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The potential of Distributed Ledger Technologies to improve product traceability assurance in the construction industry.

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ABSTRACT: Product traceability in the Architecture, Engineering, Construction and Operations sector (AECO) is a complex challenge that remains largely unsolved. Even in advanced economies it is frequently not known which specific construction products are installed in a given built asset. This leads to downstream operational, financial and safety issues throughout the asset lifecycle. Nevertheless, the fragmented and commonly adversarial nature of the AECO supply chain conspires to inhibit product traceability despite mounting external pressures to improve it. Following a critical review and synthesis of the traceability literature, one area of technology that is widely believed to have the potential to improve traceability outcomes is Distributed Ledger Technology (DLT), yet some critical questions of its ability to improve product-level traceability remain unanswered. One such question is if it has the ability to help determine the overall accuracy and reliability of traceability information or whether it can improve the link between digital information about a product and the physical product itself.

1 Introduction

Supply chains in the Architecture, Engineering, Construction and Operations sector (AECO) and others, are striving to be more responsive and resilient in pursuit of higher gains. Simultaneously pressure is mounting for them to act transparently and tackle a raft of contentious issues such as counterfeiting and unethical sourcing [1]. This trend, along with growing safety, quality and regulatory concerns, is inducing the development of traceability practice across the board [2,3]. Although an apparent dearth of sufficiently potent drivers to catalyse the wholesale adoption of traceability in AECO renders it far behind comparators. Simultaneously, the notion of *Industry 4.0* is sweeping through the manufacturing industries of advanced economies proliferating innovative technologies and business models in the quest for global relevancy and competitive advantage. The development of *traceability*, a practice within the broader area of Information Management, is foundational to the success of many Industry 4.0 innovations due to the increasingly inherent dependence on the creation and flow of information in these complex sociotechnical systems. One nascent area of technology in the emerging AECO, Industry 4.0 and Computer Science literature, Distributed Ledger Technology (DLT), is widely believed to hold the potential for radical advances in traceability in the context of supply chains. However, solutions to two fundamental problems are unresolved, undermining the potential efficacy of DLT in traceability applications above existing alternatives.

This paper examines the concept of traceability through the lens of stakeholder and information management theory before contrasting current traceability practice in AECO with that of comparatively mature sectors. Thirdly the emerging DLT literature is explored with respect to traceability, in order to identify key propositions made in support of its potential utility in construction product traceability solutions. The current challenges are highlighted leading to the synthesis of several research problems for future work.

2 The Concept and Theoretical Underpinnings of Traceability

Despite a broad use of the term 'traceability' in the business lexicon, Olsen and Borit postulated that the literature lacked a non-recursive, universally applicable definition. They posit that it is: *"the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications."* [4, p.148] The traceability literature spans computer science, quality management, supply chain management and several others. In this paper, traceability is considered in the context of supply chain management and quality management. From this broadly accepted definition, it is evident that traceability concerns the flow of information about a defined artefact between stakeholders. These stakeholders exist in varying arrangements, both within organisational boundaries and across them.

Broadly speaking, a Traceability System (TS) must contain four mechanisms. The following are synthesised from [3–6]:

- A mechanism for *identifying entities* – the most common term for this is a Traceable Resource Unit.
- A mechanism for *documenting transformations* – inputs consumed, outputs generated and the process in between.

- A mechanism for *recording attributes of entities* – facts about an entity that are not observable, e.g. its custody at any point or its data of manufacture.
- A mechanism for *retrieving trace information* – the ability to access the information.

The literature abounds with barriers to traceability in the areas of *cost* and *complexity*, but a third area, *collaboration*, in particular stands out. This refers to the lack of motivation to participate in TSs. Even in contexts where a TS is forced upon Supply Chain Participants (SCPs) (as is typical in the agriculture and automotive industries), control over information input ultimately resides with the individual SCPs [7]. Even Walmart's lauded pilot traceability system *"depends on cooperative partners agreeing on what information to contribute"* [8]. The reasons for this are several, but in particular three dynamics should be considered: first, the SCP responsible for creating / sharing traceability data may not derive any direct benefit from it. Secondly, some SCPs see the types of information they need to provide to others as commercially sensitive and therefore a potential benefit to their competitors. Thirdly, in some instances information provided by an SCP to another stakeholder may expose its creator to risk in the form of liability insofar as the provision of traceability information may be construed as a liability-transfer mechanism (if an SCP can show that the fault for an given error exists with an upstream supplier, they can transfer the liability to that supplier) [6]. In all models of TS, the quality of traceability information falls upon the shoulders of individual stakeholders, as previously noted: *"traceability is based on systematic recordings and record–keeping, there is no guarantee that the recordings are true. Both error and fraud may lead to untrue claims"* [4, p.148].

2.1 A Theoretical Framework and Exposition of the Concept of Traceability

These dynamics are modelled in figure 1 showing a hypothetical Trace Initiative (TIN) scenario in which one Supply Chain Participant (SCP_N) requires access to information from another (SCP_{N-1}) who, in turn, may request information from additional upstream SCPs (e.g. suppliers) if they do not possess it internally. The analysis of traceability is aptly informed by two bodies of theory: Stakeholder Theory, concerning stakeholder actions and agency; and Information Theory, concerning the nature of traceability information itself (with particular reference to information assurance).

Figure 1 shows that at a micro-level, SCPs may not be incentivised toward discretionary, spirited and honest participation in TINs. They may in fact arguably possess sufficient incentive to actively disrupt TINs that potentially expose them to risk. At a macro-level, if the SCP does not know which information may expose them to increased risk or disadvantage in the future – they may abandon meaningful TS participation altogether, undermining the entire TS in the process. This behaviour aligns with the self-serving motives portrayed in agency theory [9].

Figure 1. A simple trace scenario demonstrating the stakeholder dynamics
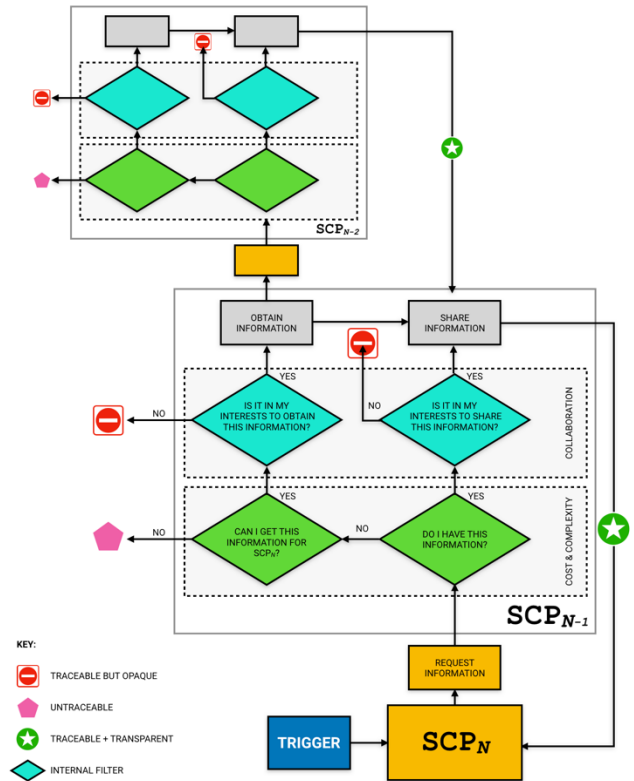
To delve further into the dynamics at play in a TIN, from the aforementioned bodies of theory, the generally accepted definition of traceability is dissected into segments in order to identify the logical requirements to achieve traceability in the context of the hypothetical TIN proposed in Figure 1. An overview of these components and requirements are shown in Table 1.

Table 1. Further logical requirements to achieve traceability

Component of Definition	Logical Requirement	ID
"the ability to access"	Ability to access and interpret information	T1
"any or all information relating to"	Defined information requirements	T2
"that which is under consideration,"	Rationale for query	T3
	A trace target (focal object)	T4
"throughout its entire life cycle,"	Scope-breadth: Internal/external	T5
	Scope-direction: Back / forward / through	T6
	Scope-timeframe: Past / present lifecycle stages	T7
"by means of recorded"	Preserved or shared information	T8e
	Captured information	T8d
"identifications"	Codified observations (data)	T8c
	Observable phenomena (events)	T8b
	Judgement of potential utility of captured information	T8a

2.2 A logical exposition of the traceability process

The following is an explanation of the sequence of events within the trace initiative demonstrated in Figure 1 from the perspective of a focal SCP, the trace initiator. This exposition uses the components of traceability from [4] to provide a detailed understanding of the informational and behavioural requirements to achieve traceability in a supply chain. This understanding provides the context within which emerging AECO and DLT traceability literature is examined to identify gaps in the knowledge and research opportunities.

T1 – To complete a trace, the trace initiator (SCP_N) must be able to access the required information (T2) which satisfies their query (T3) about a given subject of concern (T4) and interpret it as satisfactory (therefore consider it 'traceable'). The information must be preserved (T8b) internally or externally. If external, it is subject to the internal 'self–interest' filter of SCP_{N-1}.

T2 – The types of information concerning the Trace Target (T4) could include transactions / transformations / movements / custody or contextual attributes and can span across three potential 'dimensions' (T5 T7). This must have been captured and preserved (T8e–T8f) by the $SCPs_{[N-N]}$).

T3 – A trace objective is the goal of retrieving specific information (T2) from the relevant SCP (T5–T7) concerning a subject of concern (T4). This is normally in response to an internal or external 'trigger', e.g. a request from an external agency to SCP_N. Whilst SCP_N may have a specific objective, it may not be able to control the effectiveness of the trace, since it is subject to the control that other SCPs have over access (T1) and all SCPs are limited by the fulfilment of requirements T4 – T8b. The likely agreed objectives within a given system must be agreed before, since they dictate the potentially valuable data (T8a) to be captured throughout the supply chain (T5 – T7) and the lifecycle (T2) of the Trace Target (T4).

T4 – The Trace Target is the item about which information (T2) is sought, i.e. a focal product. The Trace Target and the Information Requirements (T2) are dictated by the objective of the Trace Initiator and nature of the trigger. It requires that SCPs have an understanding of what the target is, e.g. a TRU [10].

T5, T6, T7 – The information requirements (T2) about the trace target (T4) may lead the Trace Initiator to consult information sources in their own organization or that of external participants, upstream (towards the ultimate source) or downstream (towards the ultimate customer) in the supply chain. The Trace Initiative could also concern current events or historical events. In both instances, the information must: exist (T8d–T8e), be understandable (T8c) and be made accessible to the Trace Initiator (T1).

T8e – The crux of traceability is the recorded identifications which means capturing valuable and useful data (T8a – T8d)

and preserving / sharing it as required (T8e and T1) between SCPs.

T8d – The paradigm of the SCPs and likely objectives of potential trace initiatives will affect the amount of 'recorded identifications' made, due to the cost implication of gathering and storing more voluminous amounts of traceability (granularity).

T8c, T8b – Before information is captured and preserved, it must first be observed (T8b – by an observer or sensor). Observability of a datum point stipulates that it should be explicit (something which can be easily expressed), as opposed to tacit (something which is not easily expressed) and which cannot be stored in information systems [11]. If it is explicit (defined as *'highly detailed, formal and systematic'* [12]), it is codifiable as a datum point (T8d) and can therefore be captured (T8e).

T8a – Given the variety of potentially key information that is created on a continual basis in almost any scenario, a value judgement must be made on what information is pertinent to potential traceability objectives (T3), considering the potential Trace Target (T4). For example, a clear brief to a site manager to 'monitor the weather for the concrete pour' in a construction site improves the site manager's ability to notice the weather and take note, since it is inferred that weather conditions are of potential consequence. An alternative to pure human observation, would be to deploy sensors for the purpose of capturing meteorological data on site, and cross-reference this with other records to ensure the timeframes aligned.

2.3 Information Assurance Considerations

It has been noted that traceability information does not inherently equate to accurate or reliable information [3,4]. This is of critical importance and is overlooked by many authors – who infer precisely the opposite. Borit and Santos [13, p.15] summarise: *"there is no guarantee that the recordings are true or complete, as both error and fraud can lead to false claims [...] There is a clear need to verify these claims, and in this area, analytical methods and instruments play a crucial role."*

The trust in information is depicted below in Figure 2, where SCP_N wants to find out where his purchased product is from (SCP_{N-1}). SCP_N queries his TS and receives trace information back. As he did not physically observe the lorry, he has no way of verifying that the information is an accurate depiction of events. His trusts in the TS, which normally constitutes humans (shown earlier to be vulnerable to error or fraud) and machines, to provide an accurate depiction of the real events. Thus the accuracy and security of the information retrieved from a TS is crucial to reliable traceability [14] and supply chain and quality management in general [15]. This link between a physical item and its informational representation in a TS may be referred to as the Cyber Physical Bond (CPB). Examples of the potential weakness of the CPB link from the literature abound: Forged

product certification paperwork [16]; tampered IoT sensors [17]; cloned RFID tags [18].

Figure 2: Trust in Traceability Information and the Cyber Physical Bond
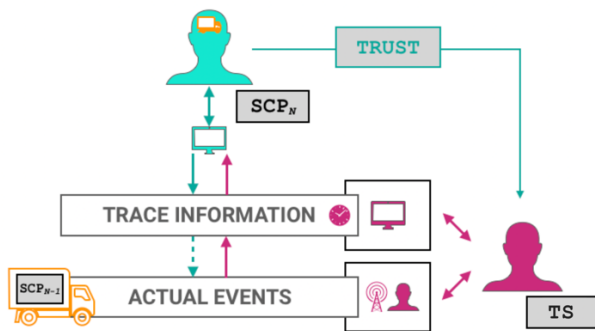
3 Contrasting current AECO traceability practice with other sectors

The automotive, agriculture and pharmaceuticals sectors are seen to have developed a comparatively mature traceability practice [3,19]. Its development in the AECO sector, as with many areas of innovation [20,21], lags behind these industries [22,23]. Whilst some low–tech voluntary initiatives exist to encourage the responsible sourcing of raw materials such as timber [24–26], there is no industry–wide scheme to facilitate the traceability of construction products through their entire lifecycle [23]. The general state-of-the-art of product traceability in the sector is summarised by an industry spokesperson *"From government, down to small sub–contractors, we suffer from a shocking lack of data. Traceability technology exists, but we understand little about our supply chains below tier 1"* [27, p.6].

The very nature of the sector introduces barriers to being more proactive in this area; its significant degree of fragmentation, project–basis, separation of activities, poor information management and adversarial relationships [28–31]. These all conspire to further entrench information in silos that stifle traceability [4].

4 Traceability Drivers and Incentives

Despite the apparent inertia, several factors point to the increasing importance of improved product traceability in construction:

- $4.8 billion is spent each year by US building owners verifying operations and maintenance data for buildings. A further $613 million is spent to rekey the information into a different format or system [32].
- The incidence of counterfeit and fraudulent products in general is increasing globally (over $1 trillion annually in 2003 [33]); and a high proportion of construction projects become victims (almost a third, according to [19]).

- Significant issues in the transfer of product information in construction projects can directly and severely affect occupant safety [34].

Despite evidence of the growing need for improved traceability in AECO, its currently established initiatives (e.g. CARES, FSC) tend to entail a narrow focus on responsible sourcing, ostensibly concerning the extractive industries [26]. The comparator industries, however, demonstrate a plethora of drivers beyond this in three broad areas (legal, economic and social drivers) with application areas of traceability spanning the extremities of the supply chain. These include: regulatory compliance, product recall facilitation, fraud/security, quality and safety management, counterfeit prevention, business efficiency, inventory control, financial analytics, waste prevention, transparency, and the supporting of origin claims; to say nothing of emerging business models which are penetrating the psyche of these industries (discussed in section 4.2). The aforementioned application areas convey a sense of being a *push* or *pull* incentive, or both [1–3,13,35–45]. This is to say that businesses in comparator industries willingly engage in some application areas (pull), whilst in others they are forced (push) to do so by external agency, such as governmental bodies or pressure groups [2].

Whilst the majority of application areas seem to be driven by the self–interests of businesses (pull), Borit and Santos [13] note that, in general, regulatory compliance mechanisms tend to induce the initial application of traceability in a sector (push). Though these levers are yet to fully materialise in AECO, recent events may mean that the sector is forced to develop traceability systems by future regulation [23,34]. This external agency may catalyse progress in the industry, but the burden it places on a sector known for its backward relationship with technology could place substantial strain on existing sub-optimal information systems [46] with consequences for the resultant information assurance.

4.1 A Paradigm Shift in Traceability Objectives

Sterling *et al.* propose that traceability 'best–practice' delivers business benefits in the four areas of compliance, risk mitigation, market access, and operational efficiencies [47]. Charlebois *et al.* [45] along with [47] and [3] concur that a more proactive stance to traceability is beneficial, with the latter stating that *"adopting traceability for strictly compliance reasons can markedly limit the value that businesses derive from implementing traceability systems."* [3, p.396].

These and other more recent work denote a paradigmatic shift from an historic reactively orientated approach that has not sought out or exploited business opportunities beyond regulatory compliance towards a faster, more reliable and cost–effective approach to traceability designed to *"capture data proactively for use to commercial advantage"* [47]. This shift, from push to pull, can be analysed as a transition from a compliance centric 'must do' activity to an

opportunistic 'can do' activity with incentives sufficiently attractive that SCPs voluntarily overcome the profusion of cost, complexity and collaboration barriers which bedevil TS adoption [2,6,48–50]. The new approach seeks to unlock new value streams and business benefits – as in the case of Amazon, a company labelled by many business commentators as predominantly a data company (as opposed to retail, its inaugural classification) due to the value it extracts from the collection and exploitation of data in new value propositions and data driven business enhancements [51,52]. This shift is in the spirit of observations made by Teece *et al.* over 20 years ago, who argued that *"knowledge, competence and related intangibles have emerged as the key drivers of competitive advantage in developed nations. This is not just because of the importance of knowledge itself, but because of the rapid expansion of goods and factor markets, leaving intangible assets as the main basis of competitive differentiation in many sectors"* [53, p.76]. Accordingly, Hartmann *et al.* [54] defined six types of data-driven business models which are anchored to the principle of the exploitation of information, alluding to the clear proliferation and maturation of the new paradigm.

4.2   Potential Development of Traceability in AECO

To envisage what such a shift in traceability in AECO could look like, one can examine the transformation underway in the manufacturing industries of developed economies; these are undergoing rapid digitalisation and innovation in a quest to remain competitive and relevant in the global marketplace [55–57]; rallying under the colloquial term of *Industry 4.0* [56,58]. The espoused benefits of the Industry 4.0 movement include more responsive and resilient supply chains, improved operational efficiency, enhanced customer value propositions, and reduced waste [58–60]. In some cases technology is enhancing the facilitation of existing approaches, in others it is catalysing the genesis of entirely new ones [61]. Far from being the mere overlaying of novel technologies on existing practices, entirely new business models are emerging based on the innovations. Three such innovations include: servitisation, cyber physical systems, and digital twinning [56,62–69]. These concepts are also discussed in the emerging AECO literature, with a major underlying driver of improved productivity in a sector commonly lambasted for its poor performance in this area. Product traceability, spanning each stage of the supply chain and throughout the full lifecycle of a product, is a key enabler of these innovations. It would also directly lead to financial and social benefits by solving the three problems identified in section 4 whilst contributing to improvements in counterfeit elimination and environmental credentials. Finally, the flow of in-use construction product data could lead to a panoply of other valuable benefits for stakeholders: manufacturers could optimise designs based on real usage data, orders of magnitude richer than laboratory-based test results; whilst facilities managers could receive predictive maintenance and product-recall alerts, driven by fresh data.

5   The Potential Role of DLT in Traceability

A central tenet to many such innovations is their wholesale reliance upon the flow of information throughout supply chains in complex sociotechnical systems. Alongside the development of technologies in areas such as robotics, sensors, internet of things, geolocation, space, and materials; the soaring dependence on information flow has arguably catalysed the accelerated development of an entirely new area within the information management field, blockchain, and a broader category termed Distributed Ledger Technology. Widely popularised by Bitcoin (its first major application), blockchain has rapidly become a poignant topic of conversation across a spectrum of academic and business literature. It is arguably one of the most novel technological and sociological developments in recent times.

There are two types of blockchain: *permissionless* (like Bitcoin or Ethereum) which is fully decentralised with no central authority, and fully accessible to anyone to participate; or *permissioned* where a central actor must grant access and permissions for someone to participate [70,71] (like Corda). In general, a blockchain can be conceptualised as a distributed append–only database [72] made up of interlinked blocks of data which contain records of the transactions made in the system between nodes (participants) since the last block was added. The blocks of transactions are confirmed and added to the existing chain by mutually mistrusting [73] 'writers' called validators [74], leading to the descriptor 'trustless' [75], since no trusted centralised third-party is needed to facilitate the effective functioning of the system.

The writers come to an agreement on the validity of the transactions communicated in the system via a self–propagating consensus algorithm [71]. Each new block that is appended to the chain references the previous block via a one–way cryptographic hash function [71], essentially a fingerprint ID of the previous block, which prevents data from validated blocks from being tampered with. Furthermore, the information within a blockchain system may hide in plain sight, sitting securely behind the protection of "very big numbers" [76] and within a small space, due to optimising Merkle Tree hashing–functions [77] whilst indefinitely preserving the integrity of historic transaction data. These features mean that blockchain systems are generally accepted to possess five key attributes, as noted in Table 2 below.

Table 2. Purported Attributes of DLT Systems

Attribute	Comment
Auditable	Provides an unbreakable audit trail of all transactions all the way back to the first (genesis) block, which can also be conceived as transaction traceability [78].
Disintermediative	There is no reliance on a third 'trusted' party to execute transactions, it is peer to peer (and information is also directly accessible) [70].

Transparent (with/without pseudonymity)	The information within blockchains is viewable by all participants [...] Users can choose to remain anonymous or provide proof of their identity to others [71]
Secure	Expensive computational algorithms create disincentives to 'hack' the system [72], and blockchains' distributed and encrypted nature makes them difficult to hack. [70,71]
Immutable	Existing data in public systems is extremely hard (and economically unfeasible) to change [77,79].

There is growing consensus in the literature that blockchain can lead to enhanced traceability in supply chains due to its novel approach to information management. An extensive body of literature asserts a degree of support for the notion that blockchains are especially well placed for the enhancement of traceability of physical artefacts in supply chains. Cole *et al.* [80, p.471] provides a succinct synthesis of the emerging consensus: *"immutability of the data means that agreed transactions are recorded and not altered. This provides provenance of assets, which means that for any asset it is possible to tell where it is, where it has been and what has happened throughout its lifetime."* Outwith the academic literature, prominent industry bodies such as IBM, Deloitte, and Oracle tend to sympathise with this stance [81].

6   Open research problems

6.1   *Distributed Ledger Technology*

There is no notable opposition to claims that blockchain can prove the provenance of data created within a blockchain system due to its advances over older technologies (namely. immutability). That being said, two erroneous propositions pervade the nascent argument that blockchain by itself will enhance traceability of non-informational artefacts. These are as follows:

- The conflation of the guarantee of the provenance of traceability information received with the validation of the claims made within the traceability information received.
- The conflation of the provision of traceability information with the utility of the traceability information provided – e.g. asserting that the presence of traceability information is tantamount to achieving traceability of a physical artefact.

For example:

> *"With improved visibility, each participant in the supply chain will be able to see the progress of goods as they move through the supply chain."*
> [82, p.72]

> *"This improved visibility provides an auditable trace of the footprint of a product, which is particularly attractive to industries where the*

> *provenance of a product is crucial."*
> [71, p.223]

> *AI augmented verification technology can help determine material provenance, while blockchain can provide real–time provenance visibility to reduce tampering and counterfeiting."* [81, p.5]

Viewed through the lens of the information assurance considerations (section 2.3), the issue of the potential weaknesses of the Cyber Physical Bond must be accounted for in the development of a balanced view of the potential utility of blockchain in traceability applications. Considering a case where the RFID tag of a physical artefact is tampered with, thus sending erroneous signals to a receiving TS, shows clearly that blockchain alone cannot guarantee the truth of information pertaining to that item.

Whilst it is plausible that blockchain could safeguard information in a TS, the safeguarding of the creation of the information is not accounted for by the current literature. Two open information assurance phenomena face blockchain-based traceability applications:

- Garbage In Garbage Out (GIGO) – the quality of the informational output of a system can only be as good as the quality of the input, which is subject to fraud and error.
- The Oracle Problem (TOP) – an oracle is the interface between real–world events and the blockchain ecosystem. For example, a reporting observer, RFID tag or third-party data feed could be oracles because they create the information that blockchains process.

An established approach to overcoming the traceability information creation dilemma could be to appoint a third-party authority over the TS. Although firstly this would place a potentially unsustainable financial burden on the supply chain. Secondly, it does not necessarily eliminate SCP animosity towards the TS. Thirdly, the introduction of a central authority with ultimate control over information creation and management in the TS may undermine of the practical or philosophical arguments for the inclusion of blockchain in the TS. The resultant research challenge is thus to seek out a solution to the assurance of the information creation process; without reliance on a single authoritative actor and whilst maximising utility of the information, solving for the stakeholder incentive dilemma elucidated by agency theory.

6.2   *Traceability in AECO*

To date, product-level traceability in AECO has received scant attention from academia, compounded by the fact that existing traceability initiatives predominantly focus on the extractive industries. The rising importance of product-level traceability as established in section 4, in tandem with the

opportunistic paradigm of traceability emanating from the Industry 4.0 movement, converge to invite research into entirely new approaches to achieving product traceability in AECO. This invitation is consolidated further by the potential opportunities presented by nascent blockchain technology research, which lays out the possibility for the creation of entirely novel decentralised business models.

The resounding issue of SCP incentives and motivations in TSs remains one of the key issues, however. No research, specifically addressing the issue of SCP incentives in AECO TSs, has been found to date.

6.3 Future Research Direction

The amalgamation of these issues provides several interesting avenues of enquiry which could lead to novel contributions to knowledge.

SCPs' incentives (perceived benefits) and disincentives (perceived risks) to participate in AECO traceability systems will be investigated through interviews with SCPs in the supply chains of selected focal products. A 'lifecycle perspective' will be adopted, taking into account the information created through the full life of a product, as well as the various stakeholders at different lifecycle stages in the AECO process.

Data will be gathered from DLT experts to garner further insight into the problems (GIGO and TOP) facing blockchain in the context of traceability applications; as well as the potential of a specific area of DLT which is not obviously considered in the blockchain-based traceability literature: token-based incentive mechanisms. These might feature cryptocurrencies and smart contracts within a decentralised business model.

The two streams of knowledge will be combined to develop a conceptual design of a TS based on a decentralised business model which features new 'pull' incentives to align the interests of AECO SCPs in order to overcome the incentive dilemma, and achieve enhanced traceability to unlock transformative benefits in AECO. This could explore the commercial exploitation of the potentially valuable data which would be contained in an AECO based TS.

7   Conclusion

The case for product-level traceability in AECO has been firmly established, taking into consideration a diverse set of drivers and mounting industry concerns. Yet the challenging structure and adversarial culture of AECO is known to stifle the proliferation of innovative technologies, and traceability systems universally are known to falter in the absence of participant buy-in. However, a paradigmatic shift in thinking towards data-driven business models and the emergence of DLT with its associated decentralised business models could hold the key to an entirely new approach to traceability in AECO which is much needed to underpin its transformation.

Although the apparently unfettered support for DLT is not empirically justifiable and the two key problems of GIGO and TOP remain, it seems that it could have a potential part to play in the assurance of traceability information by facilitating an entirely new approach. The solution to traceability in AECO hinges on the degree to which it can integrate incentives which attract SCPs into willing participation and mutually beneficial alignment, based on the benefits they will receive which must outweigh the perceived risks, rather than forcing participation through external agency. The utility of DLT for product traceability in general has yet to be examined from this perspective. One exciting area for future research is the potential use of token-based incentives in traceability systems.

The achievement of product-level traceability in AECO with wholesale buy-in could release new levels of productivity by solving pertinent operational issues, whilst underpinning radical improvements in many other areas which will benefit society as a whole.

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