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Blockchain and the Circular Economy: A Systematic Review of Traceability-Driven Sustainable Supply Chains

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Abstract

Blockchain is generally perceived as the technology that will enable circular supply chains because by knowing the contents of a product, its history, and its state, an immutable distributed ledger can provide that information. This is a review which questions the argument. It asks what the science really shows about traceability-based circularity, and it discovers that the heart of the field's thesis is an unstudied conflation: blockchain ensures that the content of a record cannot be altered after it is written, but not the content of a record when it is written. All the circularity claims that are carried by the ledger, are sourced by a physical-digital binding a scan, a sensor and attestation that the ledger cannot guarantee. The review constructs a protocol-driven assessment of the traceability–circularity literature, which is based on two analytical instruments: A four-layer traceability stack mapping the point at which cryptographic guarantees start and end; and A circularity evidence ladder that distinguishes between what is technically feasible and what is actually observed. The review is conducted in accordance with PRISMA 2020 reporting protocol, and includes a fully documented and reproducible search strategy in the four databases, registered inclusion criteria, a structured extraction form and quality appraisal. Under these five themes, together with the veracity gap cutting across, there are two main themes advanced: provenance and compliance and co-ordinating reverse logistics.The two main themes advanced are the first, provenance and compliance, and the second, co-ordinating reverse logistics, with the veracity gap between them and the other two themes, together with the veracity gap between the two, together advanced. The review calls for the veracity question to be no longer an academic one, but rather an urgent issue due to regulatory developments, especially the obligatory digital product passports. The number of screens and the PRISMA flow are reported on the running of given database queries.

Keywords: blockchain; circular economy; traceability; sustainable supply chains; digital product passport; systematic review

1. Introduction

The circular economy is based on the concept of material flow cycles in which products avoid the linear take-make-dispose approach (take-make-waste) and are instead reduced, reused, repaired, remanufactured, recycled, and recovered (Kirchherr et al., 2017; Geissdoerfer et al., 2017). The idea is both simple and a problem of information. In order for a component to be reused, it must be known to exist, be known where it is, be known of its material, its treatment, and be known for reusability. It is

not created in linear supply chains and if it is, it is siloed within companies, no one is incentivized to share it, and if they did, no one would have a way to validate it.
Blockchain came with a seemingly perfect fit in this spot. In addition to the immutability, distributed ledgers provide shared visibility among parties that have no reason to trust each other, and programmable enforcement via smart contracts (Saberi et al., 2019; Casino et al., 2019). The mapping onto the circular requirements was made quickly: the use of provenance records will allow to recover material; smart contracts will enable automatization of reverse logistics; tokens will encourage return; and shared registries will break down the information asymmetries that keep circular loops open (Kouhizadeh & Sarkis, 2018; Esmaeilian et al., 2020; Centobelli et al., 2022). A considerable number of literature now suggest that the traceability aspect, facilitated by blockchain, is a sometimes enabler of the circular supply chain; several reviews have mapped this (Schmidt et al., 2024; Böhmecke-Schwafert et al., 2022; Lin et al., 2025).
This review will be prompted by a lack of confidence in the basis of the argument. Once the record is committed to the blockchain, it is secure: No one can change it, and everyone can view the same record. It doesn't, nor can it, promise the veracity of what was written at the time. In a circular supply chain the oracle problem is not a technicality but the whole question, and the general form of the problem is given here (Caldarelli, 2020). A recycler's attestation that a batch is 30% recovered polymer, a repairer's record that a component was refurbished to specification, a supplier's claim that cobalt was ethically sourced each enters in through a human or a sensor at a physical-digital boundary the cryptography does not reach. If a fake claim is somehow put on paper, it becomes an irrefutable lie, and if it is put on paper in such a way as to be convincing, it is not obviously an improvement over putting it on paper in such a way as to be deniable.
It's important not only on a theoretical level. EU's Ecodesign for Sustainable Products Regulation becomes effective in 2024, and provides for digital product passports—first to be implemented for batteries, then for textiles, electronics, construction materials, and others by 2026–2027 by product category. Circularity data for products is no longer a goal for research but part of the law, and blockchain is one of the architectures that is suggested to transport it. As integrity has been interpreted as veracity in the literature that supports that particular architecture, the mistake is about to be engineered into compliance infrastructure at scale.
The review can thus present three questions.The review can thus ask three questions. RQ1: What is the literature saying about the link between the blockchain and traceability with circular economy outcomes? RQ2: Where does the guarantee provided by blockchain start and stop in the traceability chain and what happens to the part of it that isn't covered by the guarantees? RQ3: How much evidence can be found in the field for the circular outcomes, apart from the technical feasibility?
It has three contributions: a traceability stack which breaks down traceability into four layers and situates the integrity-veracity boundary in that stack; a circularity evidence ladder showing how various claims to circularity relate to one another in terms of what they actually evidence; and a replicable protocol operationalizing both for extraction and appraisal.

2. Background and Prior Reviews

2.1 Circularity as an Information Problem

Circular strategies are traditionally presented in an R-hierarchy, starting with refuse and reduce, moving on to reuse and repair, remanufacture and finally, recovery through recycle (Kirchherr et al., 2017). The hierarchy is also an information gradient: high value inner loops require more information than outer loops. Recycling can be done based on identity of the bulk material, remanufacturing can be done using component-level history cycles endured, stress experienced, and prior repairs. The tighter the loop, the more detailed and accurate the record has to be. Traceability is therefore the core tool to realize digital enablement of circular strategies and recognized research frontier (Kristoffersen et al., 2020). The information availability remains a key constraint on the implementation of the circular economy–sustainable supply chain nexus (Mugoni et al., 2025).

2.2 Blockchain Affordances and Their Limits

The features that blockchain has been touted as having in this field are immutability, decentralised consensus, transparency to authorised parties and programmability (Saberi et al., 2019; Wang et al., 2019). The excitement has been tempered by critical work that has already identified tensions between blockchain and circular practice from case evidence (Kouhizadeh et al., 2020), adoption barriers theorised and ranked (Kouhizadeh et al., 2021), and a persistent research–practice gap documented, where systems being deployed trail the academic proposals (Böckel et al., 2021). While the conceptual literature indicates the circular nature of blockchain, empirical investigation suggests that this is less unconditional than it might seem (Böhmecke-Schwafert et al., 2022), and analysis triangulating academic and practitioner discourse brings unresolved issues to light (Shrivastav & Bag, 2024). Theories on how adoption of blockchain leads to reconfiguration of the circular economy have emerged more recently, such as blockchain as the enabler of dynamic capabilities as a mechanism to connect adoption to reconfiguration of the circular economy (Quayson et al., 2023), and recent platform-level analysis has explored the role of blockchain in supporting specific circular practices, rather than circularity as a whole (Souza et al., 2024); and, large sample evidence confirms that blockchain adoption moderates the link between corporate circular practices and financial performance (Sun et al., 2025).

The common theme among the items in the affordance list is that each is about a property of the ledger, not a property of the world the ledger represents. Immutability is an assertion about bytes stored, consensus is an assertion about node consensus, and the programmability is an assertion about the way the nodes execute. None is a statement about a physical thing, and circularity is a statement about physical things. There is no argument about the crossing from the first quotation to the second, and it's so common, so much of the routine that it's not noticed, let alone defended, in the literature.

2.3 Traceability as a Construct

The term "traceability" is used broadly. It means, on one hand, to identify origin, on the other hand to follow a unit forward, to traces a unit backward, and to verify an attribute claim. These are distinct capabilities and distinct failure modes that are not clearly differentiated in the literature. In both cases, the idea of traceability is considered as a single construct that can be provided by a ledger; whereas, in the theory of trust, traceability is deemed as the component of the ledger that makes it valuable, not the entire ledger itself.In both, the concept of traceability is presented as an individual element that can be offered by the ledger and not as a chain that determines the value of the ledger, where the weakest link is the part that counts.

2.4 Prior Reviews and the Gap

Table 1 shows existing reviews mapped. They are good, but they are rather convergent; blockchain is promising, barriers are scalability, interoperability, privacy, cost and governance, more empirical work is needed. The convergence is itself informative and as is the omission. No one breaks down the notion of traceability into layers, no one moves to the boundary of integrity–veracity, and no one categorizes the evidence as to what it represents in terms of circular outcomes rather than technical function. This review fills a different need: it does not review coverage, it reviews appraisal.

Table 1. *Prior reviews on blockchain and the circular economy, and the gap addressed*

Review	Scope and method	Principal finding	Not addressed

Review	Scope and method	Principal finding	Not addressed
Casino et al. (2019)	SLR of blockchain applications across domains	Classification of applications; open issues	Circularity outcomes; data veracity
Böckel et al. (2021)	Research–practice gap analysis	Academic proposals outrun deployments	Layered traceability; evidence appraisal
Böhmecke-Schwafert et al. (2022)	Empirical investigation and theorising	Blockchain's CE role is conditional	Physical-digital binding
Schmidt et al. (2024)	SLR (22 articles) on blockchain and CE transition	Synergies and barriers to transition	Integrity vs. veracity; outcome evidence levels
Shrivastav & Bag (2024)	Triangulation of literature and social media discourse	Persistent unresolved issues	Traceability decomposition
Ellahi et al. (2023)	Systematic review of blockchain food traceability frameworks	Framework classification for food chains	Circular strategies; veracity of captured claims
Lin et al. (2025)	Bibliometric and literature review	Field structure and evolution	Evidence quality for circular outcomes
This review	PRISMA-guided appraisal	Traceability stack; evidence ladder	—

3. Research Methodology

3.1 Design and Reporting Standard

The review follows the PRISMA 2020 reporting guidance by Page et al. (2021) and the three-phase logic of planning, conducting and reporting for management reviews by Tranfield et al. (2003). The protocol was outlined prior to screening and is detailed below to allow protocol replication.

3.2 Search Strategy

Table 2. *Search protocol*

Element	Specification
Databases	Scopus; Web of Science Core Collection; IEEE Xplore; ScienceDirect
Query (title–abstract–keyword)	(“blockchain” OR “distributed ledger” OR “smart contract”) AND (“circular econom*” OR “closed-loop supply chain” OR “reverse logistics” OR “remanufactur*” OR “recycl*”) AND (“traceab*” OR “transparen*” OR “provenance” OR “product passport”)
Window	2016–2026 (first substantive publications in the domain to date of search)

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Element	Specification
Document types	Peer-reviewed journal articles and full conference papers
Language	English
Supplementary	Backward and forward citation chaining of included records; grey literature restricted to regulatory instruments
Inclusion	Blockchain is a studied component, not a passing mention; a circular strategy is explicitly addressed; traceability, transparency, or provenance is a mechanism or outcome
Exclusion	Cryptocurrency or finance-only focus; energy-trading applications without material circularity; editorials, abstracts, non-peer-reviewed preprints; duplicate reporting of the same study

3.3 Screening and Selection

Records are deduplicated and screened for inclusion on title and abstract, then evaluated in full text. Two reviewers independently screen the material and disagreement is resolved by discussion, interrater agreement is reported as Cohen's k. The flow of records through identification, screening, eligibility, and inclusion, along with numbers at each stage and reasons for full-text exclusion is presented in a PRISMA 2020 flow diagram on implementing the protocol (Page et al., 2021).

3.4 Data Extraction

Table 3. *Extraction schema*

Field	Values
Bibliographic	Authors, year, outlet, discipline
Sector	Agri-food; textiles; electronics/WEEE; batteries/EV; construction; plastics; luxury; cross-sector
Circular strategy	Reduce; reuse; repair; remanufacture; recycle; recover; multiple
Traceability layer addressed	Binding; capture; ledger; disclosure (see Section 4.1)
Blockchain configuration	Public; private; consortium; hybrid; unspecified
Complementary technology	IoT/sensors; RFID/QR; AI; digital twin; none
Evidence type	Conceptual; design/artefact; simulation; single case; multi-case; survey; field experiment
Outcome claim level	Ladder rungs 1–4 (see Section 4.3)
Veracity treatment	Ignored; acknowledged; mitigated by design; empirically tested
Barriers reported	Scalability; interoperability; privacy; cost; governance; skills; regulation

3.5 Quality Appraisal

Studies evaluated using criteria tailored to the type of evidence: conceptual studies have criteria related to construct clarity, argumentative warrant; design and simulation studies have criteria related to specification of assumptions, baseline comparison, and reproducibility; empirical studies have criteria related to sampling logic, data adequacy, and validity procedures. Appraisal does not exclude but rather informs about synthesis weighting.

3.6 Protocol Status and Transparency Statement

The analytical framework, protocol, and extraction schema reported here are complete and executable. The numbers in Figure 1 and any frequency statements in Section 4 are written in the placeholders and will be filled in during execution of the queries in Table 2 against the licensed databases. No counts, frequencies or study level results are reported that have not been performed in a search. The review's analytical instruments and the themes that are identified in the literature which has already been retrieved while developing the protocol is presented in Section 4, but no distributional findings are reported.

4. Findings

4.1 The Traceability Stack

The review's first instrument decomposes traceability into four layers (Figure 1), each with its own failure mode. Blockchain's guarantees apply to one of them.

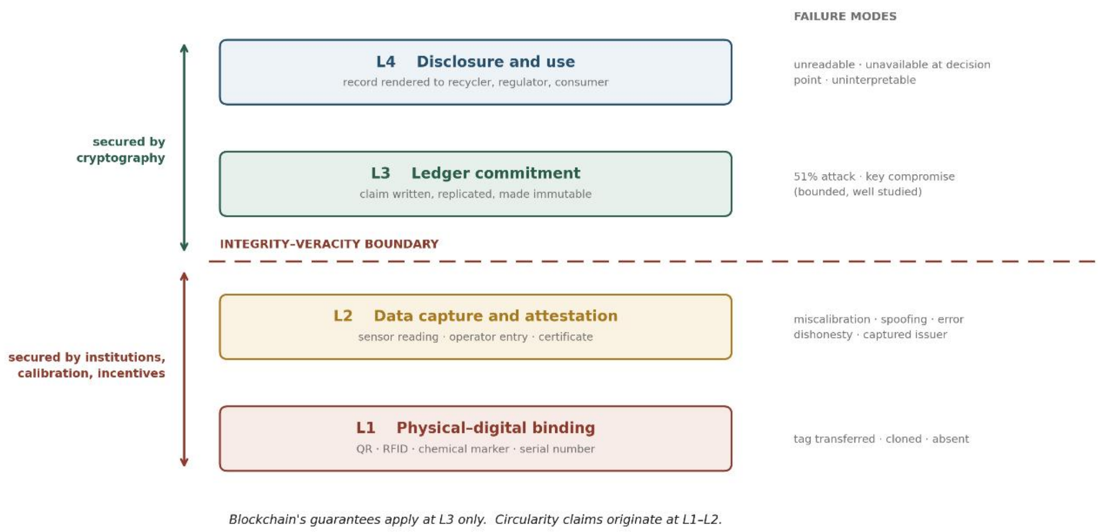

Figure 1. *The traceability stack and the integrity–veracity boundary.*

Layer 1 Physical-digital binding. Identification of a material object: QR code, RFID tag, chemical marker, serial number. Failure modes: transfer of the tag to another object, cloning, or lack of the tag. A tag that is taken to the wrong item does not leave a cryptographic property. The dependency is directly represented by deployed textile traceability platforms as the identity must be preserved during the cutting, dyeing and assembling process of the product (Alves et al., 2024).

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Layer 2 Data Capturing and attestation. The creation of a claim on the bound object: sensor reading, operator entry, certificate. Failure modes: sensor is miscalibated or spoofed; operator is wrong, pressured or dishonest; certificate is real, but its issuer is captured.
Layer 3 Ledger commitment. The writing and replication of the claim. It's where blockchain works and it's really powerful: once the record is committed, it cannot be changed and everyone that is allowed can see the same history.
Layer 4 Disclosure and use. The representation of a record to a party who relies on it to act as a recycler, regulator, consumer. Failure modes: data is illegible, incomprehensible, not available at the decision point, or only available by the party who wrote it
The integrity–veracity boundary is between Layers 2 and 3. Above it, secured by cryptography; below it, secured by institutions, calibration, and incentives—sort of the system that has been in place for tracking traceability before blockchain. The well known mantra of the field, that blockchain can make supply chains trustworthy, is only applicable to Layer 3 and Layer 3 is not the layer of circularity.

4.2 Thematic Structure of the Literature

Table 4. *Themes identified, mechanisms, exemplars, and unresolved limitations*

Theme	Proposed mechanism	Exemplar sources	Unresolved limitation
T1 Provenance and compliance	Immutable origin records substantiate material and sourcing claims	Saberi et al. (2019); Vazquez Melendez et al. (2024)	Origin claims enter at Layer 2; ledger cannot validate them
T2 Reverse-logistics coordination	Smart contracts automate return, sorting, and settlement across parties	Esmaeilian et al. (2020); Souza et al. (2024)	Contract triggers depend on attested physical states
T3 Lifecycle records and passports	Persistent product records support reuse, repair, and remanufacture	Abreu et al. (2025); Alves et al. (2024)	Record completeness across custody transfers rarely demonstrated
T4 Tokenised incentives	Tokens reward return and recovery behaviour	Kouhizadeh et al. (2020); Upadhyay et al. (2021)	Incentive to misreport rises with token value
T5 Barriers and adoption	Scalability, interoperability, privacy, cost, governance constrain deployment	Kouhizadeh et al. (2021); Böckel et al. (2021)	Barriers catalogued; few resolved empirically
T6 The veracity gap (cross-cutting)	—	Caldarelli (2020); Kouhizadeh et al. (2020)	Acknowledged in critical work; largely absent from design proposals

The first three themes have a structure to their names. Each points to a real challenge in circular supply chains, of which the four sourcing claims outlined below are substantiations: T1 – unverifiable sourcing claims, T2 – costly multi-party reverse flows, T3 – product history lost, T4 – a ledger is the solution. In all instances the ledger deals with the sharing of the information, and not its creation. If the refurbishment history of a component is true, a shared record of this refurbishment history is useful, but if it is false, it is not. T1–T3 does not explain why it should be useful. The implicit answer to the literature is that immutability prevents falsification because a permanent record increases the expected cost of getting caught. This is likely and unproven, and contradicts T4: if a token gives a reward for an event to which you've provided an attestation, the potential reward for falsifying it increases as its deterrence is increased.

The review analytical contribution is made up of Theme T6. Not one of these is subject of much discussion in the literature and they all rely on the assumption that what goes into the ledger is true, and they get more appealing to be disputed the more important they get. The perversity is vividly captured in the effect of attaching monetary value to an attested return event that creates an incentive to attest return events that did not happen, and immutability keeps the fraud in perpetuity: tokenised recovery (T4).

4.3 The Circularity Evidence Ladder

The second instrument developed for the review categorizes the type of evidence a study presents (Figure 2). For Rung 1, there is a foundational understanding that and system can be built. Rung 2's goal is to set the benchmark that it has acceptable latency, cost, and completeness with respect to the propagation of records from it. In Rung 3, it is established that actors change their behaviour in response. Rung 4 is the basis that circular outcomes are changing – Recovery rates, loop closure, retained value, avoided virgin input. The motivating claim of the field is only substantiated by Rung 4 and that rung is the one that demands a longest observation, access, and cooperation from firms that have the least to offer.

The difference that the ladder imposes is not pedantic, and two recent studies demonstrate the reasons. The benefits of blockchain implementation in food supply chains on operational aspects are measurable (Vu et al., 2025), while large sample analysis of listed firms exposes that the returns achieved by circular practices are contingent on the implementation of blockchain (Sun et al., 2025). Both are large, and neither is a Rung 4: operational and financial performance are not outcomes of a loop-closure, and a company can make money on a circular practice that it does not measure the loop-closure effect of. The need of the ladder stems from the scarcity of work that explicitly associates blockchain with circular economy performance measurement in the field (Kouhizadeh et al., 2023); in fact, the best evidence in the field is strong on something other than circularity.

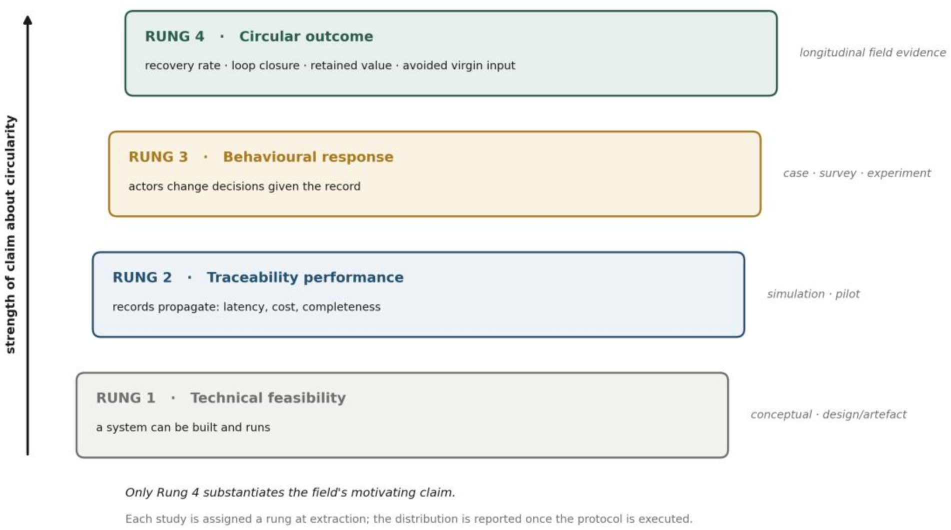

Figure 2. *The circularity evidence ladder used to classify outcome claims during extraction.*

In this protocol, the role of the ladder is classificatory rather than rhetorical, that is, each study included will get a rung and only the distribution will be reported after extraction. The instrument is pre-specified and therefore the distribution, as it may turn out, will not be a product of post hoc coding.

4.4 Regulatory Convergence

The digital product passport will convert the veracity gap from a research challenge into a compliance risk. The ESPR introduces sustainability data at the product level, which will be a market-access requirement starting from 2026–2027. The boundary question has become more concrete, and the architecture more pointed, thanks to design science work on producing end-to-end blockchain-based passport prototypes, instantiated in textile chains (Abreu et al., 2025) that feature articulated design principles. As blockchain carries passport data, it will verify the record, and the legal consequence of a false entry now attaches to a record that is by design permanent and non-repudiable, as opposed to the originals in Layers 1-2. The next two questions that arise are whether immutability is a good or bad thing if inaccurate data needs to be rectified according to a legal obligation to be accurate; and whether verification effort should be moved from the ledger to the binding.

5. Discussion

5.1 Implications for Research

The argument of the review is about optimising the wrong layer in the field. The question of what constitutes a true circular economy is at Layers 1 and 2 and is a topic of relatively little design consideration, while the question of how to design a Layer 3 that provides sufficient throughput and consensus mechanisms has been much more inventive. A reorientation suggests a different research programme: a tamper-evident physical-digital binding, a mechanism of sensor attestation and calibration provenance, adversarial testing of capture processes, and making truthful attestation the incentive-compatible option where tokens create the opposite pull. The evidence ladder suggests that there is another reorientation, towards outcome measurement, and towards publishing failures – the field's lack of negative results is a finding about the field.

5.2 Implications for Practice and Policy

The message for companies is that a blockchain traceability investment that lacks strong buy-sell relationships of the L1-L2 arrangement, lacks credibility, and that the companies do not buy the truth. The review recommends that the verification requirements should be included in the binding and attestation layers, and that the architecture requires making it explicit that the ledger should be included, but that capture is not regulated would provide the least vulnerable element of the chain for policymakers implementing a digital product passport. For standards bodies, the interoperability wave that's now in the swing of data formats now needs to include attestation semantics: a "recycled content" claim is nothing without a basis of measurement and an audit trail of it.

5.3 Limitations

The protocol is reported but not yet performed and the thematic structure here is based on literature obtained in the process of protocol development, not on completed extraction; the themes should be heard as provisional and are subject to revision. Because work that does not result in publication is not likely to be achieved with English-language and database restrictions, the latter will exclude relevant work, including unsuccessful practitioner deployments, which will be counterplausible to field's own optimism. The two instruments are analytical constructs, of which none is validated. Finally, this design takes on a specific review of the blockchain-based traceability; it does not attempt to answer comparative questions regarding whether the veracity gap is greater in blockchain than in centralised alternatives, but it does suggest that it is at least differently distributed, given how error is permanent under blockchain.

5.4 Future Research

The next step is to carry out the protocol, and the most important product of the protocol is the distribution of rungs. If such studies are present, they focus on Rungs 1–2 and the field does not have evidence for its confidence, the right answer is measurement not more architecture. Following the stack there are three ways to go. Layer 1: Design research of binding mechanisms that can't be forgery unless the claim in the binding is worth more than the forgery cost; adversarial evaluation of material fingerprinting; physically unclonable functions. Layer 2 challenges: What can be designed to make it the best strategy for truthfully reporting if a token provides a reward for a return event, and how can staking, random audit, or reputation bonding accomplish this at reasonable cost? Layer 4 is accepting work on interpretation as a passport that a recycler cannot act on within a cycle, has failed whatever cryptographic pedigree it has. Empirical studies are required in parallel with whether permissioned ledgers, centralised registries or federated architectures distribute the veracity burden differently is an untested assumption in the field.

6. Conclusion

Here is a narrow, but real thing blockchain does: It makes for a committed record that is difficult to change and easy to share. The circular economy requires something more encompassing that does justice to the movement of physical objects around. This review has been arguing for a more systematic substitution of the first for the second in the literature, and has proposed two tools to make the substitution explicit: a traceability stack to mark the integrity-veracity boundary between attestation and commitment; and an evidence ladder to distinguish between technical feasibility and circular outcome demonstration. Operationalizing both as reported in the protocol here. The argument isn't that blockchain isn't helpful for circular supply chains, it's that its help is limited to one layer of a four-layer problem, that the field has focused on the one layer where the guarantees already exist, and that mandatory product passports are coming to the unguarded layers of the problem. A record that has not been verified is not a tamper-proof record. It's a strong claim, the difference is the entire topic.

Declarations

Conflict of Interest
The authors declare no conflicts of interest related to this study.

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Ethical Approval
This study did not involve any human or animal subjects and, therefore, did not require ethical approval.

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