Dress code: the digital transformation of the circular fashion supply chain

Hilde Heim [a,b] and Caitlan Hopper [a]

[a]School of Design, Queensland University of Technology, Brisbane, Australia; [b]Manchester Fashion Institute, Manchester Metropolitan University, Manchester, UK

ABSTRACT

The overproduction and overconsumption of textile products has led to a call for systems and behavioural change towards a circular economy. Correct material flows through a circular system are difficult to achieve, but emerging technology may provide some answers. Among these technologies, blockchain, smart tags and non-fungible tokens (NFTs) are showing promising solutions. However, adopting technology gives rise to certain challenges. Observing the global trend in digital transformation, this paper investigates the adoption of blockchain and its associated technologies. Through interviews with designers and technology providers, it identifies the challenges specific to the small and medium enterprise sector. It finds a number of areas that require focus – some outside and some within the control of the business owner. These include the need for more effective communication channels between the information systems (IS) sector and fashion industry stakeholders if the digital transformation of the circular economy is to be effective.

ARTICLE HISTORY

Received 26 March 2021
Accepted 25 November 2021

KEYWORDS

Blockchain; small and medium enterprise (SME); circular economy; fashion supply chain; common data ontology; digital transformation

1. Introduction

In 2017, the independent fashion designer Martine Jarlgaard presented a blockchain application developed by the tech firm Provenance at the Copenhagen Fashion Summit (Arthur, 2018). Jarlgaard presented a romantic vision of alpacas grazing in southern England, their wool shorn and spun into garments for market and, through the magic of blockchain, their entire supply chain story, or so it appeared, was revealed. What was compelling about this presentation was that for the first time it looked like the entire supply chain could be verifiably tracked, traced and truly transparent. Admittedly other forms of traceability and methods for confirming good practice are already in place, for example certification schemes, standards guidelines and third party reports (Nimbalker, Cremen, & Wrinkle, 2013). However, the Jarlgaard/Provenance blockchain enabled solution suggested many more benefits, the most important of which is the immutable truth of the sustainability claims (Torelli, Balluchi, & Lazzini, 2019). Given the interest and hype surrounding blockchain in facilitating the circular economy for fashion since the Copenhagen presentation, this study firstly investigates the conditions under which these technologies are already deployed in the fashion industry. It then looks at the challenges encountered particularly by low-tech small-scale players who wish to adopt technology, and in particular their knowledge requirements. The study suggests strategies for future users of smart tagging, distributed ledger, and associated technologies.

2. Background

2.1. The circular economy for fashion

Traditional business models for production in the fashion industry involving taking resources, making products, and discarding them are being replaced by circular economy models. The circular economy for fashion means material is channelled away from waste disposal and kept in circulation for longer (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Parajuly, Fitzpatrick, Muldoon, & Kuehr, 2020). The circulation can take place through either closed or open loops (Kortmann & Piller, 2016; Payne, 2015; Rajala, Hakanen, Mattila, Seppälä, & Westerlund, 2018), each of which can be difficult to manage effectively. Directing the circular flow of materials through the global supply chain also requires consideration of the product lifecycle. Better product lifecycle management (PLM) has already led to innovative strategies and/or redeveloped business models (Lewis, Park, Netravali, & Trejo, 2017; Rejeb & Rejeb, 2020). These include reselling items, renting, peer-to-peer sharing, take-back and trade-in schemes. At the end of life, the circular economy model aims to decommission items in a way that will benefit business,

CONTACT Hilde Heim h.heim@mmu.ac.uk

society, and the environment by deconstructing and reclaiming components – managing them in a way that regenerates rather than contaminates ecosystems. If clothing is no longer wearable it may be directed to textile resource recovery plants for fibre separation and regeneration into new textiles – or recycling into other material such as building supplies (Heim, 2021). These various levels of recycling processes are now better served through the deployment of several technologies such as digital tagging for textile sorting (Agrawal, Sharma, & Kumar, 2018; Kumar, Koehl, Zeng, & Ekwall, 2017; Sandvik & Stubbs, 2019). Digital tagging and tracking applications provide both upstream data on the supply chain as well as information to recyclers at the end of life (Morlet et al., 2017). Tracking devices include radio frequency identifiers (RFIDs), quick response (QR) codes, beacon technology, near frequency codes (NFCs), microchips and other Internet of Things (IOT) devices as well as Artificial Intelligence (AI). For example, at the beginning of the supply chain raw fibres can be tagged through DNA tracing or nanotechnology – in which the fibres are embedded with tracking capability (Fibretrace, 2019). Fibres can be tracked to the mill and then to garment manufacture, distribution, sales, and reselling. Notably, tracing capabilities can be lost during the multiple processes undertaken along the supply chain – which blockchain enabled technologies could capture and mitigate if correctly implemented. Using readily available tracking technologies such as these is a means by which even small-scale brands and novices can already implement the technologies that in the future may be linked to blockchain. To be clear, tagging and tracking methods should not be confused with blockchain. These technologies simply provide automated access to data that can be added either to a local database – or eventually to a blockchain. The additional layer of blockchain provides data validation and security. But many fashion industry stakeholders still feel limited in their access to such tools (Hur & Cassidy, 2019). This study aims to dispel the confusion and explore the tagging options that may already be openly available, as well as how to prepare for their integration with blockchain solutions when the technology is sufficiently developed.

2.2. Why blockchain?

A blockchain is a shared network that uses mathematically generated rules to prevent the altering of records (digital.nsw, 2019). Also known as distributed ledger technology (DLT) – a blockchain sits on a network of computer servers (nodes) which can share information about transactions, identifiers, regulations, and any other data needing verification. The networks can be public or private, permissioned, or non-permissioned and or a combination of these. The information on the blocks can be in the form of financial spreadsheets, databases, images, or design documents. Each transaction or block is transmitted to all of the participants in the network and must be verified on each node or computer hosting the blockchain. Blocks typically record a resource, event, or agent – known as REA accounting (Ibañez, Bayer, Tasca, & Xu, 2020). It provides an irreversible, secure, and time stamped record where digital data is continuously authenticated. There are several complex components to the deployment of this backend architecture, even at the admission of information systems specialists (Morales, 2020). For example, this process can involve thousands of computers (a background process also requiring assessment), as it is not expected to be stored in a single cloud-based server or organisation. The technology has also generated a cluster of topic-specific terms and competencies, somewhat alien to the lay person. This has led to a degree of technostress (Pflügner, Maier, Mattke, & Weitzel, 2021) among small scale brands and individual designers. The skills and knowledge required for future users is also unclear. This study dissects smart tagging and blockchain mechanisms and brings comprehensible strategies for adoption to the field for non-technical users.

Within the fashion system, blockchain technology can connect all stakeholders in the textiles supply chain and can be applied to securely verify product and supply information (e.g. about farmers, raw material suppliers, brands, manufacturers, transporters, distributors, retail outlets, financers, consumers etc.). The technology's capabilities include providing records of provenance, information on fibre DNA, farm soil health, production methods, carbon emissions, the registering and clearing of intellectual property (IP) rights, controlling and tracking evidence of use, the legitimate use of trademarks and licences, the dispersing of commissions, identifying exclusive distribution networks, transmitting payments, brand authentication and other pertinent supply chain information (Burstall & Clark, 2017). This means for example that a stakeholder can broadcast a verified transaction, for instance, that a bale of wool has crossed a border or that a garment has been manufactured ethically in a specific location, and others can ascertain this occurrence. Despite the potential to capture trustworthy data on sustainability indicators, blockchain adoption has met with numerous challenges.

2.3. Blockchain adoption, theory, and practice

The current academic literature on blockchain adoption mainly originates from enterprise management, geographical economics and/or information systems perspectives (Yaga, Mell, Roby, & Scarfone, 2019). Beyond the studies explaining the variations of application and sectors of blockchain from FinTech to food chains, most blockchain-for-the-supply-chain studies focus on provenance, citing transparency, trust and traceability as the main advantages of the technology for the fashion/textile supply chain sector (Patel, Thomas, & Pore, 2018; Thind & Jackson, 2020). Beyond transparency, Warren, Treat, and Herzig (2019) discuss the economic advantages and other forms of new value creation including cross sector communication. The economic advantages include savings in time and efficiencies through reducing repetitive administration. Some scholars herald blockchain technology as the New Internet (O'Dair, 2019; Tapscott & Tapscott, 2016). Certain studies point out the difficulty in understanding and adoption and are calling for ease of transfer and open access (Fitzgerald, 2006; Openlink, 2018; Von Hippel, 2005). Others question the usefulness of the application and doubt the return on investment (Lay, 2018; Ley & Martínez-Pardo, 2020; Remington, 2020). All suggest the technology is still maturing and has not yet reached its full potential (Bullón Pérez, Queiruga-Dios, Gayoso Martínez, & Martín del Rey, 2020; Gartner, 2019). Nonetheless, its advantages for more efficient and verifiable supply chain flows and strong advantages for sustainable practice are compelling, hence the motivation for this study. Outside some research into blockchain's use in textile supply chains and into sustainability by Kouhizadeh and Sarkis (2018), Kouhizadeh, Saberi, and Sarkis (2021) and Caldarelli, Zardini, and Rossignoli (2021) research into the fashion sector is scant beyond verifying origin and authenticity of luxury goods in large scale and well-resourced fashion conglomerates. Building on the requirements approach proposed by Rusinek, Zhang, and Radziwill (2018), this study not only investigates blockchain's potential for facilitating sustainable practice in fashion through its capability of verifying textile product tracing from raw fibre, through manufacture to distribution, use and recycling, but also looks at the common data ontology that might be required in the first place. This level of transparency would represent significant systems change to the dominant fashion industry mechanism of relying on trade secrets and hidden (sometimes unethical) markets for competitive advantage. This also implies a change of roles in the fashion workforce of the future (Pham, Adamopoulos, & Tait, 2019).

Theoretical views on the adoption and implementation of new technologies in the supply chain have been formulated from a number of perspectives. Treiblmaier (2019) proposes Diffusion of Innovations and Technology Adoption theory for the antecedents or consequences of blockchain adoption. Treiblmaier (2019) also suggests Transactional Cost Economics, Principal Agent Theory and Adaptive Structural Theory can be applied to studies on how to structure the new supply chain; and that Resourced Based View and Network Theory can be used to view the management strategies of new supply chains. These theories deserve further research in the context of blockchain for the fashion supply chain. However, the focus of this paper is limited to the initiation of technology adoption for the supply chain and views this through the Diffusion of Innovations and Technology Adoption theories. The Diffusion of Innovations (DoI) theory expounded by Rogers (2002, 2010) offers understanding of the digital transformation that firms might experience when considering new technology for adoption. Notably, new technologies have not always been readily embraced, regardless of their publicised benefits (Rogers, 2002). The more complex the technologies, the greater the apprehension among users. Nonetheless, fashion brands are experiencing pressure to adopt technology even though they may be wary of the consequences of ill-informed implementation (Bevilacqua & Adragna, 2019; O'Dair, 2019). Few studies on blockchain address the knowledge needs of Technology Adoption (TA) (Demirkan et al., 2008). Furthermore, Technology Adoption theory is rarely combined with fashion studies approaches (Jenss, 2016; Skov & Melchior, 2010) meaning effective knowledge transfer can be lost. Circling back to Rusinek et al.'s (2018) work, this study argues that fashion industry stakeholders that are new to the technology, underinformed and perhaps apprehensive of digital transformation need guidance for technology adoption – and adds that gaining competitor buy-in is an additional challenge. Usefully, operations and information scientists Nayak and Dhaigude (2019) offer a conceptual model of sustainable supply chain management in small and medium enterprises using blockchain technology, based on the Interpretive Structural Model (ISM). This model is generalised for all enterprises – not exclusively for the fashion supply chain. By applying the ISM model's hierarchy of considerations (Nayak & Dhaigude, 2019) this study critically analyses the conditions required for blockchain adoption – including knowledge requirements. The guidance offered in this study uniquely conflates blockchain requirements with fashion supply chain operations knowledge.

2.4. Existing pilot studies

As the capabilities of blockchain specifically for the supply chain is an emerging phenomenon (since around 2017[1]), this study now also examines the grey literature found in reports, white papers, media releases, webinars, feasibility studies and similar publications. The grey literature reveals that few use cases of blockchain supporting circular economies exist within the fashion industry. Those that do are found within the large-scale enterprise and rely on associated technologies. For example, selected sustainable fibres and fabrics from the Lenzig Group can be tracked throughout the production process with Fibrecoin – a digital fingerprint software developed by the Hong Kong based Textile Genesis technology platform (Textilegenesis.com, 2020). The blockchain platform VeChain has collaborated with fashion brands H&M, Babyghost, and Reebonz to develop digital tags that use tracing technology to help customers verify manufacturing information, authenticity, and encourage recycling (Gates, 2019). Online e-retail giant Zalando, in collaboration with circularfashion.com launched their circularity. ID pilot in 2021 whereby customers can enter the garment's ID and gain transparency on sustainable manufacture. The Alexander McQueen subsidiary, MYAMQ established in 2020 tracks garment resales. VeChain has developed a non-fungible token (NFT), which can also connect to the digital twin of an asset, object or product and incentivises circularity by attributing value to a product. NFTs are not legal tender but their value is agreed upon by participating stakeholders and this value can move through the supply chain.

Investment by tech firms in the technology, and proof-of-concept collaborations were the main themes emerging from the grey literature. Furthermore, these innovative or re-invented business models share a number of attributes: they are financed by large-scale, well-resourced firms, are motivated by being 'first-in-market' or early adopters and rely on collaboration across industries. The collaborations usually occur in a triangular configuration of (1). Technology consultant/provider, (2). Large fashion/luxury goods conglomerate, and 3. Sustainability organisation. The pilot studies found in the grey literature are executed on privately customised blockchains, meaning that other stakeholders on the supply chain may not have access to their information-sharing capabilities.

Few recommendations for stakeholders who wish to implement the technology to facilitate circularity in the fashion supply chain were discovered in the literature. More crucially, there are few guidelines to adequately prepare the workforce of the future with the skills needed for digital transformation (Sun & Zhao, 2018). Scholars agree that, considering its complexity and multifaceted applications, blockchain deserves more research – and, empirical research (Agrawal et al., 2018; Bai & Sarkis, 2020; Kouhizadeh et al., 2021; Kouhizadeh & Sarkis, 2018). This study aims to build on the current literature on blockchain adoption in the fashion sector by focussing on early-stage adoption challenges particularly in the small-scale sector and how these may be overcome to maximise the opportunity of the technology to further circularity goals in the future.

3. Methodology

Given the intersection of Fashion Studies, the Circular Economy, the theories of Diffusion of Innovations and Technology Adoption steering this research, a qualitative approach was considered methodologically fit for this study (Creswell, Hanson, Clark Plano, & Morales, 2007; Roulston, 2010). Despite, some scholars presenting the potential for blockchain technology through pilot case studies, few have engaged with the technology directly and few empirical investigations of individual users have been undertaken. Therefore, participant-centred open-ended interviews were conducted with individuals working either in the fashion industry and/or information systems industries. The interviews were initiated with small to medium circular fashion entrepreneurs and blockchain technology solutions providers, to identify the barriers and ascertain the challenges of blockchain technologies for the fashion supply chain. Additionally, the authors of this study participated in a bespoke pilot study for this research to fully understand the blockchain mechanism and thereby better analyse and interpret results.

The research was conducted in two phases to provide triangulation of data sources, validity, and relevant reliability. Firstly, a contextual review was undertaken into both academic and grey literature (Race, 2008) – investigating existing use cases of blockchain in the fashion industry. The current use cases (all in large-scale firms) informed the structure of the participant interviews. Second, twelve interviews were conducted in late 2019 and early 2020. The interviewees were chosen from two industry groups (Fashion or Information Systems) and individuals were selected based on their expertise and/or professional roles. The first group was chosen from a pool of local Australian small to medium fashion enterprises that implement technology (or intend to) for their circular economy business objectives. The second group was chosen from a selection of technology providers (both national and international) that offer blockchain solutions. Information on

participants is outlined in Table 1 below. Participants are identified by position and number for anonymity.

Interviewees were asked in 45-minute recorded video link interviews, a range of questions around their core philosophies on circular fashion practice. Questions probed their use and investment in technology; approaches to value creation for the firm, the customer, and circularity; and their recommendations for other small-scale firms who wish to implement technology to facilitate circularity in the fashion supply chain. The research questions sought to discover: (1) How fashion industry and information system professionals perceive the effectiveness of blockchain and related digital technologies in the circular economy, including challenges. (2) How the future roles for stakeholders in the circular supply chain are changing, including opportunities provided by new technologies. (3) Their understanding of new skills and knowledge required for digital transformation in the circular supply chain. and constant comparative analysis. The interview data was interpreted using emergent theme coding after the recording was transcribed. In this way, core themes were identified based on emerging response patterns and led to inductively arriving at grounded theory analysis (Corbin & Strauss, 2014; Creswell et al., 2007; Thomas, 2006). Theme codes were reviewed with participants after the interview and cross-checked with the researchers' own experience with the technology to ensure data validity and dependability. Themes arose across technical, social, and entrepreneurial opportunities, challenges and skills and knowledge requirements.

Table 1. Participant list.

Interviewee position and code	Industry	Business Details and Industry experience
Group 1	**Fashion**	
Proprietor 1	Fashion	Circular fashion micro label, niche market established 5+ years.
Founder 1	Fashion	Local (Australian) manufacturing premium (certified ethical) denim, established 30+ years.
Proprietor 2	Fashion	Importer (certified) sustainable products, established 15+ years.
Founder 2	Fashion/ Technology	Tech service provider of digitised patternmaking and garment fit software.
Founder 3	Fashion/ Technology	Textile waste recovery start-up, certified B-Corp.
Proprietor 3	Agriculture/raw fibre producer	Cotton farm proprietor.
Group 2	**Information Systems (IS)**	
CEO 1	Blockchain Technology	Platform that authenticates Australian beef provenance, security, payments; records transactions and incentivises purchasing.
CEO 2	Blockchain Technology	Platform that provides open source blockchain applications.
Founder 4	Blockchain Technology	Platform that aggregates government and public resources such as citizen entitlements, registers, and natural assets.
Founder 5	Blockchain Technology	Blockchain start-up platform. Small-scale, Melbourne based.
Consultant 1	Blockchain Technology	International blockchain platform in FinTech.
Founder 6	Blockchain Technology/ Agriculture	Embeds nanotechnology particles into fibres for supply chain tracing. Also cotton farm proprietor.

4. Findings

The research revealed several challenges in the adoption of blockchain technology – some outside and some within the control of the fashion industry stakeholder. The stakeholders interviewed were aware of the technologies available because of media reports and were keen to adopt. The themes of technical, social, and entrepreneurial challenges and opportunities arising from the interview data is divided into requirements similar to those found by Rusinek et al. (2018) and compared to the 12 areas proposed by the Interpretive Structural Model (ISM) for validity and reliability in Table 2. These themes and their relation to the literature are expanded below.

4.1. Technical challenges

4.1.1 Access to software, digital literacy, common data ontology and interoperability

Technical requirements for the adoption of blockchain and related technologies relate to several of the ISM

Table 2. Themes, findings, and ISM comparative table.

Theme	Findings/requirements	Interpretive Structural Model
Technical	Access to software Digital Literacy	ICT, infrastructure planning, acceptance
	Common data ontology	External stakeholders
	Interoperability	ICT, infrastructure
Social	Data contribution	Cultural
	Global governance	Government support
	Competitor co-option	Competitor
	Communication, acceptance, and value of accurate data input	People, supplier acceptance
Entrepreneurial	Value perception	Cultural
	Return on investment	Financial
	Building on legacy systems	Management, execution
	Consumer demand	Customer acceptance

model categories, namely planning, infrastructure acceptance and buy-in from external stakeholders. In a report by Accenture, solutions architect Wei Yin Han suggests a combination of technology and human resources are required, that is:

> the technology to capture the data (wearable, IoT, human), the technology to store the data (blockchain/DLT/plain database), the technology to process the data (AI/ML, plain programming or even human brain), and the technology to make the data understandable and actionable by the human (applications, smart phone interfaces and web pages). (Han, 2020, p. 1)

However, blockchains need to interoperate (effectively connect with each other) for the system to work at ideal capacity. According to one (IS) respondent, the interoperability impasse partially led to the collapse of many blockchain start-ups at the end of 2017, after the generalised blockchain platform Ethereum was created. Blockchain technologies also need to interoperate with so-called legacy systems – for example product lifecycle management (PLM) systems, accounting software, inventory, and customer management systems. This implies that accurate input into currently available data bases should be more highly valued as this will help prepare data exchange for blockchain in the future. The tedium of accurate data entry will be a challenge (opening opportunities for automation) –and necessary for better supply chain transparency.

The complexity and number of stakeholders in the supply chain has led to fractured data records, meaning no common communication exists. Developing a common data ontology is an opportunity for brands and tech providers to collaborate – in a way not required to date. Creating a common language will be one of the biggest challenges facing the deployment of the software – particularly if an affordable, open-access platform is to be developed. This means that all supply chain stakeholders must agree on common terminology (e.g. quality measures for wool) and agree upon sets of data parameters for sustainability (e.g. carbon emissions, ethical labour practices, chemical use etc). Interestingly, in 2021, four years after bringing blockchain to the attention of the fashion industry at the Copenhagen Fashion Summit, Provenance has developed a sustainability framework that lists parameters and invites firms to upload their sustainability information (Provenance, 2021). This is not an open-source service and there are no indicators that the information is connected to blockchain, but it does take a decisive step towards commonly shared language and information contribution. Relatedly, some organisations are already creating universally accessible and free-to-use databases for the fashion industry including Source Map and Open Apparel Registry, whereby fashion firms are encouraged to contribute their data. However, while well-meaning initiatives are cropping up in the industry, the emergence of multiple platforms may be heading once again for a fractured data storage situation – albeit more detailed, transparent, and globally shared.

4.2. Social outlooks

4.2.1 Data contribution, global governance, competitor co-option and data value

According to the software specialists interviewed, blockchain implementation requires a collaboration mindset. This seems feasible in the light of emerging sharing economy values – but fashion industry stakeholders remain reticent. For example, developers are finding that blockchain is not always wanted in its 'purest' form by large scale firms (Allen, 2020; Ohlsson, 2020). The ideal arrangement is that every transaction is included and visible on-chain. Asia Pacific Rayon (APR) has a blockchain tracking system developed by Singapore based tech company Perlin. Bales of cellulose produced from sustainable plantations in Indonesia and elsewhere are marked and tagged with beacon technology. The records are publicly accessible, clear and comprehensive on the APR 'follow your fibre' website (APR, 2020). Information on tree provenance is thorough but information on labour practices less so. Firms can elect to omit pieces of information that may be misconstrued or harmful. This is their decision – but is not in the spirit of 'full' blockchain disclosure. This 'manipulation' of the technology is one of several challenges regarding trust in the utilisation of the technology.

The investigation found that social opportunities include the global governance of emerging technologies. As the regulations around the deployment of the technology are still in development, many fashion firms are not yet willing to rely on its capabilities. Furthermore, as blockchains are indexes of standardised information that can be shared with organisations outside the firm – including customers and competitors, few participants seemed convinced that their data would be secure and anonymised – and still provide useful intelligence. This supports the need for governance around the systems. Laws pertaining to blockchain regulations that are currently in development (DISER, 2018), demonstrating another still maturing aspect of the technology.

A related concern in adopting blockchain voiced by the participants is how to get all suppliers up and downstream on board, which is a significant requirement for achieving transparency. A single brand attempting to

obtain company information may be viewed as a competitor. This creates the supplier paradox known as the competition/co-operation (or co-option) clash (Schmidt, Foerstl, & Schaltenbrand, 2017; Wilhelm & Sydow, 2018). As inter-firm relationships are often tenuous and fiercely guarded, this emerges as another challenge to blockchain adoption. Supply chain relationships, although ostensibly transactional, are often precariously balanced. An unexpected response to the supplier co-option paradox was provided by two respondents in this study. Two medium-sized firms, an organic cotton grower (Founder 6) and a local, sustainable jeans manufacturer (Founder 1), collaborated on creating a 'beginner' blockchain with their main suppliers – including offshore textile mills. Their motivation had less to do with circularity objectives – and more to do with the common desire to innovate. Each was willing to absorb costs, share time and expertise to implement the innovation. One of the partners (Founder 6) also owns the technology firm which provided the software solution. The platform was launched in November 2020 and as yet has not shown tangible economic results such as increase in sales for the garment manufacturer. Still, the initiators are delighted with their achievement, seeing themselves as pioneers in the space – believing the innovation to enhance their marketing efforts, reinforce sustainability credentials and strengthen business profiles. The initiative has resulted in adoption of the technology by other fashion firms providing initial evidence that competitors adopt technology if the competitive advantage outweighs disclosure.

The implementation of an affordable, permissionless blockchain offering – although democratising – would represent a significant shift in the functioning of the fashion system, which previously has relied on secrecy for competitive advantage (Swan, 2015). The fashion industry's complexity further complicates the adoption of blockchain. Not only is the supply chain lengthy, but it also has several interconnections and subbranches that enable the assembly of a garment – and in a circular economy – its disassembly. Although plug-and-play applications do not yet exist, adoption will require a degree of preparation on the part of the brand. One sustainable fashion brand participating in this study, with a fundamental circular economy approach (Proprietor 1), offers an exemplary, if unintentional, preparation in gathering and publishing data in detail about the provenance of the supplies for each of their garments:

> We do have a QR code, we put that on every label – the story of how our garment was made - you can look up where the fibre was grown, and you can see all that information on the [web]site even if the garment sells right down the track, second hand. It's very manual and nothing like fancy or fool proof and you know there's a lot of room for error … (Proprietor 1)

Like the information required for e-commerce applications such as Shopify, documenting detailed information on each garment will be the requirement for all firms that wish to show transparency on-chain in the future. Although an arduous exercise, the storage of inventory management and supply chain information is recommended in preparation for future adoption.

4.3. Entrepreneurial opportunities

4.3.1 Value perception, ROI, legacy systems, and consumer demand

Entrepreneurial opportunities include value perception, and tangible or perceived return on investment (ROI) relates to the ISM cultural, financial managerial, and customer acceptance model. The interviews revealed a disparity in the understanding of the capabilities of the technology – with some founders already very well informed and planning on implementing capabilities beyond tracking and tracing. These capabilities include smart contracts (that automatically trigger transactions when certain conditions are met – for example duty paid at border crossings) – or the use of tokens (NFTs) – in which an agreed upon value is created between parties – independent of third parties such as banks. One of the participating recycling firms has the tokenisation of circularity firmly in mind for their business plan. The founder recounts:

> I've always believed that we would have our own currency and that would be driven by tokenisation … So, if I'm working directly with the brand and they have a mill in Asia well then, we work in a blockchain [branded] token that has an agreed value and that way we can also cap the fluctuation within the marketplace. (Founder 5)

Tokens are also ideal for the implementation of incentives and rewards. By adding an agreed value to a garment, it can be traded and shared as it moves through the circular economy. NFTs have formed a fundamental blockchain mechanism since its inception – but have enjoyed more attention recently – particularly in relation to digital visual assets such as virtual designs. Again, the understanding of the technology is limited and often misrepresented by the hype (Gartner, 2019), which points to the need for better digital literacy among users.

The value created by adopting blockchain technologies is still somewhat elusive. One of the technology

providers interviewed (CEO 1) suggested that value will be realised when competitors in the market offer the technology as a 'value add' to their product to gain market dominance. For example, the Circularity. ID offered by Zalando drives customer engagement – while benefitting the circular economy, it ensures a new competitive advantage for the firm. Beyond marketing strategies, the key advantage of the technology is its workflow efficiency in merging multiple data information sources. Tellingly, Cao et al. (2020) and Foth, Mitchell, Mann, Rittenbruch, and Anastasiu (2019) point to the value derived from information itself and the value the firm and the customer places on the indisputable proof of a claim. This may seem to stray from 'circular economy practice' but does hint at the shift in value creation and the direction business models may take in the future, that is, understanding the value of their data, its accuracy, and its potential contribution to the circular economy at large.

Blockchain's economic value lies in saving, rather than making money. In the use case of the Everledger and Louis Vuitton collaboration (Consensys, 2019), savings are realised in avoiding counterfeit sales and mitigating market share loss – rather than facilitating circular objectives that favour a sharing economy position. Facilitating the circular flow of materials is an additional benefit rather than a key driver because its economic value to the firm (particularly the small-scale firm) is currently negligible in relation to the ROI (Earley, Goldsworthy, Vuletich, Politowicz, & Ribul, 2016).

Another participating brand (Proprietor 3) has subscribed to a slew of certification agencies to strengthen their circular fashion claims. However, the owner laments no significant advantage or recognition of their efforts. The firm is interested in adopting blockchain technology but is sceptical of its benefits.

> I see blockchain as helping us with the weight of the accreditations … if blockchain can actually help us, you know, not rely on those certifications, and actually proved our social impact and minimising our environmental impact we would be interested. (Proprietor 3)

Evidence found on technology provider platforms and offered by software licensees demonstrate that the costs incurred in time and money can be significant for a firm (Consensys, 2019; Saxena & Srivastava, 2019; Warren et al., 2019). Initial costs may involve hiring a blockchain provider to create a unique digital ID. The price increases each time the firm generates another block and escalates depending on the complexity and amount of data uploaded. Costs can range from $25 K for a consultation to over $1M per solution (Saxena & Srivastava, 2019). Considerable understanding of technology is required to deploy the software – and does not lie within the capabilities of the small fashion firm (Volpicelli, 2018). The costs are justified considering the hours involved, however, the brand may query the ROI. Nonetheless, some media hype suggests that off-the-shelf solutions will make adoption more affordable (Gartner, 2019; Maguire, 2019). For example, the barrier to entry was reported as relatively low for high end brand Alyx. The brand produces 80 per cent of its output in Italy in collaboration with suppliers who are proponents of transparency. Alyx swing tags feature a scannable QR code that showcases the entire supply chain history of the garment from raw fibre through to shipping. Tech firm Evrythng stores and uploads the data and labelling company Avery Dennison makes tags with digital identities for each garment. The Alyx pilot took over six months to execute. Although some services claim to be open access, they still incur considerable costs, expertise and time (Maguire, 2019).

5. Discussion/Implications

Evidence that blockchain can facilitate the circular economy in fashion was not indubitably produced in this study. The study also found that expectations of blockchain and related smart tagging technologies do not align with its current capabilities. This has to do with the still evolving development of the software. As a result, there is currently neither an affordable nor universal open access platform available to connect to, nor is there understanding on the part of the brand on what to do if connected. This means that the universally digitally connected fashion supply chain is yet to materialise. However, the study did point to the need for more accurate and detailed data input and sharing among competitors, which would represent significant systems change in the fashion industry. It also finds that effective, two-way communication between technology providers and end users as well as digital literacy are gaining significance.

5.1. Implications for practice

The novelty of this study lies in the practical steps that small-scale firms, individuals, and novices can take now in preparation for blockchain adoption. Crucially, taking these steps, that is, documenting, valuing, and sharing detailed, accurate data will in themselves advance the circular supply chain. Blockchain will provide a bonus level of validated and secured data. The

implication for practice is that innovations are required around trans-disciplinary communication – as fashion entrepreneurs and technology providers do not easily understand each other's requirements. Some legacy enterprise software and platforms already exist and are well placed for adoption such as enterprise management systems (EMS) customer reference management (CRM) accounting systems such as MYOB and Xero and product lifecycle management (PLM) systems. They require fastidious data input far removed from the glamourous world of fashion, which itself may cause concern. But more targeted work is required within the firm regarding record keeping (Wang & Ha-Brookshire, 2018). Initially, communication may be based on simple common ground for example where the brand may already have some familiarity with applications, such as working with e-commerce platforms or integrating garment smart tags. Beyond developing more effective communication channels, conducting user experience research into pilot prototypes may be of use to firms. For example, testing open access applications would provide understanding of the capabilities, level of interest, competitive advantage, validation of circularity measures and willingness by small scale firms to adopt.

5.2. Implications for theory

There are five main factors that influence adoption of an innovation: Relative Advantage: the innovation is seen as better than the idea, programme, or product it replaces; Compatibility: consistency with the values, experiences, and needs of the potential adopters; Complexity: difficulty to understand and/or use; Trialability: ability to test or experiment before making a commitment to adopt; Observability: ability to provide tangible results (LaMorte, 2019). In the case of blockchain, none of these parameters are convincingly attained. However, this study's implication for theory suggest new parameters are emerging around technology adoption because of the rapid emergence of multiple, complex, and interconnecting technologies and the need for greater digital literacy (Abrahams, 2017; Kouhizadeh et al., 2021). The key issues are that knowledge and understanding of the capabilities of the technology need to be developed as does an understanding of the value it can create (Warren et al., 2019). Once understanding the value, the fashion industry stakeholder may embrace technology requirements more readily and be motivated to take action towards adoption. This might occur as brands observe adoption by their competitors in the marketplace – and fear loss of market share if they do not adopt (Cao et al., 2020). This also suggests that the motivations to adopt blockchain will be commercial rather than social (concern about achieving circularity goals) – another topic for further investigation. Fortunately, either way, the circular economy would benefit.

6. Conclusion

This study adds to the literature on blockchain adoption by fashion industry stakeholders, revealing an appetite for digital transformation and willingness to adopt if affordable and mature. It also adds to the literature by identifying several barriers to adoption – each of which also represent opportunities that may be investigated in the future as the technology continues to develop towards open access offerings. As blockchain is effectively a back-end solution, it requires the integration of additional technologies for full implementation. However, each additional technology represents further investment. The outlay hardly seems to warrant the outcome at the moment, and yet, the buzz around the technology appears to be increasing with evidence of more and more firms experimenting with the software (Lay, 2018). Significantly, more effective interdisciplinary communication is required as well as an increase in digital literacy on the part of the non-technical user. Blockchain and its associated technologies may significantly improve sustainable fashion practice in the future if understood and harnessed by the more agile small-scale business, thereby moving towards a more effective circular economy.

Note

1. Blockchain for cryptocurrency was developed around 2009 by Nakamoto. The mathematical theory behind the technology has existed since the 1990s, with cryptography developed since the 1970s.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the QUT Centre for a Waste Free World Institute for Future Environments (IFE) Strategic Support Grant.

ORCID

Hilde Heim http://orcid.org/0000-0002-2533-5953
Caitlan Hopper http://orcid.org/0000-0002-8692-2123

References

Abrahams, N. (2017). The reality of blockchain in Australia, lots of plans but waiting for big hit. *The Financial Review*. Retrieved from https://www.afr.com/technology/the-reality-of-blockchain-in-australia-lots-of-plans-but-waiting-for-the-big-hit-20170816-gxx6cs

Agrawal, T. K., Sharma, A., & Kumar, V. (2018). Blockchain-based secured traceability system for textile and clothing supply chain. In S. Thomassey & X. Zeng (Eds.), *Artificial intelligence for fashion industry in the big data era* (pp. 197–208). Singapore: Springer.

Allen, R. (2020). *Blockchain: Supplychain showcase*. Retrieved from https://www.youtube.com/watch?v=WNUU-O0DcR4

APR. (2020). *Follow our fibre*. Asia Pacific Rayon. Retrieved from https://www.followourfibre.com/

Arthur, R. (2018). Innovators. In *Martine Jarlgaard on how blockchain can redefine fashion*. Retrieved from https://podcasts.apple.com/us/podcast/martine-jarlgaard-on-how-blockchain-can-redefine-fashion/id1331242374?i=1000415548890

Bai, C., & Sarkis, J. (2020). A supply chain transparency and sustainability technology appraisal model for blockchain technology. *International Journal of Production Research*, *58*(7), 2142–2162. doi:10.1080/00207543.2019.1708989

Bevilacqua, G., & Adragna, M. C. (2019). *Blockchain technology for the fashion supply chain: Asn analysis of its potentialities in supporting traceability and sustainability*. Politechnic di Milano.

Bullón Pérez, J. J., Queiruga-Dios, A., Gayoso Martínez, V., & Martín del Rey, Á. (2020). Traceability of ready-to-wear clothing through blockchain technology. *Sustainability*, *12*(18), 7491.

Burstall, R., & Clark, B. (2017). Blockchain, IP and the Fashion Industry. *Managing Intellectual Property*. Retrieved from https://www.managingip.com/Article/3667444/Blockchain-IP-and-the-fashion-industry.html?ArticleId=3667444

Caldarelli, G., Zardini, A., & Rossignoli, C. (2021). Blockchain adoption in the fashion sustainable supply chain: Pragmatically addressing barriers. *Journal of Organizational Change Management*, *34*(2), 507–524. doi:10.1108/JOCM-09-2020-0299

Cao, S., Dulleck, U., Powell, W., Turner-Morris, C., Natanelov, V., & Foth, M. (2020). *Beefledger blockchain-credentialed beef exports to China: Early consumer insights*. Brisbane: Queensland University of Technology. Retrieved from https://eprints.qut.edu.au/200267/15/BeefLedger_Survey_Results_Report_V7.pdf

Consensys. (2019). *LVMH, ConsenSys, and Microsoft Announce Consortium for Luxury Industry Consensys*.

Corbin, J., & Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage publications.

Creswell, J. W., Hanson, W. E., Clark Plano, V. L., & Morales, A. (2007). Qualitative research designs: Selection and implementation. *The Counseling Psychologist*, *35*(2), 236–264.

Demirkan, H., Kauffman, R. J., Vayghan, J. A., Fill, H.-G., Karagiannis, D., & Maglio, P. P. (2008). Service-oriented technology and management: Perspectives on research and practice for the coming decade. *Electronic Commerce Research and Applications*, *7*(4), 356–376.

digital.nsw. (2019). *Emerging Technology Guide: Blockchain*. State of New South Wales. Retrieved from https://www.digital.nsw.gov.au/digital-transformation/policy-lab/emerging-technology-guide-blockchain

DISER. (2018). *Standards Australia leading the development of international standards for blockchain*. Canberra: Commonwealth of Australia.

Earley, R., Goldsworthy, K., Vuletich, C., Politowicz, K., & Ribul, M. (2016). *The textile toolbox: New design thinking, materials & processes for sustainable fashion textiles*.

Fibretrace. (2019). *Fibretrace*. Retrieved from https://www.fibretrace.io/

Fitzgerald, B. (2006). The transformation of open source software. *Mis Quarterly*, *30*, 587–598.

Foth, M., Mitchell, P., Mann, M., Rittenbruch, M., & Anastasiu, I. (2019). *Submission to the Australian Council of Learned Academies Internet of Things Report* 2020.

Gartner. (2019). Interpreting technology hype. *Gartner*. Retrieved from https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

Gates, K. L. (2019). Fashion & Food Industry Update: More companies adopting Blockchain Solutions. *Lexology*. Retrieved from https://www.lexology.com/library/detail.aspx?g=7e6e3bf7-f92b-421d-81f2-9b61f6db4c95

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The circular economy – a new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768.

Han, W. Y. (2020). *Technology is not the only answer*. Linked In https://www.linkedin.com/feed/update/

Heim, H. (2021). *Fashion Facade: textile waste innovations for the built environment*. (Ed.),^(Eds.). Design Cultures, Rome.

Hur, E., & Cassidy, T. (2019). Perceptions and attitudes towards sustainable fashion design: Challenges and opportunities for implementing sustainability in fashion. *International Journal of Fashion Design, Technology and Education*, *12*, 208–217.

Ibañez, J. I., Bayer, C. N., Tasca, P., & Xu, J. (2020). *REA, triple-entry accounting and blockchain: Converging paths to shared ledger systems*. Available at SSRN 3602207.

Jenss, H. (2016). *Fashion studies: Research methods, sites and practices*. Bloomsbury Academic, an Imprint of Bloomsbury Publishing, Plc. Retrieved from http://qut.summon.serialssolutions.com/2.0

Kortmann, S., & Piller, F. (2016). Open business models and closed-loop value chains: Redefining the firm-consumer relationship. *California Management Review*, *58*(3), 88–108.

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics*, *231*, 107831. doi:10.1016/j.ijpe.2020.107831

Kouhizadeh, M., & Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in greening supply chains. *Sustainability*, *10*(10), 3652.

Kumar, V., Koehl, L., Zeng, X., & Ekwall, D. (2017). Coded yarn based tag for tracking textile supply chain. *Journal of Manufacturing Systems*, *42*, 124–139.

LaMorte, W. (2019). *Diffusion of Innovation Theory*. Boston School of Public Health. Retrieved from http://sphweb.

bumc.bu.edu/otlt/MPH-Modules/SB/BehavioralChangeTheories/index.html

Lay, R. (2018). *Digital transformation – the ultimate challenge for the fashion industry*. Denver, CO: Deloitte Consulting. Retrieved from https://www2.deloitte.com/ch/en/pages/consumer-industrial-products/articles/ultimate-challenge-fashion-industry-digital-age.html

Lewis, T. L., Park, H., Netravali, A. N., & Trejo, H. X. (2017). Closing the loop: A scalable zero-waste model for apparel reuse and recycling. *International Journal of Fashion Design, Technology and Education*, *10*(3), 353–362.

Ley, K., & Martínez-Pardo, C. (2020). *6 ways to drive funding to transform the fashion industry*. Word Economic Forum. Retrieved from https://www.weforum.org/agenda/2020/01/funding-circular-fashion-industry/

Maguire, L. (2019). Matthew Williams is using blockchain to tell Alyx's story. *Vogue Business*. Retrieved from https://www.voguebusiness.com/technology/1017-alyx-9sm-blockchain-matthew-williams

Morales, G. (2020). Research interview. In H. Heim (Ed.).

Morlet, A., Opsomer, R., Herrmann, S., Balmond, L., Gillet, C., & Fuchs, L. (2017). A new textiles economy: redesigning fashion's future. *Ellen MacArthur Foundation*.

Nayak, G., & Dhaigude, A. S. (2019). A conceptual model of sustainable supply chain management in small and medium enterprises using blockchain technology. *Cogent Economics & Finance*, *7*(1), 1667184.

Nimbalker, G., Cremen, C., & Wrinkle, H. (2013). *The Australian fashion report: the truth behind the barcode*.

O'Dair, M. (2019). *Distributed creativity: How blockchain technology will transform the creative economy*. Cham: Palgrave Macmillan.

Ohlsson, B. (2020). *About Us*. Retrieved from https://www.geora.io/about/

Openlink. (2018). Blockchain food traceability can revolutionize the industry. *Openlink*. Retrieved from https://www.openlink.com/en/insights/articles/blockchain-food-traceability-can-revolutionize-the-industry/

Parajuly, K., Fitzpatrick, C., Muldoon, O., & Kuehr, R. (2020). Behavioral change for the circular economy: A review with focus on electronic waste management in the EU. *Resources, Conservation & Recycling: X*, *6*, 100035. doi:10.1016/j.rcrx.2020.100035

Patel, J., Thomas, S., & Pore, N. (2018). *A blockchain-based framework for apparel & footwear supply chain traceability*.

Payne, A. (2015). Open-and closed-loop recycling of textile and apparel products. In *Handbook of life cycle assessment (LCA) of textiles and clothing* (pp. 103–123). Cambridge, UK: Elsevier.

Pflügner, K., Maier, C., Mattke, J., & Weitzel, T. (2021). Personality profiles that put users at risk of perceiving technostress. *Business & Information Systems Engineering*, *63*(4), 389–402.

Pham, C., Adamopoulos, A., & Tait, E. (2019). *Towards a triple bottom line perspective of blockchains in supply chain*.

Provenance. (2021). *Sustainability framework*. Retrieved from https://www.provenance.org/framework

Race, R. (2008). Literature review. In L. Given (Ed.), *The Sage encyclopedia of qualitative research methods* (Vol. 1, pp. 487–489). Thousand Oaks, CA: Sage.

Rajala, R., Hakanen, E., Mattila, J., Seppälä, T., & Westerlund, M. (2018). How do intelligent goods shape closed-loop systems? *California Management Review*, *60*(3), 20–44. doi:10.1177/0008125618759685

Rejeb, A., & Rejeb, K. (2020). Blockchain and supply chain sustainability. *Logforum*, *16*(3), 363–372.

Remington, C. (2020). Report calls for sustainable tech investment. *Eco Textile News*. Retrieved from https://www.ecotextile.com/2020012125567/fashion-retail-news/investment-essential-to-scaling-sustainable-tech-report-says.html

Rogers, E. M. (2002). The nature of technology transfer. *Science Communication*, *23*(3), 323–341. doi:10.1177/107554700202300307

Rogers, E. M. (2010). *Diffusion of innovations*. New York: Simon and Schuster.

Roulston, K. (2010). Analyzing and representing interview data. In K. J. Roulston (Ed.), *Reflective interviewing: A guide to theory and practice* (149–175). Sage Publications Ltd.

Rusinek, M. J., Zhang, H., & Radziwill, N. (2018). Blockchain for a traceable, circular textile supply chain: A requirements approach. *Software Quality Professional*, *21*(1), 4–24. Retrieved from https://gateway.library.qut.edu.au/login?

Sandvik, I. M., & Stubbs, W. (2019). Circular fashion supply chain through textile-to-textile recycling. *Journal of Fashion Marketing and Management: An International Journal*, *23*, 366–381.

Saxena, P., & Srivastava, S. (2019). How to determine the blockchain app development cost. *Appinventiv*. Retrieved from https://appinventiv.com/guide/blockchain-app-development-cost/

Schmidt, C. G., Foerstl, K., & Schaltenbrand, B. (2017). The supply chain position paradox: Green practices and firm performance. *Journal of Supply Chain Management*, *53*(1), 3–25.

Skov, L., & Melchior, M. R. (2010). Research approaches to the study of dress and fashion (Vol. 10). *The Berg Fashion Library*. Retrieved from http://www.bergfashionlibrary.com/bewdf/BEWDF-v10/EDch10003.xml

Sun, L., & Zhao, L. (2018). Technology disruptions: Exploring the changing roles of designers, makers, and users in the fashion industry. *International Journal of Fashion Design, Technology and Education*, *11*, 362–374.

Swan, M. (2015). *Blockchain: Blueprint for a new economy*. Sebastopol, CA: O'Reilly Media, Inc.

Tapscott, D., & Tapscott, A. (2016). *Blockchain revolution: How the technology behind Bitcoin is changing money, business, and the world*. Penguin.

Textilegenesis.com. (2020). *Textile genesis*. Retrieved from https://textilegenesis.com/

Thind, R., & Jackson, T. (2020). *Undressing the supply chain: The case for blockchain in fashion* [*Fashion business cases*]. *Bloomsbury Fashion Central*. doi:10.5040/9781350996014.0029

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237–246.

Torelli, R., Balluchi, F., & Lazzini, A. (2019). *Greenwashing and environmental communication: Effects on stakeholders' perceptions*. Business Strategy and the Environment.

Treiblmaier, H. (2019). Combining blockchain technology and the physical internet to achieve triple bottom line sustainability: A comprehensive research agenda for

modern logistics and supply chain management. *Logistics*, *3* (1), 10.

Volpicelli, G. (2018). Does blockchain offer hype or hope? *The Guardian*. Retrieved from https://www.theguardian.com/technology/2018/mar/10/blockchain-music-imogen-heap-provenance-finance-voting-amir-taaki

Von Hippel, E. (2005). Open source software projects as user innovation networks. *Perspectives on free and open source software*.

Wang, B., & Ha-Brookshire, J. E. (2018). Exploration of digital competency requirements within the fashion supply chain with an anticipation of industry 4.0. *International Journal of Fashion Design, Technology and Education*, *11*(3), 333–342.

Warren, S., Treat, D., & Herzig, J. (2019). *See the full picture of the value of blockchain*. Retrieved from https://www.accenture.com/au-en/insights/blockchain/wef-building-value

Wilhelm, M., & Sydow, J. (2018). Managing coopetition in supplier networks–a paradox perspective. *Journal of Supply Chain Management*, *54*(3), 22–41.

Yaga, D., Mell, P., Roby, N., & Scarfone, K. (2019). Blockchain technology overview. *arXiv Preprint ArXiv*, *1906*, 11078.