 2017; Okorie et al., 2020; Sundin & Lee, 2012; Yadav et al., 2020; Tan et al., 2020
B17	Financial constraints	Blockchain implementation in remanufacturing needs handsome capital; hence, most startups and small and medium scale enterprises (SMEs) face challenges in generating funds. This could be even more difficult in times of emergency, such as during the COVID-19 pandemic.	Durneva et al., 2020; Farooque et al., 2020; Hazen et al., 2017; Huang et al., 2019; Okorie et al., 2020; Öztürk & Yildizbaşi, 2020; Sundin & Lee, 2012; Upadhyay, 2020; Wang & Wang, 2019
B18	Lack of interest in shift towards transition	Most remanufacturing processes are still in an infancy stage. Hence, practitioners are hesitant to shift towards incoming new technologies within the remanufacturing.	Durneva et al., 2020; Lohmer & Lasch, 2020; Okorie et al., 2020; Pisitsankkhakarn & Vassanadumrongdee, 2020; Singhal et al., 2020
B19	Market uncertainty	Unlike OE manufacturing, uncertainty in the availability of used products and market space is high in remanufacturing. Because of this uncertainty, blockchain inclusion becomes more constrained without standard functional parameters.	Durneva et al., 2020; Hazen et al., 2017; Lohmer & Lasch, 2020; Öztürk & Yildizbaşi, 2020; Yadav et al., 2020; Tan et al., 2020

(Continues)

TABLE 2 (Continued)

S. No.	Barriers	Explanation	Source
B20	Still requires human observation	Quality inspection of remanufactured products is more important than that of OE products. But with the assistance of blockchain, products inspected under remanufacturing still need final human observation and approval.	Durneva et al., 2020; Huang et al., 2019

TABLE 3 Ranking for barriers

S. No.	Barriers	Rank
B1	Lack of legal security	2
B2	Lack of corporate governance	11
B3	Lack of business model and road map	3
B4	Lack of legislation	15
B5	Lack of standardization and generalization	10
B6	Scaling of technology	4
B7	Issues with data privacy (under GDPR)	12
B8	Operational challenges	9
B9	Adoption slowdown	16
B10	Lack of knowledge on cost and resources to implement	17
B11	Difficulties in selection of sharing data	6
B12	Lack of awareness on blockchain risk	1
B13	Lack of value chain actor's engagement	8
B14	Fear of fraudulent activity	14
B15	Lack of tools and apps for block chain integration in remanufacturing	5
B16	Lack of stakeholder awareness	7
B17	Financial constraints	18
B18	Lack of interest in shift towards transition	20
B19	Market uncertainty	13
B20	Still requires human observation	19

common barriers is compiled. For assigning ranks for the barriers, a semi-structured interview was conducted with five case decision makers, each of whom has substantial experience in remanufacturing and technologies. With their assistance, the collected common barriers are ranked as shown in Table 3. Among the 20 collected barriers, 10 barriers were eliminated for the next phase of analysis. This activity of mapping barriers increases the accuracy of the results and deepens the understanding of effective barriers. Among these 20 barriers, the shortlisted 10 barriers are important barriers that have a direct impact on the remaining 10 barriers. Moreover, analysis of these shortlisted barriers can directly affect the focal firm's resources and thus increase their efficiency in decision making. Table 4 shows the final shortlisted set of barriers of BCT implementation for remanufacturing.

TABLE 4 Final set of barriers consider for interrelationship analysis

S. No.	Barriers	Rank
B1	Lack of legal security	2
B3	Lack of business model and road map	3
B5	Lack of standardization and generalization	10
B6	Scaling of technology	4
B8	Operational challenges	9
B11	Difficulties in selection of sharing data	6
B12	Lack of awareness on blockchain risk	1
B13	Lack of value chain actor's engagement	8
B15	Lack of tools and apps for block chain integration in remanufacturing	5
B16	Lack of stakeholder awareness	7

4.2.3 | Phase III: DEMATEL

Phase III includes the final set of barriers for interrelationship analysis. The barriers are analyzed based on previously discussed steps.

Step 1: Initial relationship matrix *A*

The initial relationship matrix has been set up from the replies of five case decision makers as calculated from Equation 1. The obtained initial relationship matrix for the barriers is shown in Table 5.

Step 2: Normalized direct relationship matrix *X*

The normalization of the obtained initial relationship matrix is shown in Table 6, with the assistance of Equations 2 and 3.

Step 3: Total influence matrix *T*

Based on the normalized direct relationship matrix *X*, the total influence matrix has been set up through Equation 4, and the same has been shown in Table 7.

Step 4: Sum of rows and columns

TABLE 5 Initial influence matrix

	B1	B3	B5	B6	B8	B11	B12	B13	B15	B16
B1	0	2	3	1	1	2	1	2	2	2
B3	3	0	3	1	1	2	1	3	2	3
B5	2	2	0	1	1	2	1	2	2	2
B6	4	3	4	0	3	3	2	3	3	4
B8	1	3	4	2	0	3	2	3	3	4
B11	2	3	2	1	1	0	1	2	2	2
B12	3	2	4	1	1	2	0	2	2	3
B13	3	1	3	1	1	2	1	0	2	3
B15	3	2	4	1	1	2	1	2	0	2
B16	2	3	2	1	1	2	1	2	2	0

TABLE 6 Normalized direct relationship matrix

	B1	B3	B5	B6	B8	B11	B12	B13	B15	B16
B1	0	0.068966	0.103448	0.034483	0.034483	0.068966	0.034483	0.068966	0.068966	0.068966
B3	0.103448	0	0.103448	0.034483	0.034483	0.068966	0.034483	0.103448	0.068966	0.103448
B5	0.068966	0.068966	0	0.034483	0.034483	0.068966	0.034483	0.068966	0.068966	0.068966
B6	0.137931	0.103448	0.137931	0	0.103448	0.103448	0.068966	0.103448	0.103448	0.137931
B8	0.034483	0.103448	0.137931	0.068966	0	0.103448	0.068966	0.103448	0.103448	0.137931
B11	0.068966	0.103448	0.068966	0.034483	0.034483	0	0.034483	0.068966	0.068966	0.068966
B12	0.103448	0.068966	0.137931	0.034483	0.034483	0.068966	0	0.068966	0.068966	0.103448
B13	0.103448	0.034483	0.103448	0.034483	0.034483	0.068966	0.034483	0	0.068966	0.103448
B15	0.103448	0.068966	0.137931	0.034483	0.034483	0.068966	0.034483	0.068966	0	0.068966
B16	0.068966	0.103448	0.068966	0.034483	0.034483	0.068966	0.034483	0.068966	0.068966	0

TABLE 7 The total influence matrix

	B1	B3	B5	B6	B8	B11	B12	B13	B15	B16
B1	0.11618	0.17025	0.23334	0.08504	0.08778	0.1645	0.08787	0.16999	0.1645	0.18388
B3	0.22953	0.12243	**0.2552**	0.09336	0.09637	0.1806	0.09647	0.2168	0.1806	0.23303
B5	0.17505	0.16493	0.1323	0.08238	0.08504	0.15936	0.08513	0.16468	0.15936	0.17814
B6	**0.32962**	**0.28501**	**0.37307**	0.09342	0.1932	**0.27436**	0.1632	**0.28355**	**0.27436**	**0.33947**
B8	0.21468	**0.26014**	**0.33953**	0.14502	0.08519	**0.25036**	0.14986	**0.25875**	**0.25036**	**0.31162**
B11	0.18245	0.20114	0.20504	0.08539	0.08815	0.10067	0.08824	0.17167	0.16518	0.18566
B12	0.23584	0.19381	**0.29347**	0.0963	0.09941	0.18628	0.06618	0.19254	0.18628	0.23945
B13	0.21518	0.14603	0.23925	0.08752	0.09035	0.16931	0.09044	0.1095	0.16931	0.21847
B15	0.22235	0.18107	**0.27739**	0.09044	0.09336	0.17495	0.09345	0.18079	0.11043	0.19556
B16	0.18245	0.20114	0.20504	0.08539	0.08815	0.16518	0.08824	0.17167	0.16518	0.12114

The sum of rows (r_i) and the sum of columns (s_i) were obtained through Equations 5 and 6 and shown in Table 8.

Step 5: Causal influence diagraph

The final step of the DEMATEL has been concluded with the diagraph as shown in Figure 2. Based on the values of sum of rows and sum of columns, the barriers are placed in their respective cause and effect group.

4.2.4 | Phase IV: Implications of results

This is the final phase of the proposed framework; in this phase, the obtained results are explored in order to provide useful implications for practitioners to achieve circular manufacturing through effective blockchain-led remanufacturing. The more detailed discussions on the implications and recommendations can be seen in the upcoming sections.

TABLE 8 Sum of influences given and received by the barriers of blockchain implementation in remanufacturing

Barriers		*ri*	*si*	*ri* + *si*	*ri*−*si*
B1	Lack of legal security	1.46334	2.103342	3.566681	−0.64
B3	Lack of business model and road map	1.704381	1.92596	3.630341	−0.22158
B5	Lack of standardization and generalization	1.38636	2.553629	3.939989	−1.16727
B6	Scaling of technology	2.60925	0.944258	3.553507	1.664992
B8	Operational challenges	2.265522	1.006975	3.272498	1.258547
B11	Difficulties in selection of sharing data	1.473598	1.825572	3.29917	−0.35197
B12	Lack of awareness on blockchain risk	1.789561	1.009066	2.798627	0.780495
B13	Lack of value chain actor's engagement	1.535358	1.919958	3.455315	−0.3846
B15	Lack of tools and apps for block chain integration in remanufacturing	1.619781	1.825572	3.445353	−0.20579
B16	Lack of stakeholder awareness	1.473598	2.206418	3.680016	−0.73282

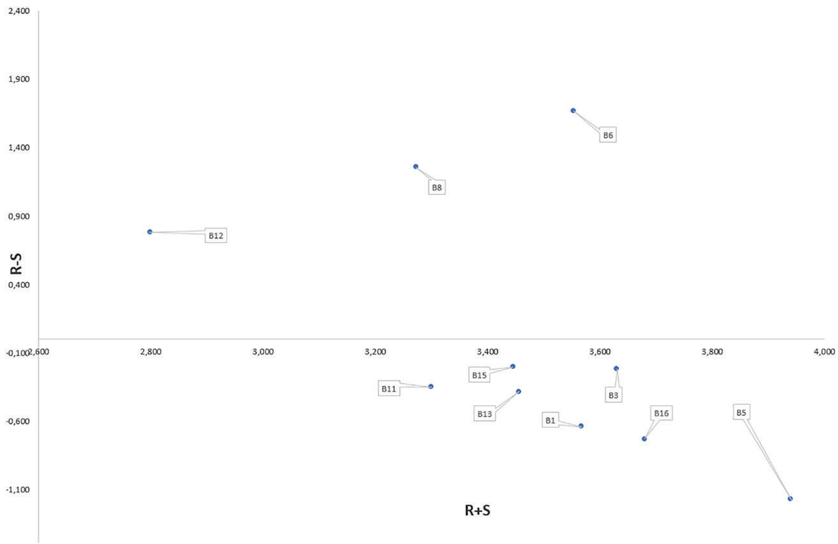

FIGURE 2 Influential diagraph on barriers of blockchain technology implementation in remanufacturing [Colour figure can be viewed at wileyonlinelibrary.com]

5 | RESULTS AND DISCUSSION

This section intends to analyze the interrelationships among the essential barriers through a series of exploration. In addition, based on that, useful recommendations are given for practitioner implications of blockchain in the remanufacturing sector.

Among the common collected barriers of blockchain technology in remanufacturing for achieving CM, the essential barriers were identified through ranking based on the replies of case decision makers. From the ranking, among 20 common barriers, 10 barriers were selected and shown in Table 4. Further, these essential barriers have been analyzed with the assistance of DEMATEL, and the results are shown in Table 8. Based on the obtained values, the influential digraph was drawn as shown in Figure 2. The diagraph can be categorized into two groups, cause and effect. The cause group consists of barriers which are influencing other essential barriers, whereas the effect group consists of barriers which are influenced by cause group barriers. As per the diagraph, B6, B8, and B12 lie in the cause group, and the remaining barriers lie in the effect group. Specifically, "scaling of technology" (**B6**), "operational challenges" (**B8**), and "lack of awareness on blockchain risk" (**B12**) are the most influencing barriers among the essential barriers; these factors focus on the process of blockchain implementation in remanufacturing. The priority among the essential barriers of BCT in remanufacturing is as follows: B6 > B8 > B12 > B15 > B3 > B11 > B13 > B1 > B16 > B5.

The major aim of the study is to use the findings as a guide to assist practitioners who seek to implement blockchain technology in remanufacturing. Hence, to bridge the gap between the academic's and the practitioner's perspectives, a feedback session was conducted with the case decision makers with the obtained results. In this session, the obtained results are shared, and after several rounds of discussions, the case decision makers are comfortable with the results. Some of the findings are as expected, and some of them caught the case decision makers by surprise. For instance, the case company is involving remanufacturing of only one product, calipers, so the standardization and generalization of blockchain in their operations are not a primary concern. That view is reflected in the study's findings that "lack of generalization and standardization" (**B5**) is the least influential barrier among essential barriers. As mentioned earlier, some of the results are a shock to the case company; they were not aware of such barriers. For example, “scaling of technology” (**B6**) holds the top position in the influential graph; however, other existing studies suggested several other barriers as key barriers, such as high cost, regulatory uncertainty, and BCT risks. Hence, these apparently contradictory results were new to the case decision makers.

Earlier studies and existing strategies on blockchain implementation focused on products and services involved in forward value chains. Compared to forward value chains, remanufacturing processes involve more complex tracking due to the reverse supply chains. The case company collects used calipers from various sources and unlike OE calipers, these remanufactured calipers require effective tracking to make the whole remanufacturing value chain efficient. For instance, the first process at the case remanufacturing plant is sorting with inspection. Inspectors observe the quality in the sorting stage to eliminate damaged calipers. These data must be circulated through the system so customers can get the final remanufactured products without compromising the quality. It is expected that in coming years, the number of used incoming calipers will be higher, so the size of the data is expected to increase. Compared to OE, remanufactured products need more data to motivate the customer to purchase the remanufactured products; a lack of trust for remanufactured products is the key reason for lower acceptance rates by customers. The current blockchain technology has the limitation of processing data, which makes scalability a concern. According to Ahl et al. (2020), scalability in BCT is the key driver for implementation; this study highlights the potential of increasing the scalability of BCT in various sectors including green transition. These statements are also supported by Andoni et al. (2019)'s study, in which they state that currently researchers are more engaged to improve speed and scalability by offering different solutions, including increasing the block size, utilization of sharing, sidechains, and payment channels that promise instant finality. Next to that, the result claims that with the practitioner's perspective, operational challenges, on integrating BCT in remanufacturing process, include coordinating with other value chain actors for seamless data transaction, dealing with uncertainty, and measuring performance. The lack of coordination among value chain actors is the major factor which hinders the effectiveness of green logistics and consequently affects remanufacturing (Tan et al., 2020). Therefore, it is necessary to integrate BCT in remanufacturing processes in such a way to address these issues. Considering operational challenges in BCT integration in remanufacturing is essential.

Finally, the third influential barrier is “lack of awareness on blockchain risk” (**B12**). Remanufacturing contexts involve sensitive data from tracking to information, so safety and security over transferred data are essential to convince top level managers to adopt BCT in remanufacturing. Current studies do not provide much evidence on the upcoming risks involved in the BCT implementation; very few studies have discussed these associated risks (Patil et al., 2020; Yadav et al., 2020). No definite study addresses remanufacturing, so the absence of work on this topic makes top management seriously consider the integration of BCT in their remanufacturing firms. The unknown risks impact not only the remanufacturing focal firm but also every entity in the value chain. The result is that remanufacturing companies are hesitant to implement BCT in their firms.

These three causal barriers influence other barriers. If these three influential barriers of BCT implementation have been addressed, then the other barriers would be addressed by themselves. Hence, practitioners must focus on the strategies or practices to mitigate these three barriers in particular, without bothering to frame mitigating strategies for all other barriers. To explore the interdependencies, this study has used Table 7, “the total influence matrix,” to understand the interrelationship among considered barriers. Based on the threshold values, we determine no mutual influential relationship among the final barriers. Concerning with influential relationship, among 10 final barriers, five barriers (**B3**, **B6**, **B8**, **B12**, and **B15**) do possess influences over other common barriers. All relationships that meet or exceed the threshold value are marked in bold in the total influence matrix (Table 7).

“Lack of business model and roadmap” (**B3**), “lack of awareness on blockchain risk” (**B12**), and “lack of tools and apps for blockchain integration in remanufacturing” (**B15**) have an influence on “lack of standardization and generalization” (**B5**). Due to BCT's recent success, several companies began to develop certain applications of BCT within their own field, bringing different confidentiality measures, protocols, coding languages, and communication mechanisms with several parties involved. These differences make the BCT applications so challenging, which is why there is a need for standardization and generalization in the BCT application among the value chain partners. At present, most of the companies are reluctant to adopt BCT due to this lack of standardization and generalization. According to Tiscini et al. (2020) and di Carlo et al. (2016), business models guide the organization to make strategic decisions for sustainability in the business environment. The contour given by the business models includes standards and generalizations, which is why the lack of business models and roadmap with blockchain ultimately results in a lack of standardization and generalization. Risks also play an important role in delivering standards to BCT. As a new strategy, BCT possesses more than other dated strategies. For example, Fedorov et al. (2018) highlight the potential risks of using BCT in applications. There are still more risks that are not yet unfolded in BCT applications, and this lack of knowledge (**B3**) about risks makes the assessment of standards for BCT harder. More recent features in different applications are getting smoother in operations due to the availability of digital tools and apps, but, unfortunately, BCT itself has fewer tools and apps. This absence interrupts the smoothness of operations, making the demotivation of companies to adopt BCT. Under such disadvantages, companies cannot standardize or generalize the processes within BCT, as reflected in the results that both (**B3**) and (**B15**) impact (**B5**).

In addition to the above, “Scaling of technology” (**B6**) has a greater impact on considered final barriers. (**B6**) affects (**B1**), (**B3**), (**B5**), (**B11**), (**B13**), (**B15**), and (**B16**). Although (**B6**) has been identified as the most influential barrier in the study, it is necessary to understand the individual influences of (**B6**) relative to other barriers.

Currently, there are few successful solutions to the scalability challenges in BCT, but in such solutions, the increasing scalability results with the implications for security and decentralization (Cryptopedia, 2021). Due to the greater throughput of data, the chances of cyberattacks are high, which in turn force remanufacturers to think about the adoption of BCT to achieve CM. Concerning the fact, it has been clear that scaling technology (**B6**) affects "lack of legal security" (**B1**).

According to Lacity (2018), companies are not well established with the BCT business models, so they struggle to create and reap insured business values. This failure of BCT business models is primarily due to the lack of theoretical understanding of the essential elements of the BCT business models (Weking et al., 2020). These elements include knowledge of business model patterns, taxonomy, and architecture. However, identification of these elements requires a rigorous examination of various desired long-term benefits/outputs, which mainly include scalability. Although companies propose a successful BCT business model but may be still limited in scalability, business models do not provide the desired long-term benefits/outputs. Therefore, it is necessary to tackle the scalability challenges (**B6**) to eliminate the lack of successful business models (**B3**) in the application of BCT to achieve CM.

As previously mentioned, "lack of standardization and generalization" (**B5**) is the most influenced barrier for BCT adaptation to achieve circular fabrication. This factor aligns with (**B6**): Due to the lack of scalability, several companies are currently hesitant to promote BCT in real cases. With the lack of real examples, it is difficult to formulate standards and generalizations for the BCT applications. Furthermore, scalability challenges (**B6**) affect the selection of sharing data (**B11**) with value chain partners. While there is a huge data inflow, current BCT systems become slow and affect the level of scalability; this level directly reflects the time of data transfer to different entities involved. The BCT system can only process certain transaction data that delays the verification of the data being shared (Bitpanda, 2020). Such delays due to scalability issues force practitioners to react quickly with their data sharing decisions, so results are obtained when (**B6**) affects (**B11**).

In recent years, digital tools and apps have been created to solve various complex problems and make the process more user-friendly. Due to lack of scalability in BCT applications, the complexity of data transfer and data management decision making becomes complex. Such complex operations make companies think about the adoption of BCT. In addition, the lack of tools and apps for BCT increases the complexity of scalability in data transactions. In recent years, a few tools (DAML, bloXroute, Cordite XKD, Cordium, and Platform 6) have been used by practitioners in the BCT applications for flexible implementation and quick access to the large set of inventory data. This confirms that there is a strong relationship between (**B6**) and (**B15**).

BCT is used for data transaction, where the information is shared with stakeholders and value chain partners involved in the operations. Such information relies heavily on input from stakeholders and value chain partners based on market fluctuations. This asymmetric information among stakeholders and value chain partners can disrupt the entire system and, further, lead to failures (Ghode et al., 2020). Despite the importance of stakeholders and value chain partners, several studies (e.g., Balasubramanian et al., 2021) confirmed that the voices of these partners are not monitored during the implementation of BCT in operations. In addition, these partners often show less interest in the adoption of BCT. Several factors influence the partners' intention to engage in BCT-based data transaction. These factors are often related to the long-term planning and goals. Most of the stakeholders are unaware of BCT and its essential elements for effective implications of BCT to achieve these desired results promptly. This lack of awareness (**B16**) forces partners to limit the sharing of their data, and this ultimately results in a lack of commitment (**B13**). Both (**B16**) and (**B13**) are the results of a lack of long-term success for BCT and high-profile real-life cases. Most of the current BCT applications are limited to commerce or new strategies such as circular manufacturing. Currently, there is not a single high profile real case that can motivate the partners to get involved in BCT operations. This lack of high-profile real cases is mainly due to the great challenge facing large companies, scalability. Most of the high-profile real cases have *n* number of data, which can be more difficult for the custom BCT to act as quickly as possible, leading to lack of security. Combined influences point to the "lack of scalability" (**B6**), "lack of stakeholder awareness" (**B16**), and "lack of value chain actor's engagement" (**B13**). In the same way as (**B6**), "operational challenges" (**B7**) also have similar effects on (**B3**), (**B5**), (**B11**), (**B13**), (**B15**), and (**B16**).

Eliminating these barriers to implementing BCT in remanufacturing to achieve CM has several direct and indirect impacts on SDGs. Each of the highly influential barriers has been related to its respective SDGs. Scaling technology (**B6**) improves the efficiency of remanufacturing on a global scale, which in turn increases the partnerships for the goals (SDG17), which is further evident in decent work and economic growth (SDG8) in the remanufacturing sector. But BCT as a new technology, this scaling up can motivate the industry's innovation culture, which facilitates SDG 9 (industry, innovation, and infrastructure).

By eliminating, "operational challenges" (**B8**) in the remanufacturing with the concern of CM can impact decent work and economic growth (SDG8). This elimination further helps the industry to build a resilient industrial infrastructure.

Finally, by eliminating "lack of awareness on blockchain risk" (**B12**), the industry can educate the employees with the new technology and promote learning opportunities (SDG 4—quality education). In addition, eliminating (**B12**) impacts effective BCT implementation in remanufacturing, increasing sustainable economic growth and productivity (SDG8—Decent Work and Economic growth).

6 | CONCLUSION

This study examines the application of blockchain technology in remanufacturing context for achieving circular manufacturing. Due to the existing gap on the research for blockchain implementation in remanufacturing processes under the context of CM, this study attempts to explore the barriers of BCT implementation. A model framework has been proposed and validated with the Danish context. Initially, 20 common barriers of blockchain technology implementation in remanufacturing were identified with the assistance of literature review and experts' opinions. Further, the same was used to identify the essential barriers through ranking from the replies of case decision makers. Among the initial 20, 10 barriers are finalized for analyzing the interrelationship among the identified essential barriers. Further, the influential barriers have been identified through the application of DEMATEL. The results showed that "scaling of technology" (**B6**), "operational challenges" (**B8**), and "lack of awareness on blockchain risk" (**B12**) are the three key barriers that demonstrate high influence among other essential barriers of BCT implementation in remanufacturing. The results were explored with both acknowledgements of scientific literature and feedback from field experts and case managers. Based on exploitation of results, useful recommendations to eradicate the influential barriers have been shared with case industry managers. With these recommendations, the industrial managers can easily identify the influential barriers and prepare strategies to address those barriers for effective BCT implementation in remanufacturing. This study serves a serious contribution at practitioner's level by bridging the theoretical knowledge with real case scenario. Despite its contributions, this study includes some limitations. The major limitation is that this study considers case study methodology; i.e., the data obtained for this study is from a single source of application which might not be perfectly applicable to other remanufacturing applications. In addition, the results might also have an impact with the basic DNA of the case company. Hence, in future research, this study can be adapted with the proposed research framework with different fields of remanufacturing applications. This study only focuses on the application of BCT in remanufacturing under the circular manufacturing. It would be fruitful to extend this study with the comparison of BCT applications in both traditional manufacturing and remanufacturing. This kind of analysis could improve the understanding of practitioners towards the importance and uniqueness of remanufacturing under CM over traditional manufacturing processes.

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