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Elements of Blockchain-based Circular Business Models in Manufacturing: A Synthesis of the Literature

Luke Tonnaer[1] Banu Aysolmaz[1] Oktay Turetken[1]

[1]**Eindhoven University of Technology, Netherlands**

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Luke Tonnaer[1,*], Banu Aysolmaz[1,*], Oktay Turetken[1]

[1]Information Systems Group, Eindhoven University of Technology, Netherlands

*b.e.aysolmaz@tue.nl

Abstract

The manufacturing industry faces barriers to transitioning to a circular economy. Blockchain technology can help manufacturing supply chains overcome barriers and achieve core principles of circular economy, for example, through increased traceability of materials among network partners. However, the current literature lacks an overview of the contribution of blockchain to circular business models (CBMs) that can be used as a reference to facilitate the implementation of blockchain-based circularity solutions in manufacturing. In this study, we performed a systematic literature review to identify the studies that provide blockchain applications and use cases for CBMs in the manufacturing industry. We classified the selected articles according to the elements of networked business models, as such solutions involve multiple businesses that collaborate tightly. Our results show traceability and transparency as the central value propositions of CBM networks. We provide a classification of network actors and roles, their coproduction activities, and common benefits they gain and costs they incur to achieve the value propositions. Our results provide a better understanding of the body of knowledge on the use of blockchain for CBMs and highlight understudied points. Manufacturing companies can leverage our comprehensive classification and enumeration of CBM elements to inform and optimize the design of their own CBMs. In future work, we aim to provide more assistance to companies by developing reference blockchain CBM blueprints and applying them to CBM design to evaluate their effectiveness and utility.

Keywords

circular economy, business models, blockchain, manufacturing, systematic literature review.

Introduction

The circular economy concept disrupts existing business models by removing the linear take-make-waste approach and introducing a closed-loop value chain in product and service development. Despite the potential benefits and drivers of transitioning to the circular economy, several critical barriers cause manufacturing businesses to be reluctant to transition to a circular economy. Common barriers are the lack of trust among partners, low consumer comprehension of sustainability practices, and difficulty of achieving mutual value for the whole network (Suchek et al., 2021; Babbitt et al., 2018; Fehrer & Wieland, 2021). Blockchain could be a moderator by strengthening drivers and mitigating barriers in the transition toward a circular economy

(Böhmecke-Schwafert, Wehinger & Teigland, 2022). The fundamental attributes of blockchain can be translated into circular economy practices such as transparency, reliability, traceability, and real-time information sharing (Aslam et al., 2021).

Seebacher & Schüritz (2017) define blockchain as "*a distributed database which is shared among and agreed upon a peer-to-peer network*". Recent studies have proven the supportive role of blockchain in the circular economy, for instance, by facilitating traceability in complex supply chains and accurate information sharing (Agrawal et al., 2021; Saberi et al., 2019). Several papers touch upon the potential use cases of blockchain in the manufacturing industry and highlight their corresponding benefits (e.g., Gong et al., 2022; Khadke et al., 2021; Steenmans & Taylor, 2018). However, the current research on blockchain applications for circular economy practices lacks an overview of the use cases and the characteristics of the corresponding circular business models (CBMs).

Circular economy can provide solutions, particularly for challenges of the manufacturing industry and its supply chains. Manufacturing companies depend on their supply of materials, as they are vital in product creation. Hence, this industry is increasingly under pressure due to its linear economy approach causing unsustainable production and increased solid waste generation (Lieder & Rashid, 2016; OECD, 2022). Furthermore, the earth's resources are limited, resulting in increased competition for scarce resources creating volatility in price (Lieder & Rashid, 2016). In contrast, the circular economy concept could yield higher profits and reduce the costs of materials (Ellen MacArthur Foundation, 2013). Transitioning to a circular economy in the manufacturing industry requires collaboration between multiple businesses (Lieder & Rashid, 2016). The preservation or recovery of value from materials and products is vital to the success of the circular economy, and the development of networked business models as references can assist in realizing this within the manufacturing industry. Since this industry comprises complex networks and a competitive environment, information technology, and especially blockchain, is a significant moderator in enabling this transition (Böhmecke-Schwafert, Wehinger & Teigland, 2022; Lieder & Rashid, 2016).

Accordingly, in this study, we aim to investigate *"How could blockchain contribute to circular business models for companies operating in the manufacturing industry?".* This paper presents the results from our systematic literature review on studies that examine blockchain applications and use cases that contribute to CBMs. We classify 30 articles that we identified with respect to business model elements relevant to a networked business model. By classifying the use of blockchain for CBMs in manufacturing, we aim to improve the theoretical understanding of the potential contribution of blockchain to circular economy and provide support to companies that intend to operate or expand their circular economy practices in the manufacturing industry.

Research design

We conducted a following the guidelines of Kitchenham & Charters (2007) and the concept-centric approach for data extraction and synthesizing of Webster & Watson (2002). We started with the planning phase, identified the need for a review, and specified the research question, as discussed in the introduction. As a part of the review protocol, we included the databases of Scopus and Web of Science (WoS) for peer-reviewed articles since they publish extensive and relevant research on blockchain and circular economy. We also decided to include the *first-tier grey literature* (Garousi, Felderer & Mäntylä, 2019; Levy & Ellis, 2006) to reach relevant blockchain applications in practice using the Google Scholar database. We defined the following keyword combination as the search string in the title, abstract, and keywords of articles: *(blockchain OR "blockchain") AND ("circular economy" OR "closed loop supply chain" OR "green supply chain" OR "circular supply chain")*. This search string is set broad to cover all potential blockchain applications for circular economy practices in a manufacturing value chain.

To identify the relevant articles, we defined a set of inclusion and exclusion criteria as part of the review protocol. We included studies published in English from 2017, as the interest in adopting blockchain for the circular economy began to gain traction that year. We included studies that are journal articles, conference papers, and grey literature, including books, magazines, government reports, and white papers. Considering our research question, we included studies that provide a blockchain application or use-case in manufacturing value chains while focusing on at least one circular economy principle (i.e., reduce, reuse, recycle, & recover) suggested by the 4R framework (Kirchherr, Reike & Hekkert, 2017). Particularly, we expect that studies depict a blockchain application or use case as a network value proposition relevant to a manufacturing chain. We excluded articles that study only technical details of blockchain without any focus on business model aspects and those that incorporate blockchain as part of other technologies, e.g., Industry 4.0.

In the second step, we conducted the review according to the review protocol (depicted in Figure 1). The initial search from the selected databases retrieved 510 studies (as of 30 September 2022) distributed as 184 from Scopus and 126 from WoS. Since Google Scholar yielded too many results, we retrieved the first 200 results sorted by relevance, after which the studies were no longer relevant. After removing the duplicates, 283 studies remained. Next, we screened the papers on the title, abstract, and keywords, leaving 115 studies. We performed a detailed review of these papers on their full text, leading to 27 relevant studies. A forward and backward search was performed for these studies until no new potential studies were identified. This search only retrieved three new studies, resulting in a final dataset of 30 studies.

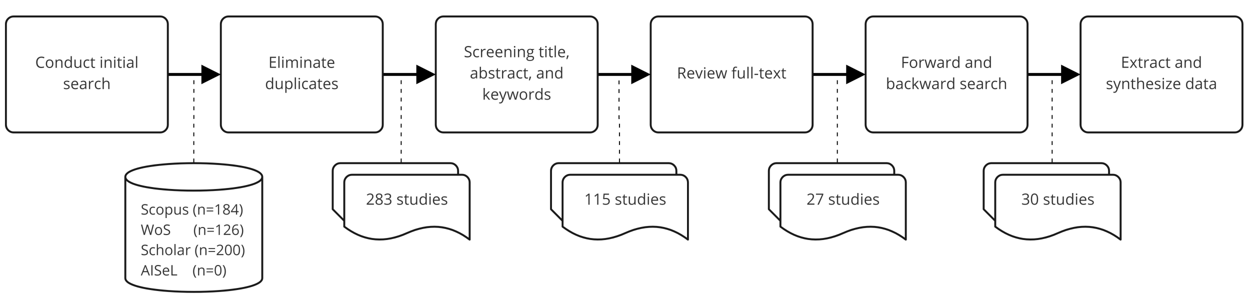

Figure 1: Refinement steps in the SLR protocol and resulting numbers of articles.

We synthesized and classified the selected studies with respect to *research characteristics* and *business model elements*. The *research characteristics* category aims to identify the general characteristics of a published study on publication type, research type, and research method. Each study is grouped into one of the sub-categories. The publication type is included to identify peer-reviewed, white papers, or grey literature tier 1 as defined by Adams et al. (2017). The research type (Wiener, Saunders & Marabelli, 2020) and research method (Collins et al., 2021) are specified as done in similar studies in this research domain.

The *business model elements* category focuses on discovering the characteristics related to the elements of networked business models. To identify the sub-categories of the business model elements category, we adapted the business model elements identified by Turetken et al. (2019) for value networks established as the elements of the Service-Dominant Business Model Radar (SDBM/R). Each study may address one or more CBM elements, including the *network value proposition (co-created value in use)*, which represents the value of the designed solution to the customer(s) of the business model, *network actors, actor roles, actor coproduction activities* performed to produce the network value proposition, *and benefits and costs* incurred by each actor, financial or non-financial, due to participating in the business model (Turetken & Grefen, 2017). For example, the sub-category *network actors* depicts whether the studies report certain network actors in their blockchain application or use-case and notes each actor represented in a particular study.

Results

We present the results of the classification of the selected articles according to the categories of research characteristics and business model elements.

Research characteristics

The results are depicted in Figure 2. For the research type, while most studies are conceptual, we can observe that the number of empirical research studies doubled in 2022. For the research method, the use of descriptive methods and case studies is most common. The findings align with the argument by Böckel et al. (2021) that studies for a blockchain in a circular economy is a developing research field and mainly comprises conceptual studies.

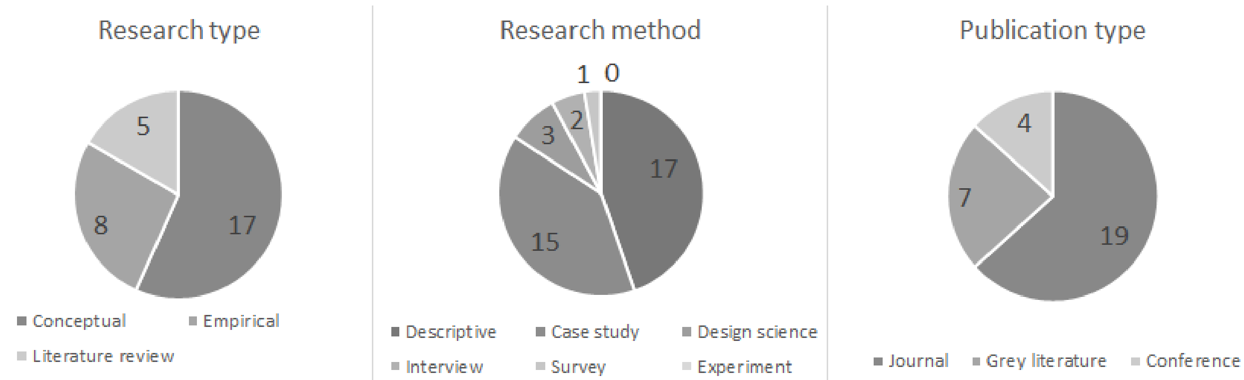

Figure 2: Categorization of the identified articles for research characteristics

Business Model Elements

The element ***network value proposition*** is central to a networked business model, as it represents the added value of a specific business model to be achieved by the network for a specific customer group (Gilsing et al., 2020). For this element, we adapted the classification of Böhmecke-Schwafert et al. (2022) for the purpose of using blockchain applications in a circular economy: traceability & transparency, waste management, incentivization, renewable energy, and sharing economy. We introduced traceability and transparency as individual categories and removed the renewable energy and sharing economy as they are less relevant or not applicable to the manufacturing industry. The blockchain applications per study are categorized based on keywords into one or more sub-categories: *traceability, transparency, waste management, and incentivization*. We followed a thematic coding approach to specify network value propositions under each sub-category, presented in Table 1. We observe that studies mostly identify network value propositions for traceability and transparency, and the propositions of the other categories inherently build on the value items defined in the traceability and transparency categories. Thus, we deduce that while essential value is generated for waste management and incentivization, value related to traceability and transparency are the core and inherent propositions provided through blockchain in CBMs.

Table 1: Identified network value propositions organized into categories

Category	**Network value proposition**

Traceability (*28 articles*)	Providing an immutable trail of critical data on the production of circular materials
	Balanced circular product outflow with renewable or recycled material flow
	Traceable responsibility of operations by individual transactions signed by value chain actors
	Authentication and assessment of the condition of products and their components
	Having a digital twin of a physical asset to depict its economic value and govern ownership
Transparency (*25 articles*)	Accurate and efficient life cycle assessment for circular products
	Efficient procedural auditing required for the production of circular products
	Automated reporting system for company environmental impact
	Product passport for the composition and authenticity of circular products
	Rapid supply and demand information on renewable and recycled materials required for the production of circular products
Waste management (*13 articles*)	Accurate waste handling through access to data on product composition
	Product life extension through trusted second-hand markets for remanufacturing and reselling
	Extended product responsibility during the lifecycle and at the end of life

Incentivization (*16 articles*)	Increased environmentally conscious consumer purchasing behavior by active or passive rewarding in the form of tokens
	Increased environmentally friendly consumer consumption behavior through clear product data
	Increased interest in second-hand products through trustworthy and accurate product history
	Efficient regulatory assessment of compliance and automated incentivization/ penalization for companies

We determined 23 studies that identify the business model element of ***network actors***, which study network actors involved in blockchain applications. We further coded these studies and identified ten different actor types mentioned, as depicted in Figure 3. In most studies (8 of 13), the consumer was defined as not integrated into the blockchain but only having access to public information on the blockchain.

We further investigated, as the next element, if ***actor roles*** of the network actors are identified in the studies by using the categorization of actor roles in networked business models by Turetken et al. (2019): *customer, focal organization, core actor, and enriching actor*. All value chain participants must be involved to create a closed loop on the blockchain. Their information related to circular product creation and proper waste management is essential for blockchain to stimulate the circular economy (Ajwani-Ramchandani et al., 2021; Steenmans & Taylor, 2018). The recycler represents the recycling facilities and supplies raw materials for the (intermediary) manufacturing companies. The waste management business is the stakeholder that accurately collects and segregates waste. The (intermediate) manufacturer company manufactures finished goods and products for consumption. The brand owner, also referred to as the Original Equipment Manufacturer (OEM), markets the final product under their brand name and pledges the circularity of their products (Shou & Domenech, 2022). The *auditor* (or NGOs) is also required in the development of blockchain. Thus, we designate network actors of *waste management company, recycler, manufacturer, intermediate manufacturer, brand owner/OEM*, and *auditor/NGO* as core actors in the CBM. Several blockchain application examples show blockchain ecosystems governed by a *blockchain provider*, that creates the blockchain ecosystem (Shou & Domenech, 2022; Dindarian & Chakravarthy, 2019) taking the *focal organization* role. Auditors and non-governmental organizations (NGOs) validate circularity claims for products. Governmental bodies accelerate and support the transition towards a circular economy with legislation. The consumer represents the buyer and user of the circular product the brand owner sells. In most studies (8 of 13), consumer was defined as not integrated into the blockchain but only having access to public information on the blockchain. Thus, auditors/NGOs, governmental bodies, and consumers are considered *enriching actors* that contribute to a CBM through their activities.

Our analysis identified that only six studies explicitly stated, to a certain extent, the role of the network actors in a blockchain. Thus, we observe a lack of identification of the roles that network actors take to contribute to a CBM integrating blockchain. The actor role of *customer*, which is the actor role for whom the core network value proposition is to be provided, is not explicitly mentioned. We found only one study that can indicate the brand owner as a customer by providing the link between the upstream and downstream value chain and pledging the circularity of a product to its consumers (Shou & Domenech, 2022). We suggest that customers in a blockchain-based CBM can be one or more of the network actors since a blockchain solution can provide the value proposition to more than one network actor type, e.g., both the brand owner and the manufacturer.

Figure 3: Categorization of identified articles for network actors

The element of ***actor coproduction activities*** defines the activities that each actor performs to offer its own actor value proposition and achieve the network value proposition (Turetken et al., 2019). The element of *actor value proposition* identifies how the actor contributes to the network value proposition. Since these two elements are highly related by actor coproduction activities specifying services to realize the actor value proposition, and it is more likely that studies explain actors' activities rather than stating the actor value proposition, we focused on analyzing the articles for actor coproduction activities. Among the selected articles, we identified ten studies that relate to this element. We present the identified coproduction activities for network actors in Table 2.

Table 2: Actor coproduction activities identified for network actors

Network actor	**Coproduction activity**
Recycler (*Core actor*)	- Creates the hash value for renewable or recycled materials by uploading information and corresponding proof documents on the blockchain (Centobelli et al., 2021; Rusinek, Zhang & Radziwill, 2018). - Initiates the blockchain for the recycled or renewable materials by creating the genesis block so that they are used and tracked in the following steps of circular product creation and waste management (Shou & Domenech, 2022; Kouhizadeh & Sarkis, 2018).

(Intermediate) manufacturer (*Core actor*)	- Verifies the circularity (e.g., origin, recycling process) of the materials received from the recycler (Rusinek, Zhang & Radziwill, 2018; Kouhizadeh & Sarkis, 2018). - Collects sustainability data and proof documents during the creation of a circular product (or component) and uploads this information onto a blockchain (Dindarian & Chakravarthy, 2019). - Creates a unique digital identity for a physical asset on the blockchain as the first step in product authentication (Rusinek, Zhang & Radziwill, 2018).
Brand owner (*Customer*)	- Ensures that circular products with their brand name comply with regulations and standards by validating the information provided by the manufacturer (Shou & Domenech, 2022). - Promotes and markets circular products by using blockchain data (Shou & Domenech, 2022).
Waste management company (*Core actor*)	- Enables closing the loop in manufacturing by waste collection to extend the life of materials and registering this on blockchain (Ajwani-Ramchandani et al., 2021; Hristova, 2022). - Uploads information on the status of waste segregation activities, including recyclable, renewable, reusable, and non-reusable waste (Mastos et al., 2021).
Auditor/NGO (*Core actor*)	- Validates product circularity claims (Ajwani-Ramchandani et al., 2021).
Consumer (*Enriching actor*)	- Buys and uses circular products (Rusinek, Zhang & Radziwill, 2018) typically by only accessing the blockchain information so that sustainable purchasing behavior is encouraged
Blockchain provider (*Focal organization*)	- Develops the blockchain application (Centobelli et al., 2021; Rusinek, Zhang & Radziwill, 2018). - Grants access to new nodes (i.e., the user of blockchain) joining the blockchain (Centobelli et al., 2021; Rusinek, Zhang & Radziwill, 2018).
Governmental body(*Enriching actor*)	- Provides incentives for circularity and blockchain (Ajwani-Ramchandani et al., 2021).

The business model element ***actor benefits and costs*** specify the benefits to be accrued by each actor through participating in the value chain as an actor in the networked business model, and the costs to be incurred to participate in the business model, considering both the financial and non-financial aspects (Turetken & Grefen, 2017). Since we identified traceability and transparency as core network value propositions in CBMs implementing blockchain, we analyzed the selected articles to identify benefits and costs related to them. 23 studies identify costs and benefits, which are relevant for different groups of network actors, as we present in Table 3. The decentralized ledger as a benefit is studied most prominently, which is relevant when the value proposition is focused on either traceability or transparency on the value chain. We distinguished 21 separate benefits identified in 27 of the articles. On the other side, six separate costs to be incurred by network actors are distinguished in six studies.

Table 3: List of benefits and costs related to traceability (TRC) and transparency (TRP) network value propositions

		Applicable Network Actor(s)								**Relevant value type**			
#	**Benefits/Costs**	**Recycler**	**(intermediate) manufacturer**	**Brand owner**	**Waste mng. company**	**Auditor/ NGO**	**Consumer**	**Blockchain provider**	**Governmental body**	**TRC**	**TRP**	**# of articles**	
BENEFITS													
1	Decentralized ledger	X	X	X	X	X	X		X	X	X	9	
2	Reliable data	X	X	X	X	X	X		X		X	8	
3	Sustainability awareness						X				X	8	
4	Accelerated auditing procedure					X				X		7	

5	Reduced administration cost	X	X	X	X	X	X		X	X		6	
6	Information availability	X	X	X	X	X	X		X		X	6	
7	Waste value				X						X	5	
8	Accurate documentation	X	X	X	X	X	X		X	X		4	
9	Information disclosure	X	X	X	X						X	4	
10	Tamperproof ledger	X	X	X	X	X	X		X	X	X	3	
11	Increased trust	X	X	X	X	X	X		X	X	X	3	
12	Reduced manual work	X	X	X	X					X		3	
13	Unique value proposition			X						X		3	

14	Regulatory compliance	X	X	X	X					X		3	
15	Reduced information asymmetry	X	X	X	X	X	X		X		X	3	
16	Brand loyalty			X							X	3	
17	Regulatory efficiency								X		X	3	
18	Accurate waste handling & segregation				X						X	2	
19	Waste management figures					X			X		X	2	
20	Material quality compliance	X	X								X	1	

21	Supplier visibility			X							X	1	
COSTS													
1	Implementation cost	X	X	X	X					X	X	2	
2	Training costs	X	X		X					X		1	
3	Shared confidential information		X	X						X		1	
4	Maintenance cost	X	X	X	X	X	X	X	X	X	X	1	
5	Operation cost	X	X	X	X					X		1	
6	Eliminated power	X	X	X	X						X	1	

Discussion and Conclusion

The objective of this study is to investigate the contribution of blockchain to CBMs in the manufacturing industry. To achieve this objective, we performed a systematic literature review that identified 30 articles that provide blockchain applications and use cases related to CBMs. We analyzed and classified these studies based on research characteristics and elements of networked business models. Through our results, we contribute to the theoretical understanding of how blockchain can be used for the design of CBMs to achieve various value propositions. More specifically, our classification of the selected articles based on business model elements sheds light on diverse network value propositions achieved through blockchain, involved network actors, actor coproduction activities, benefits obtained, and costs accrued by those network actors. We distinguish 17 different network value propositions and determine that traceability and transparency are the core value proposition types for CBMs implementing blockchain in the manufacturing industry. We found nine different network actors identified by the studies, while the roles of these actors in the value chain were hardly specified. The list of actor coproduction activities provides a catalog of services that diverse network actors offer to contribute to the network value proposition. Lastly, we observe that while benefits are heavily studied, costs to be accrued by the actors to achieve the value proposition are hardly examined. Overall, network value propositions and benefits we identified align with the common barriers to circular economy. For example, various benefits related to the transparency value proposition, such as reliable data, information availability, increased trust, and reduced information asymmetry are found to be applicable for almost all network actors. These can address the barrier of the lack of trust among partners. Similarly, benefits such as sustainability awareness and information availability identified for the consumer indicates that blockchain can be used to overcome the barrier of low consumer comprehension of sustainability practices. Nevertheless, future research can investigate the circular economy barriers and the use of blockchain to address them in a more structured way. Furthermore, in our study, we identified the understudied points in the literature about business model elements that should be examined more to develop a better understanding of blockchain use for CBMs. To improve this understanding, the literature can be analyzed further, for example, by classifying the studies for blockchain-specific (e.g., blockchain type) and circular economy-specific (e.g., circular economy principles of reduce, reuse, recycle, recover) aspects.

A networked business model is defined by designing business model elements for actors (Turetken et al., 2019). Since our classification results provide an enumeration of possible values of these elements in a blockchain-based CBM, manufacturing organizations can use the results as input while designing their CBMs using blockchain. In our future work to better guide organizations in this endeavor, we aim to develop reference blockchain CBM blueprints, which combine relevant elements to achieve identified networked value propositions. Organizations can choose a blueprint based on the value proposition they want to achieve, then use it as a guideline to design their own business model. We plan to evaluate the effectiveness and utility of these blueprints in CBM design by applying them in companies. Furthermore, blockchain use for CBMs should be analyzed and classifications should be developed for other industries that need circularity solutions.

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