THE EFFICIENCY OF SINGLE TRUTH: TRIPLE-ENTRY ACCOUNTING

Working paper

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ABSTRACT

We conduct a gap analysis to identify shortcomings in current accounting systems, juxtaposing the application of blockchain-inspired triple-entry accounting (TEA). The application of TEA remediates a number of issues or "pain points" in the accounting domain, from multi-party logistic nightmares and billing inefficiencies to "creative accounting." An inventory of current practice further reveals that, although not intended to serve as an ultimate accounting tool in most cases, DLT has been used to develop a quasi or full TEA application in many separate instances. DLT developers are, with innovative TEA applications, breaking new ground in the accounting world, especially in the logistics and supply chains sectors. Anecdotal evidence suggests that the efficiency effects may well surpass the primary DLT-based TEA input costs, in particular given the addition of single truth: a common, shared ledger with IoT oracles between parties potentiates an agreed understanding of the facts. A TEA system thus reduces friction between parties, and thus lowers costs related to reconciliation and risk management.

Keywords: triple-entry accounting, distributed ledger technology, blockchain, single truth.

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I. INTRODUCTION

From Cuneiform clay tablets dating back to the bronze age to the Aztec talking knots systems, the accounting profession is as old as it is universal. In 1494, the mathematician and monk Luca Pacioli ushered in a revolution in accounting practice by codifying double-entry accounting. Just like Pacioli, William McCarthy, Todd Boyle and Ian Grigg gave birth to a paradigm shift between 1982 and 2005 with their vision for a ledger shared between transacting parties (Ibañez et al, 2020).

Now, the discipline is experiencing something of a second revolution in the form of triple-entry accounting made possible through a new technological underpinning: Distributed Ledger Technology (DLT). The best known mechanism underpinning DLT systems is that transactions made by participants of the DLT are batched and encoded into groups or "blocks" of data. Each block is cryptographically linked or "chained" to the previous block, thereby forming a "blockchain" originating from some original genesis block.

Innovation, however, is not an end in itself. In spite of the hype, the exact ways in which this technology proves its usefulness is not always clear. Specifically, claims about the potential benefits to be brought about by blockchain technology would profit from further empirical enquiry. This is particularly true for research that contrasts costs and benefits.

This paper attempts to provide a first answer to this question, focusing on the efficiency effects of blockchain-based triple-entry accounting (TEA) in particular. We build on existing research to analyze how existing weaknesses and inefficiencies in accounting practices can be addressed and actually are addressed through existing TEA and DLT applications.

With this purpose in mind, this paper is structured in the following manner. First, we lay out the methods employed. Second, we show the results of our literature review: a gap analysis on classical double-entry accounting or CDEA (see Boyle, 2003g; 2003j) and an overview of potential solutions through blockchain or blockchain-inspired TEA systems. Third, we share our empirical findings, by classifying the use cases identified according to their architecture and by enumerating the actual solutions found for each gap previously identified. Fourth, we discuss the implications of our findings, with a particular emphasis on Vitalik's scalability trilemma. We conclude the paper with summary observations.

a. METHODOLOGY

i. RESEARCH QUESTION

How do DLT-based triple-entry accounting applications stand in comparison to their traditional alternatives, from the point of view of efficiency?

ii. OBJECTIVES

1. GENERAL OBJECTIVE

Elucidate the benefits and costs of DLT-based triple-entry accounting applications, relative to non-DLT based, redundant bookkeeping applications.

2. SPECIFIC OBJECTIVES

1. Discern shortcomings and inefficiencies in existing accounting practices.
2. Identify the benefits of DLT-based triple-entry accounting applications according to existing literature.
3. Pinpoint the main use cases of DLT-based triple-entry accounting applications.
4. Identify the benefits of DLT-based triple-entry accounting applications in current practice (either already-deployed applications or PoCs).
5. Ascertain the primary costs associated with DLT-based triple-entry accounting applications.
6. Judge the aforesaid costs and benefits in order to establish the specific business scenarios in which the latter may be noticeably larger than the former.

iii. DESIGN AND ANALYSES

Approaching the topic from the perspective of accounting theory and practice, this study:

1. conducts a *gap analysis* of deficiencies in modern day accounting and accounting-related management practices;
2. identifies *theoretical solutions*, through a literature review, how DLT technology overcomes those problems;
3. takes inventory, through purposive key informant interviews and drawing on secondary data, of *practical applications* addressing these issues that implement DLT-based TEA in some fashion.

iv. Data Collection

A first round of data collection was undertaken between November 2019 and June 2020. This included a review of theoretical literature, analysis of company white papers, expert interviews and key informant interviews. This includes contact with representatives of all the companies studied (and many others excluded from the study upon a first review), which were made so as to obtain primary data.

Once collected and processed, the information collected was sent back to the companies studied for verification of its accuracy, constituting a second round of data collection, undertaken between March 2020 and July 2020. A third round of data collection took place from January 2021 to February 2021, by which the entire working paper was sent to the companies studied for their review and update.

v. Limitations

While this methodology provides insights for the academic and practitioner communities on the outlook of DLT-based accounting systems, we also foresee a number of limitations that would qualify the resulting conclusions, without awareness of which our results would be misunderstood.

First, as the analysis of use cases was purposive, and an effort was made to consult with leading practitioners and solution providers, the results should not be construed as exhaustive or representative. Featured use cases were not randomly selected.

Key informant interviews were held with the principals and developers of featured use cases. While data obtained were taken at face value, subjectivity must be assumed.

Furthermore, while most companies agreed to share information over email or video-conference, there were exceptions. These include failed projects, with whom contact could not be made, and SkyCell, who refused to participate in the study. In these cases, data was obtained from white papers and third party sources (all duly quoted), which qualifies the currentness of the information.

Moreover, while this paper focuses on DLT-based TEA, some of the costs and benefits identified may be attributed to non-DLT TEA or to non-TEA DLT as well. The inspiration behind our approach lies in the TEA typology laid out in Ibañez et al (2021). The authors, following Todd Boyle (1999; 2003b), argue that, on top of the essential characteristics that must be present in TEA systems by definition, there are quasi-essential features that should be present in most TEA systems to maximize their economic desirability. Since economic efficiency is the focus of this paper, and since the one of the “fathers” of TEA intended some of these features to be present in real-life TEA software, we do the same

thing. In consequence, the TEA systems conceived or studied in this paper may include certain elements such as DLT technology, IoT devices, and automated data entry, which are not a part of the definition of TEA. This risks, however, creating the impression that some benefits stem from the triple-entry mechanism itself when this is not really the case.

Finally, a shortcoming of the paper is that "the adoption of the with/without, rather than the before/after, perspective in comparing alternatives" -- a principle put forward by Sassone (1988: 74) -- cannot be fully taken into account, since *actual* use cases are necessarily situated in time. This makes the before-and-after comparison almost inevitable, unless the new technological arrangement is deployed *in parallel* to the previously existing system.

II. TRIPLE-ENTRY ACCOUNTING (TEA)

TEA is an accounting model implemented in software based on a transaction record which is shared between two parties and that relies on signed messages to reach an agreement regarding what the record is. Specifically, the bookkeeping system is structured in a "signature -- signature -- signature" or "offer -- acceptance -- validation" manner: triple-entry bookkeeping (Ibañez et al, 2020). This stands in contrast with other ways of building shared records (table-entry and delegation to a notary) and with maintaining redundant, duplicative mirroring records. The triple-signed receipt is thus the bookkeeping mechanism at the heart of the accounting software, that is, the application or platform that allows information to flow into the decision-making areas of the firm, by means of systematizing, compiling, collating, synthesizing, processing, analyzing and/or auditing.

As shown by Ibañez et al. (2020), TEA is the result of the parallel, independent work of Ian Grigg and Todd Boyle, which converged in 2004-2005. While Grigg focused on the mechanics of triple-signed receipts, Boyle's work developed the economics of triple-entry records and explored database design issues. In other words, Grigg's work was centered around *how to build* a shared record, whereas Boyle prioritized *how the record should look like*.

Moreover, Boyle introduced the influence of the Resources-Events-Agents (REA) accounting model. REA advocates for shared, atomic transaction records able to support multiple "views" of themselves. Therefore, these records may serve as a basis for integrated enterprise information systems within companies, as well as for "collaboration spaces" between firms (McCarthy, 2016).

The advent of blockchain (which itself might have been influenced by TEA; Grigg 2014; see also Ibañez et al, 2020) made it possible to construct completely trustless TEA systems, by enabling the possibility of decentralized signing, timestamping and ordering. REA adherents also consider blockchain to enable Open-edi Business Distributed Transaction Repositories, REA-based shared records which are compatible with a TEA configuration.

The first attempt at building a TEA system underpinned by blockchain was ConsenSys' Balanc3 initiative, started in 2016. While Balanc3 was shut down, it inspired a number of projects (startups and consortia) with the same objective. After surveying the potential advantages offered by TEA according to our literature review, this paper surveys many of those projects.

III. GAP ANALYSIS AND POTENTIAL SOLUTIONS

a. DOUBLE ENTRY BOOKKEEPING

i. ADVANTAGES

> *"What advantages does he derive from the system of bookkeeping by double entry! It is among the finest inventions of the human mind" (Goethe; 1824: 45).*

Traditionally, the acts of contracting, transacting and accounting have involved separate work steps. First, the act of contracting had to be completed. Second, each party delivered what it obliged itself to do (the transaction). Then, the resulting cash or asset flows had to be recorded (bookkeeping). Finally, the information could be processed (accounting).

To complete the third step, for centuries the defining practice comprised "double-entry bookkeeping," a method that requires every transaction to be recorded in one account's credit entry and the debit entry of another account. Instead of one list or ledger, the accountant keeps two: one lists incoming and the other payments (credits and debits). Recording both from where money comes and where it goes leaves verifiable trails. When the total of debit entries match the sum of credit entries, the aggregate result is a balanced ledger.

Historically, double-entry bookkeeping has also been *redundant* bookkeeping. A transaction is recorded twice, as each party has to make its own record of the transaction. The result is a mirroring, duplicative record, as what one party "views" as incoming is viewed as outgoing by the counterparty.

The superiority of the double-entry system over its single-entry predecessor lay in that proper employment of the former provides a way to trace inconsistencies back to their origin. For instance, if the decrease in cash is not recorded following a purchase, but the increase in inventory is, the ledgers will not be balanced. The trail of error can be followed to the unbalanced entries.

ii. LIMITATIONS

While representing an absolute innovation in record-keeping, traditional double-entry accounting is also accompanied by distinct costs and caveats. These limitations are as follows.

1. DATA GENERATION, INTEGRITY, REPORTING, REDUNDANCY AND QUERIES

a. DATA GENERATION, TRANSPORTATION AND FIXING INTO A RECORD

Manual input of data requires slow, extensive and repetitive human work (Andersen, 2016: 2; Hambiralovic and Karlsson, 2018: 33; Mazurel, 2020a; Mohanty, 2018: 47; Request, 2018b: 10, 12). The printing, mailing, filing and handling of paper documents entail high logistical costs (Boyle, 2001f; 2001g).

b. DATA INTEGRITY

Many invoices are sent in paper or by email, and are processed manually. Especially with complex invoices (e.g. when discounts, VAT and other payment terms or conditions are included), this generates a risk of running fraudulent invoices. Furthermore, human mistakes render data error-prone and ambiguous. Thus, a labour intensive and time consuming process of semantic interpretation by both parties is needed (Boyle, 2001b; 2001f; 2001j; Dai, 2017: 65; Hambiralovic and Karlsson, 2018: 34; Vaidyanathan, 2017: 9-10, 23).

c. REPORTING COSTS

Large books require a costly and time-consuming bookkeeping process (Mohanty, 2018: 47). Moreover, books are imperfect due to the excessive aggregation (i.e. lack of granularity) of data (Boyle, 2003g; McCarthy, 1982).

d. DATA REDUNDANCY

Each party in a transaction has its own database with accounting entries, which effectively duplicates data entry (AB, n.d.; Andersen, 2016: 2; Boyle, 2000f; 2000g; 2001j; 2003g; Hambiralovic and Karlsson, 2018: 38, 40; Request, 2018: 9, 12; Vaidyanathan, 2017). Moreover, each party's information is viewpoint-dependent: a transaction is a single event but the record held by one party is not useful to the other[5] (Boyle, 2000f; 2003g; 2003k) and may even be in disagreement with the counterparty's record (Boyle, 2002a).

[5] What one party needs depicted as accounts payable, the other needs as accounts receivable (Boyle, 2000g).

e. PROVENANCE

Firms engage in multitudinous transactions through large numbers of agents, which either do not communicate with each other, or communicate poorly, sending large amounts of important information over email or on paper (Smart Containers Group, 2018: 11; Hambiralovic and Karlsson, 2018). A general overview of granular-level data is difficult to achieve (Boyle, 2003g). This is especially applicable to provenance (Kim and Laskowski, 2018: 1) of physical goods, but also of immaterial elements, such as digital invoices).

"Goods travel through an often vast network of retailers, distributors, transporters, storage facilities, and suppliers that participate in design, production, delivery, and sales, yet in almost every case these journeys remain an unseen dimension" (Provenance, 2015). Viewpoint dependence impedes "drilling down into an expense to understand their supplier's costs and sources" (Boyle, 2003k).

In spite of consumers and governments demanding more transparency, "supply chains are conventionally held secret" (ibid). However, even when the information is available, it is hard to set up efficient traceability systems (Golan et al, 2003). In fact, no single organization can be "trusted to broker all data about every product's supply chain" (Provenance, 2015).

2. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

a. DISCREPANCIES AND DISPUTES

Ambiguity in contracts (Mik, 2017: 18), manual invoice creation and separate accounting sheets per party lead to discrepancies, resulting in a costly reconciliation process (Boyle, 2003c; Figure Technologies, 2020: 2; Vaidyanathan, 2017: 9-10). Moreover, disputes undermine mutual trust, create tensions, and can even lead to the termination of the business relationship.

Furthermore, disputes introduce uncertainty in the firm's activities, as the burden of a number of payments is dependent upon the result of dispute resolution processes. Finally, even balanced entries are not necessarily accurate as, for example, there could be different ways to judge the value and recoverability of debt (Damodaran, 2009: 296, 394; Gopal, 2009: 49).

Intra-firm discrepancies may also take place, due to the simultaneous execution of changes in assets or liabilities in more than one business information system (Boyle,

2002c).[6] The usage of secondary systems to reconcile these discrepancies introduces "rigidity and problems throughout the software environment" (Boyle, 2000g; 2001j).

b. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

Queries and calculations (e.g. invoice calculation) take time and effort, and intervention by third-parties is often required (e.g. third party invoice creation). According to Request (2018b: 13), the cost of the accounting officer's time to process an invoice is between $5 and $15 in the computer consulting industry. Similarly, DLT Labs indicated that the "cost of picking up a piece of paper" ranges between CAD 5 and CAD 50 (Owen, 2019).

Moreover, in most cases, there is a delay in a debtors' settlement of the payment, which is partly due to redundant data entry (Vaidyanathan, 2017: 9).

c. PAYMENT MATTERS

Overpayment (or underpayment by a debtor) may occur with a given frequency due to mistakes (Boyle, 2001j; Dai, 2017: 23, 67; Request, 2018b: 9). Moreover, "everybody is playing the game of paying fewer overpayments than the overpayments that fall in their own favor" (Boyle, 2003c).

In addition, settlements usually go through banks, a system which is "too expensive for micropayment scenarios, exposes SMEs or their xSPs to great security risks, reveals customer lists to banks, as well as their trading partners' customer lists, creates a disincentive for users to send transactions detail where banks can see them, [and] breaks data integration when banks can't forward business data or manifest to payees" (Boyle, 2003h). Rsoner and Kang (2016: 656) further highlight that the lack of a central settlement institution for cross-border payments makes them more inefficient and riskier.

Finally, financing operations (such as factoring and invoice financing)[7] are required due to inefficiencies[8] and other delays in payment. (PayPie, 2018: 9; Request, 2018: 12; Vaidyanathan, 2017; Vliet et al, 2014). According to PayPie (2018: 9), most business payments get paid after 90-120 days, which is also costly in terms of lost opportunities.

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[6] For instance, "a request for inventory may not indicate whether this is a prepaid, or accounts payable, or other terms required for accounting." (Boyle, 2001j)

[7] In factoring, the factoring company takes over collection, whereas in invoice financing, the customer retains control of it.

[8] See Panuparb (2019) for a calculation of the costs of inefficiencies in invoicing and payment.

3. FRAUD AND AUDITING

a. FRAUD AND AGENCY PROBLEMS

Double-entry accounting is not immune to tampering (Mohanty, 2018: 47): a balanced ledger does not ensure accuracy of the entries themselves (Gopal, 2009: 49), as the Enron,[9] Monte dei Paschi[10] and Wirecard[11] scandals vividly illustrate. Since "fabricated transactions and verifications" may take place, regular auditing is necessary (Hambiralovic and Karlsson, 2018: 6). Note that even though the auditing profession benefits from this widespread misconception, audits do not confirm that bookkeeping entries are facts, but only opine that the accounting is true and proper.

Moreover, auditing is itself subject to errors, time consuming and costly: Gee and Button (2019: 6; see also Dorris, 2018: 8; Pacio, 2019b: 4) report that fraud in accounting costs the global economy approximately £3.89 trillion per year.

b. AUDIT NATURE

A company's books represent the entity's opinion about its own finances, whereas an auditor opines over the opinion, e.g. as being "fair, true and proper."[12] This means that auditor statements are not entirely fact-based.

Furthermore, large books require preparing, consolidating, reviewing and evaluating reports and accounts, an auditing process that is time-consuming and costly (Auditchain, 2018; CIAA, 2019; Figure Technologies, 2020: 2; Mohanty, 2018: 47). takes time (CIIA, 2019). In 2018, UK FTSE 100 companies faced audit costs above £700m (Fino, 2018).

The risks of agency problems and auditor capture, which are hard to detect due to the complexity of the auditing task, add another layer of difficulties (Macey and Sale, 2003: 1168; Watts and Zimmerman, 1983). Furthermore, auditor fieldwork is required, since physical inventory examination is often necessary. This drives up auditing costs (Dai, 2017: 37).

This also affects lenders, who are unwilling to concede lending requests to SMBs because they have no access to real-time financial insight at a reasonable cost (PayPie, 2018; n.d.). According to PayPie (n.d), traditional financial institutions turn down 72% of funding requests, "while approvals can take 2 to 7 business days for due diligence, and 2 to 5 business days to get the money in the bank." This can have a considerable impact on

[9] See Powers et al (2002) and CNN (2019).

[10] See Martinuzzi (2019) and Sirletti and Di Pasquale (2019).

[11] See BBC (2020).

[12] Furthermore, an entity may have multiple opinions, depending on the reader.

SMBs, 25% of whose bankruptcies are due to the lack of a positive cash flow (PayPie, 2018: 9).

c. AUDIT SAMPLING

Traditional, manual auditing is necessarily "based on a sampling of records in identified risk areas [sampling the documentation underpinning certain figures] and therefore may fail to capture all relevant data" (Alawadhi et al, 2015: 8; see also Hambiralovic and Karlsson, 2017: 25; Vaidyanathan, 2017: 25).

d. AUDIT FREQUENCY

Audits range from days to months, and audit reports are released months after the event (Ashton et al, 1987), which could imply crucial delays in times of crisis. Additionally, crises are expected to generate delays, as low profits are associated with longer audit delays (Suryanto, 2016: 29).

4. SECURITY AND CONFIDENTIALITY

a. SECURITY (MUTABILITY)

Conventional databases are vulnerable to attacks, especially in the modern context of increased frequency of communication (Dai, 2017: 55; Hearn and Brown, 2019: 4). They are also subject to internal corruption, political pressure, maintenance shutdowns and "nightmarish IT bureaucracy" (Hearn and Brown, 2019: 4).

Moreover, payment requires sharing banking information on both the payer and the payee's side, which creates a risk of interception, fraud and reuse of data (Hambiralovic and Karlsson, 2018: 33; Request, 2018b: 10). Furthermore, uploading accounting information to the cloud exposes "sensitive data (...) to an untrusted environment" (Dai, 2017: 55).

In addition, the reception of the money by the counterparty is often verified manually, resulting in a payment process that takes time and is risk-prone. The inclusion of third parties to take care of some of these issues may solve a number of them, but at the cost of multiplying potential breaches.

Finally, database security based on passwords protects the database only at the entry point, relying upon the integrity of data processing personnel. This creates a risk of unauthorized individuals gaining access to passwords and hence the database contents.

b. CONFIDENTIALITY

Companies seek to avoid the unnecessary revelation of private information, given the tension between the goals of confidentiality and transparency (Brown, 2018; Mohanty, 2018). Auditing statements requires showing sensitive information to auditors and trusting that they will respect confidentiality (Ijiri and Kelly, 1980: 122).

As Ijiri and Kelly (1980: 119) explain, this is because freedom from external inquiries enhances organizational performance in various ways. First, by assuring autonomy, which improves motivation. Second, by promoting a competitive spirit: disclosure threatens competitive advantages, deterring from developing the advantages in the first place. Third, privacy mitigates bureaucratic hurdles, which make organizational units have to explain every detail of their activities. Finally, "privacy promotes experiments since failures can be compensated by successes without having to explain embarrassing results from failures."

In sum, traditional accounting practice suffers from accuracy issues, security issues and, ultimately, cost issues. Furthermore, assuring the correctness through audits entails additional costs. Finally, nonexistent or fraudulent transactions may still be recorded, and the database where entries are recorded may be vulnerable to attacks. Put in "tech" terms, the "pain points" associated with double-entry accounting are that it does not control for insider fraud, as well as that it does not consolidate the tasks of contracting, transacting and accounting. A new system was needed to address the inherent weaknesses of this accounting system.

b. DLT-BASED TRIPLE ENTRY ACCOUNTING

i. ADVANTAGES

The DLT implementation of triple-entry accounting[13] attempts to combine the contracting of a transaction with the execution and the recording thereof. In a smart contract, if certain conditions are met -- which could be either an exogenous event or e.g. the physical delivery of goods by one of the parties to the contract --, (semi) automated execution of the transaction is triggered. Moreover, when a smart contract supported by the TEA network is used to conduct the transaction (e.g. in financial transactions), the smart contract itself serves as a record of the transactions undertaken for the books of *both*

[13] See the limitations section in our methodology for a discussion of why we study the costs and benefits from DLT-based triple-entry accounting and an acknowledgement of the resulting problems of attribution.

parties simultaneously: a *single truth* or a single version of truth (Aste et al, 2017: 22). The ledger both enables and verifies the transaction.

1. DATA GENERATION, INTEGRITY, REPORTING, REDUNDANCY AND QUERIES

a. DATA GENERATION, TRANSPORTATION AND FIXING INTO A RECORD

Where possible, manual input of information is (at least partially) replaced by IoT oracles, which would, in principle, allow for cheaper, faster and more accurate data entry (Dai, 2017: 71; Hambiralovic and Karlsson, 2018: 23; Request, 2018b: 14).

b. DATA INTEGRITY

With TEA, it becomes infeasible to delete or update the instrument without counterparty approval (Mohanty, 2018: 49). Moreover, verification can be enabled at multiple points, as ledgers may be continually broadcasted "at various aggregation levels based on users' roles and demands" to managers, auditors, creditors, stakeholders and other interested parties: (near) real-time disclosure (Dai, 2017: 60-61). Finally, automation and interconnectedness may help minimize human errors and increase integrity (ESMA, 2016: 18; Hambiralovic and Karlsson, 2018; Request, 2018b: 13; Vaidyanathan, 2017: 11, 23; Tyra, 2014).

c. REPORTING COSTS

A public company's aggregate level data is made public through its annual financial report. However, the detailed book with specific transactions is confidential. DLT systems allow granular-level data (which would e.g. be visible and validated by an internal auditor) because entries are facts. This allows for faster composition into aggregate, proof of membership-level data (which would be accessible and validated by the public), and releases time and budget for higher level thinking.

The facilitation of the measurement, recording, reconciliation and viewing of financial information could reduce reporting costs (IFC, 2017; see also Boyle, 2000g), tax filing and payment costs (Boyle, 2001j) and compliance costs (ICAEW, 2018; see also Di Gregorio, 2017). According to Ibrahim (2018: 73), blockchain's "potential savings in processing and bookkeeping costs fall within the range of 50%-80%."

d. DATA REDUNDANCY

When the fulfillment of an obligation by a party (e.g. through the delivery of a good) triggers a smart contract, payments are (semi) automatically executed, thereby fulfilling the obligation of the counterparty. The asset and cash flows are recorded identically and automatically in a shared public place that serves as an input for both sets of books, with no need for duplication of efforts[14] (Boyle, 2001j; 2003a; Hambiralovic and Karlsson, 2018: 34, 46; Request, 2018: 9; Vaidyanathan, 2017: 22; see also Boyle, 2003k).[15]

e. PROVENANCE

IoT devices make the granular tracking of physical characteristics and product whereabouts possible (Kim and Laskowski, 2018: 14). A DLT system can achieve the provenance evaluation and tracing goals without the very high costs and risks of biases and extortion that a centralized system would entail (Provenance, 2015).

Furthermore, provenance tracking can also be improved for non-physical goods. DLT can show that e.g. an invoice comes from a trusted source. More precisely, provenance of source can be handled more safely with pseudonymous systems such as TEA systems (for example, the Ricardo Payment System) and blockchains, which can be the basis for fuller identity systems.

2. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

a. DISCREPANCIES AND DISPUTES

TEA can enable internal integration, but also external integration (Boyle, 2002c), as a TEA system can embody a trusted third party or TTP (Hambiralovic and Karlsson, 2018: 21). The use of IoT oracles reduces the possibility of disputes and removes the need for costly reconciliations between counterparties (AB, 2019; Bible et al, 2017: 4; see also Aste, 2017: 20; ICAEW, 2018; Vaidyanathan, 2017: 6), enhances the fluidity of payment collection -- thereby reducing the need for financial intermediaries -- and increases the coherence of recordkeeping and trust (Aste, 2017: 21).

Moreover, the application of Ricardian smart contracts in a DLT ledger has the potential of further reducing disputes by minimizing the need for juridical interpretation (Mik, 2017: 18).

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[14] Ijiri and Kelly (1980: 117) had also anticipated that distributed databases (shared databases for parent companies and their subsidiaries, which they had regarded as "technically feasible") would reduce redundant data entry.

[15] In 2001, Todd Boyle (2001g) estimated that intrinsic data reconciliation and integration would lead to labor savings of at least 5 million man-hours for the US. This would equal USD 150 billion (using 1998 figures) which equals USD 229 billion after adjusting for inflation for the year 2020.

b. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

Many positive effects may be derived from the ability to process information in real time and the possibility of effectively combining clearing and settlement into a single instantaneous step, together with the automation of payments, the bindingness of facts recorded by the ledger, the impact of the Internet of Things and the lack of need for reconciliation. This could reduce settlement times, delays in payment, provenance tracing time and the difference between payment and review (Bible et al, 2017: 4, 9; BOyle, 2001j; Dai, 2017: 33, 59; ESMA, 2016: 10; Hambiralovic and Karlsson, 2018: 4; Mohanty, 2018: 47), which also means increased reputation (Request, 2018b: 9).

c. PAYMENT MATTERS

With automated payments, the probability of errors may decrease, in spite of not being fully eliminated as a rule.[16] While at some point there has to be some data entry, shifting and minimizing those instances allows to reduce errors. Request (2018b: 10) goes even further to state that "no manual input error [is] possible."

Moreover, the aforementioned reduction in payment waiting periods entails a fall in the need for associated financing costs (factoring, reverse factoring; ibid: 14). Refunds could furthermore be facilitated as the TEA system offers proof of contract and payment (Boyle, 2001j). Finally, payment histories could enable the computation of empirical reputation metrics without the need to reveal private information to other parties and without depending on banks (Boyle, 2003d). This would reduce transaction costs, incentivize due diligence and further reduce financing costs due to increased creditworthiness transparency (Boyle, 1999; 2001j; 2003d; 2003h; 2003j).

3. FRAUD AND AUDITING

a. FRAUD AND AGENCY PROBLEMS

Through DLT technology, the risk of fraud is expected to decrease (Hambiralovic and Karlsson, 2018: 20; Dai, 2017: 59, 67): "time-delay between entry and review is minimized, and wrongful entries are instantly visible and virtually impossible to erase" (Hambiralovic and Karlsson, 2018: 38), which impairs and deters fraudulent transactions. Corrupt employees and other actors are more easily detected in real time (Hambiralovic and Karlsson, 2018: 43; AB, n.d.). Moreover, a transaction will only go through if "done

[16] See the Ricardo Payment System(Grigg, 2001, 2003; Grigg and Howland, 1997; Howland, 1996) for an example of full elimination of manual input errors.

according to set rules assigned to the transaction" (Hambiralovic and Karlsson, 2018: 31). Finally, the information asymmetries that make agency problems arise are eliminated through the shared ledger (Aste et al, 2017: 22-23).

b. AUDIT NATURE

TEA's and DLT's repercussions in audit costs are threefold. First, it enables fact-based accounting, i.e. (running code and) data audits itself. In other words, books have such internal strength and are so encompassing that can be relied on as facts

Second, the cost of auditing is reduced. Third, the character of the audit task is impacted, thus modifying the price-quality ratio of audit services.

The cost of auditing falls as a result of reduced reliance on auditors for scrutinizing transactions, reduced auditor fieldwork (as remote examination could substitute physical inventory examination) and increased comparability of two parties' accounts without compromising data privacy (Dai, 2017: 37; Fanning and Centers, 2016: 57). Lowering the cost of auditing unambiguously increases the net value derived from the business.

As explained, DLT also enhances internal and external auditing/validation. Furthermore, DLT fundamentally strengthens the independent assurance function -- the external audit -- by improving speed and sampling.

Finally, the nature of the audit task changes, as auditors have more time to focus on more meaningful questions. For instance, auditors could concern themselves with the recording and classification of transactions,[17] a task whose judgmental elements often require specific knowledge of the business that takes time to acquire (ICAEW, 2018: 6).

c. AUDIT SAMPLING

With DLT in accounting, viewing permissions (*observer nodes*) enable *whole population sampling*, also known as *100% testing*, where the number of transactions audited is "n = N" or "n = all;" (Alawadhi et al, 2015: 8; Liu et al, 2019: 27; Meyers, 2020). This removes the chance factor, as well as sample selection biases introduced by auditor's subjective judgements (sample selection). The result is more robust and less uncertain audit conclusions (Vaidyanathan, 2017: 25), superior fraud detection abilities and mitigation against auditor capture. Combined with fact-based accounting, this allows observers to audit based on the entire set of relevant facts.

[17] For instance: "If a transaction credits cash, is this outflow due to cost of sales or expenses, or is it paying a creditor, or creating an asset?" (ICAEW, 2018: 6).

d. AUDIT FREQUENCY

Audit frequency could increase even up to continues, real-time auditing, with an auditor becoming a permissioned node within the DLT network and constantly monitoring transactions as they occur (Hambiralovic and Karlsson, 2017: 25). This enables identification of abnormal behaviours in real time (Dai, 2017: 31, see also 74).

A proposed example of a continuous, real-time accounting application occurring between agencies and audit authorities is the Federal Court of Accounts of Brazil (TCU), which advocates timestamping transactions as they are written to the DLT system (Oliveira Simoyama et al, 2017) as a way to create obstacles for corruption.

4. SECURITY AND CONFIDENTIALITY

a. SECURITY (MUTABILITY)

DLT provides a series of advantages in security. Firstly, there is tamper-proof, immutable record-keeping[18] (Tasca and Tessone, 2018: 5; Ward and Lundkvist, 2016: 12:42), preventing parties from disputing or modifying the record of a transaction once agreed (Oliveira Simoyama, 2017: 181). This makes it difficult for rogue traders and other bad actors to disrupt the system, modifying records in their favour (Kim et al, 2019: 186; Makridakis and Christodoulou, 2019: 10).

Secondly, there is "no single point of attack" as is the case with current systems (ESMA, 2016: 12). Thirdly, a more empirical internal accounting basis results from the application of DLT to the execution and recording of transactions at the lowest level of line transactions, which informs and controls the higher-level statutory accounts.

Finally, unlike conventional password-based security, cryptosystems protect the database not only at the entry point, but "even if an unauthorized person walks through it, assuming, of course, that the physical security over the encryption-decryption device is properly maintained" (Ijiri and Kelly, 1980: 121, see also Diffie and Hellman, 1976).

b. CONFIDENTIALITY

Private and permissioned blockchains protect data privacy by only awarding access to predetermined or preselected, relevant parties (Dai, 2017: 12). Thus, by sharing

[18] The cryptographic links between blocks mean that modifying any previous block in the chain would invalidate all subsequent blocks, making the chain — as a whole — very difficult to manipulate. In Satoshi Nakamoto's original 2008 white paper, the probability of an attacker successfully manipulating the blockchain becomes prohibitively expensive and/or exponentially more improbable even after only a handful of blocks are added. Given that modifying any previous block in the chain would invalidate all subsequent blocks, the cryptographic links between blocks are, technically speaking, secure.

information securely but transparently to, and only to, the relevant parties (Mohanty, 2018: 42), the tension between transparency and confidentiality can be resolved, allowing to achieve both.

ii. Potential limitations and costs

As explained at the beginning of this paper, while TEA is a relatively straightforward concept to build a shared transaction record through signed messages, our interest lies in the DLT incarnation of TEA. DLT may allow to "bring TEA to life," thereby realizing many of its potential benefits, as well as other benefits stemming from DLT in itself. Nonetheless, the application of DLT in accounting implies the introduction of a technology that has its own limitations and costs. This section provides an overview of these issues, as well as issues specific to TEA (whether DLT-based or not), without prejudice to the existence of some solutions to them (see section *VII. Discussion*).

1. Potential limitations

a. Agency problems and auditing

In principle, there are a number of drawbacks that could also emerge from the application of DLT in accounting. New agency problems might ensue with the curators of the network, as well as with those administering the oracles (when not fully automated). As for auditors, while the auditing of transactions would be easier, auditors would require new, more elevated skill sets (e.g. reading code) to detect potential fraud. Finally, real-time auditing might not be in the interest of many incumbent parties, who take advantage of time lags in reporting periods to "conceal activities in an effort to gain an element of surprise or a delay in the disclosure of materially negative trends in performance" (Auditchain, 2018: 17). This could lead to obstacles in implementation.

b. Inflexibility

Moreover, immutability is not in itself a panacea. Oracles are vulnerable to "man-in-the-middle" attacks (Piscini and Kehone, 2018: 6, 8) and they can be corrupted. For instance, imagine a smart contract retrieving the value of debt owed according to economic variables published in a website. If the website were hacked, the smart contract would execute in an undesirable manner. RFID tags are also susceptible to manipulation

(Mitrokotsa et al, 2009). In such scenarios, un-doing the "immutable" blocks in the ledger could require a costly fork (Psaila, 2017b: 3).

Another drawback of inflexibility is manifested in that solutions resorting to smart contracts may end up excessively tied up by rigid arrangements. While smart *Ricardian* contracts could mitigate rigidity, they display the drawback of having a very limited history of implementation (Auditchain, 2018: 17). Furthermore, smart contracts might impair the possibility of efficient breach (Arruñada, 2017).

Even Todd Boyle, who originally put forward the TEA concept and advocated for or "encrypted" and "persistent" storage of transactions (Boyle, 2001e; 2001f), warned against excessive inflexibility resulting from immutability: since many entries to books are part of an unfinished business process, they are tentative, ambiguous and possibly incorrect. On certain occasions, it may be necessary to allow deletion so that the general ledger is in sync with business reality (Boyle, 2000b; 2003l; 2003h).

Immutability should then be a feature of only a part of the information within the TEA system: "posted information" (Boyle, 2003l). However, the system should also acknowledge the tentative character of "unposted information," allowing to delete tentative entries via journal type transactions (as opposed to edits which leave no trail). This is also the position of David Hartley (2020), CEO of Pacio, who also points out the need to be able to delete personal data to accommodate privacy reasons and to meet GDPR requirements.

The issue of rigidity is also fundamental because, at least for most contracts, it is not efficient or even possible to address every possible outcome. This is no less true for smart contracts (Bible et al, 2017: 9). For this reason, the parties may also "include some level of flexibility so they do not limit themselves" (ibid). This opens the door to vulnerabilities, errors, difficulties in renegotiation/modification of terms, settlement problems and disputes, especially since "smart contracts have not been tested thoroughly in the court system" (ibid).

c. TRUST

As for trust, while DLT systems such as blockchains may reduce the need for it, one should bear in mind that permissioned blockchains are not completely trustless. A decision by the majority of the members or by a centralized agency with override authority could roll back transactions (e.g. Ethereum fork). Therefore, the trustlesness of a permissioned blockchain relies on the credible decentralisation of the block producers and the architecture of the consensus protocol (Liu et al., 2019: 23; see also Arruñada, 2017: 104).

d. DECENTRALIZATION

Another shortcoming of a DLT system could be that, if set up as a decentralized network, power could unexpectedly end up centralized by an unforeseen circumstance (e.g. Bitcoin's mining pools in China).

e. ATTACKS

Despite the potential of DLT, security is still recognized as one of the main challenges for TEA systems (Odom, 2013; Request, 2018a: 25), especially given the immaturity of DLT technology (Barrit et al, 2019).

Decentralization has some drawbacks. Due to decentralization, there is no fraud department to report e.g. a phishing attack (Psaila, 2017b: 3; see also Bible, 2017: 10). Rückeshäuser (2017: 16) goes as far as to state that the risk of fraud is even higher with blockchain, as "exerting the majority of computer power is easier than circumventing internal and external control systems in conventional accounting systems."[19]

Moreover, "as any new technology matures it will be under constant attack from cybercriminals and hackers testing and probing for vulnerability" (Vaidyanathan, 2017: 31; see also Boyle, 2003g), which suggests one cannot be fully sure about the security of DLT. Odom (2013), for example, points out a number of technical vulnerabilities in Open-Transactions, such as the risk of buffer overflows by an attacker. Request (2018a: 25), in turn, warns against the theft of signature keys.

It has also been pointed out that corrupting a DLT network provides "economies of scale" to the hacker:

> *"A flaw in the system could have wider consequences. Indeed, if someone was to break into the system, he/she might have access not only to the information stored at the point of attack but to the full breadth of information recorded on the ledgers (...) Furthermore, if the technology itself (e.g., the encryption techniques) was hacked, the risk of contagion could extend beyond the single DLT network under attack, as the protocols*

[19] Psaila further (2017a: 3) even argues that the natural boundary to the risk of unnoticed modification of a paper receipt (due to its physical nature) is nonexistent in electronic files, which cannot be perceived physically. This statement can be challenged, however, as digital signatures and hash chains provide strong protection against modification in practice, as long as there is independent software.

used by different DLT networks tend to be similar." (ESMA, 2016: 17)

Naturally, this assumes that the aforementioned chance of breaking into the system is actually large. However, for the moment it is in fact user-centric problems (lost keys, stolen keys, infected software) that dominate the landscape of issues, with design/architecture breaks being smaller in number and quicker in fixing.

Finally, there are other limitations to the technology, such as the possibility of payments to incorrect addresses, internal leaks and losses of private wallet keys (Hambiralovic and Karlsson, 2018: 26; Psaila, 2017b: 3), as well as risks specific to private blockchains, including reliance on trusted parties and few nodes "rather than the power of the masses as in public chains" (Hambiralovic and Karlsson, 2018: 19).

f. NECESSITY

It is crucial to consider to what extent TEA is really *necessary*. That is, to what extent it is not only possible, but also economically viable and efficient. In this direction, Boyle (2001e) argues that any midrange accounting package with a browser interface[20] able to support a high-end multi-company accounting system could permit building a shared transaction repository. Transactions could be recorded in a classic double-entry manner "within such a ledger for each party, just as intercompany transactions have been formed within controlled groups, for the last 100 years".

Nevertheless, Boyle (2001e) also noted that multi-company classic double-entry accounting ledgers do not work out of the box, because:

- "they impose a number of unnecessary structures on the parties, (...)
- [they] constrain their choice of software to a common platform[,]
- the "trusted third party" has way too much access to all of your data,
- the processing of external transactions is too tightly coupled, (...)
- maintaining two CDEA ledgers goes far beyond what is strictly necessary to achieve the objective of the shared repository;[21] (...)
- [the] process is way too complex. To create correct double-entry postings to every unrelated company requires knowledge that only exists inside the companies (...)

[20] "Such as Great Plains or Lawson" (Boyle, 2001e).

[21] See also McCarthy (2001).

- [the] computer processing [cost] for a whole midrange/ERP system is too great. Doesn't scale due to hardware costs[,]
- it is far too difficult to add new companies, and each new company requires too much system resources."

For these reasons, Boyle (2001e) concluded that this "model has no hope of widespread adoption" and, in turn, a TEA system with a "single truth," i.e. a record of the *essential*[22] components of a shared transaction was necessary (Boyle, 2002b). Nonetheless, it is still necessary to ponder whether there are respects in which non-DLT or non-TEA systems could be more efficient (Barrit et al, 2019).

2. COSTS

The relative costs of setting up and maintaining a DLT platform should be taken into account. In this sense, we should note that a DLT accounting system could be overlayed on top of an existing traditional system, or could replace it. In the former case, it remains to be seen whether this would just signify an additional layer of costs, or whether it would entail synergies that make up for them, leading to net benefits even if the original system is not replaced. Furthermore, triple-entry accounting is not necessarily conceived to require DLT, which begs the question of whether it would be better to compare DLT TEA use cases with non DLT TEA use cases. Nonetheless, since the TEA cases identified in the next section are all DLT-based, this shows that the one thing more relevant than Boyle and Grigg's theory is evolving practice.

Following Sassone's (1998: 74) typology, it seems that the "cost displacement/avoidance," supplemented with the "time savings time salary" approach would be most appropriate to evaluate the costs and cost savings of DLT platform. That is, one should compare the costs that setting up and maintaining a DLT TEA system would entail, with the costs that such a system would displace -- if already existing -- or avoid -- if still not existing, but expected -- (Sassone, 1988: 76-77). One should supplement this with the time savings time salary approach, by calculating the time investments that the system will require as well as save, and then "multiply that by the workers' loaded salaries or wages" (Sassone, 1988: 78).

Some of the main costs that a DLT-based TEA system would entail include:

[22] CustomerID, vendorID, product IDs, date, time, and price (Boyle, 2000f; 2002c).

- Hardware costs (Czarnek and SecondLeo, 2014). This includes the costs of hardware machines (to process the consensus algorithms, mine, forge, etc.). Prices can go from USD 2000 to USD 3000 per machine (ibid). Czarnek and SecondLeo (2014) estimate that the Nxt network would require USD 50,000 in hardware per year in order to sustain a system the size of Bitcoin. Bitcoin, in turn, requires USD 70 million per year in hardware.
- Energy prices times megawatts-hour / hash rate (hashes per second[23] or H/s) ratio (ibid). Czarnek and SecondLeo (2014) estimate a cost of USD 0.12 cent per kWh, whereas 520,000 MWh per year are needed to power Bitcoin and 66 MWh per year would be needed for a Bitcoin-sized Nxt network.
- Maintenance costs (Liu et al, 2019: 25).
- "Reconciliation between records on a blockchain, other reports, and physical existence" (ibid).
- The cost of "obstruction from managers due to externality of increased transparency." (ibid)
- Security costs: there are "no universally recognized, generally accepted metrics by which to measure and describe cybersecurity improvements" (Rosenzweig, 2019), it is particularly hard to quantitatively compare the security of blockchain systems with non-blockchain systems and even more so with paper-based systems. Granted that with a proof-of-work based blockchain, one can measure the computing power needed for a 51% attack given the current hash rate, thus calculating ") the cost of such an attack (Mekić et al, 2018: 34-35); nevertheless, this is an incomplete metric: other security costs, such as the cost of "potential information leakage to outsiders, including business competitors and customers" (Liu et al, 2019: 25) should also be taken into account.

These costs should be taken in relation to the system's computational capacity (Larimer et al, 2018). A hypothetical cost-benefit analysis framework should take these costs into account, as well as other cost savings that a DLT-TEA system could bring about, such as reducing supply chain financing costs (see Panuparb, 2019).

[23] Solved hash functions sent to the network (Mekić et al, 2018: 31), per machine or for the whole pool.

IV. CURRENT PRACTICE

a. TRIPLE ENTRY ACCOUNTING USE CASES INVESTIGATED -- AND THEIR ARCHITECTURE

White papers and the academic literature may point out some benefits of DLT-based triple-entry accounting. Even in the absence of direct empirical knowledge of these applications, theoretical inquiry and business concepts amount to much more than mere and baseless speculation. Methods such as induction and deduction can aid in ascertaining the effects of TEA from knowledge of the broader reality. For instance, even if cost-saving effects from shared ledgers were not empirically proven, they can reasonably be assumed to exist, since redundant ledgers have positive costs and with positive costs two ledgers are more expensive than one.

Nevertheless, empirical inquiry is still king. Only through empirical data collection can the significance of a benefit be ultimately measured. Furthermore, theoretical speculation may assume away important variables, thus polluting relative cost-benefit comparisons. For this reason, we approached existing TEA use cases to obtain information on their costs and benefits.

Exhausting the universe of TEA applications is hardly feasible, particularly given that TEA is an architectural configuration that can be arrived at inadvertently (Ibañez et al, 2020). Moreover, some use cases might embody the principles of TEA more fully than others, i.e. there is a continuum between "a flavor of TEA" and "an application designed to materialize the designs of Todd Boyle and Ian Grigg." There is thus a risk of diluting the most representative applications through wide sampling.

For these reasons, we resorted to a method of purposive sampling, relying on web-based searches for projects utilizing the terms "triple-entry accounting," as well as a few representative applications emerging from key informant interviews. Hence, our universe of use cases is composed of the following applications and platforms explicitly advertised as TEA use cases: Gilded, Request, Pacio/Tender, bBiller, Balanc3, Provenance/Figure, PayPie, Open-Transactions, Fizcal/PrimePayroll, Luca+, Ledgerium, Auditchain, AB Fingertips Suite, Track.Capital.

We also studied R3 Corda, for design deliberately meant to be grounded on triple-entry bookkeeping, as well as two CordApps in which an accounting layer was built on top of the bookkeeping layer: Fusion LenderComm, Siam Commercial Bank B2P. These use cases emerged from key informant interviews, as did four other use cases: T-mining DLT Labs, TradeLens, ThoughtWorks and SkyCell/LogiChain.

Finally, we included Bitcoin, Ethereum and XRP Ledger in our research due to their salience and for comparison purposes. Note that Bitcoin is regarded to be the first

example of blockchain-based triple-entry bookkeeping (Grigg, 2011, 2014, 2019b, 2019d; Ibañez et al, 2020; Tyra, 2014; Sleeter, 2014).

The following table displays the full list of use cases studied for this paper, as well as their main features and architectural characteristics, as per the data collection of our research.

	Type	Industry sector	TEA	DLT	Blockchain	Ecosystem or language	Consensus mechanism	Intentionally TEA	REA	Public, private, permissioned, permission-less	Digital identity verification	Network based settlement	Smart contracts	Ricardian contracts	Gossip protocol	Commercially deployed	Clients	Integrates IoT
Bitcoin	Ecosystem	Payment	**bookkeeping only**	✓	✓	Bitcoin	PoW	✗	✗	Public, permissionless	pseudo-anonymous	✓	limited	✗	✓	✓	1 million active addresses[24]	✗
Ethereum	Ecosystem	Smart contracts	**enabled**	✓	✓	Ethereum	PoW	✗	✗	Public, permissionless	pseudo-anonymous	✓	✓	✗	✓	✓	434,000 active addresses[25]	✓
XRP Ledger	Ecosystem	Payment & finance	✗	✓	✓	XRP	XRP Consensus	✗	✗	Public, permissionless [26]	pseudo-anonymous	✓	✓	✗	✓	✓	1,400,000 wallets	✗
R3 Corda	Platform	General purpose, origins in finance	**enabled**	✓	✗	Corda	Validity and uniqueness consensus	✓	✗	Supports all models	identified[27]	✓	✓	✓	✗	✓	R3 Corda Consortium	✓
Fusion Lender-Comm	Application	Finance	✓	✓	✗	Corda	Validity and uniqueness consensus	✓	✗	Private, consortium	identified	planned	✓	✗	✗	✓	NP Paribas, BNY Mellon, HSBC, ING, State Street and Natixis	expec-ted
Siam Commercial Bank B2P	Application	Finance	✓	✓	✗	Corda	Validity and uniqueness consensus	✓	✗	Private, consortium	identified	✗ (bank)	✓	✗	✗	✓	Siam Cement Group, Minor Food, Sansiri	✗
T-mining	Platform	Logistics	✓	✓	✓	Ethereum	PoS	✗	✗	Private, consortium	identified	✓	✓	✗	✓	✓	International Liquid bulk player with HQ in the Netherlands	✓
DLT Labs	Application	Logistics	✓	✓	✓	Hyperledger Fabric	Raft & kakfa	✗	✗	Public, permissioned	identified	✓	✓	✗	✓	✓	WalMart	✓
TradeLens	Application	Logistics	✓	✓	✓	Hyperledger Fabric	Raft & kakfa	✗	✗	Private, permissioned	✓	✗	✓	✗	✓	✓	120 participants	✓
Thought-Works	Application	Energy trading		✓		Quorum (Ethereum)	Raft	✗	✗	Private, consortium	identified	✓	✓[28]	✗	✓	✓	VAKT	

[24] Number of unique addresses that were active in the network in successful transactions either as a sender or receiver (Glassnode, 2021a).
[25] Number of unique addresses that were active in the network in successful transactions either as a sender or receiver (Glassnode, 2021b).
[26] Uses a Unique List Node for validation, but it is recommended only.
[27] However, if an identified node is willing to route traffic to pseudonymous parties, even an entire Corda network could be pseudonymous.
[28] Smart contracts are used only to store state.

Gilded	Application	Payment	✓	✓	✓	Request	PoW/PoS*	✓	✗	Public, permissionless	planned (identified)	✓	✓	✗	✗	✓	1,000 users+	✗
Request	Ecosystem, platform and Application	Payment + DeFi	**enabled**	✓	✓	Ethereum (& IPFS)	PoW/PoS[29]	✓	✗	Public, permissionless	pseudo-anonymous	✓	✓	✗	✗	✓	$780,000 transacted	✗
Provenance / Figure	Application	Finance	✓	✓	✓	Hyperledger Fabric	PoS	✓	✗	Public, permissioned	identified	✓	✓	✗	✓	✓	100+ members	✗
Luca+	Application	E-invoicing	✓	✓	✓	Ledgerium	dPoS & PoS	✓	✗	Private, consortium	identified	✓	✓	✗	✗	✓	76 financial institutions	✗
Ledgerium	Platform	Accounting + auditing	✓	✓	planned	Ethereum & Quorum*	PoA	✓	✗	Hybrid (Quorum)	identified	✓	✓	✗	✗	**planned**	planned	✗
Pacio/ Tender	Platform	Business suites	✓	✓	✓	Holochain	Configurable	✓	✓	Configurable	Configurable	✓	planned	planned	✓	**planned**	planned	planned
PayPie	Application	Credit Risk Analysis	✓	✓	✓	Ethereum (& IPFS)	PoW	✓	✗	Public, permissionless	pseudo-anonymous	✓	planned	✗	✓	**planned**	planned	✗
Auditchain	Protocol ecosystem, platform and application	Real-time auditing	**n/a**	✓	✓	Interoperable layer 2 protocol	PoW & PoS	✓	✗	n/a	identified	✓	✓	✓	n/a	**planned**	60 members	✗
Open-Transac-tions	Platform	Finance	**bookkeeping only**	✓	✓	Off-chain implementa-tion of Bitcoin protocol	own	✓	✗	n/a	pseudo-anonymous	✓	✓	✓	n/a	**planned**	planned	✗
SkyCell / LogiChain	Application	Logistics	✓	✓		Ethereum, Hyperledger Fabric and Corda		✗	✗	Private, consortium	identified	planned	planned	✗	✓	**planned**	planned	✓
bBiller	Application	Supply chain payments	✓	✓	✓	Not yet decided	Not yet decided	✗	✓	Public, permissionless	Not yet decided	✓	planned	✗	n/a	**planned**	planned	planned
Fizcal/Prime Payroll	Application	Accounting, auditing	✓	✓	✓	no data	no data	✓	✗	no data	no data	✓	no data	no data	no data	✗	✗	✗
Balanc3	Application	Enterprise asset management	✓	✓	✓	Ethereum & IPFS	PoW	✓	✗	no data	pseudo-anonymous	✓	planned	✗	✓	✗	✗	✗
AB Fingertips Suite	Application	Accounting	✓	✓	✓	The Accounting Blockchain		✓	✗	no data	no data	✓	✓	✗	no data	✗	✗	no data
Track. Capital	Application	Accounting	✓	✓	✓	IBM Blockchain (Hyperledger Fabric)	Kafka	✓	✗	Private, permissioned	no data	no data	no data	no data	no data	✗	✗	no data

Table 1: Architectural survey of triple-entry use cases.

[29] Uses PoW but plans to move to PoS when Ethereum moves to PoS.

b. PINCH POINT FIXES USING TRIPLE ENTRY ACCOUNTING

Upon studying the use cases listed above, the following pinch point fixes of the gaps identified above emerged. Note that the statements made by the companies reviewed were taken at face value.

1. DATA GENERATION, INTEGRITY, REPORTING, REDUNDANCY AND QUERIES

a. DATA GENERATION, TRANSPORTATION AND FIXING INTO A RECORD

Automation of data input was an advantage in almost all of the cases reviewed. Some companies reported this to be the case already and others expected to achieve it in the future. Loudon Owen (2019) -- CEO at DLT Labs -- and Christiaan Sluijs (2020a) -- CTO at T-Mining -- reported that data collection was automated, with Internet of Things (IoT) devices playing a very important role. Both DLT Labs and T-Mining implemented GPS tracking technology to know exactly when and where shippings are, as well as to input into the ledger the amounts to be paid the moment they become payable. This has largely replaced the usage of emails and phone calls to communicate location, itinerary and amounts payable.

DLT Labs also specifically noted that Walmart necessitated 70 carriers to carry goods to their facilities. Each of those carriers charged a fee consisting of a fixed cost plus 170 variable charges, such as total mileage, off-road mileage, and many more quantitative and qualitative factors. The resulting complexity used to be hard to handle and the usage of IoT devices has enabled the automation of calculations.

Moreover, DLT Labs noted that Walmart requires approximately 500,000 deliveries per year, but that number was *unavailable* before setting up the system at issue. It was only the implementation of the TEA system that enabled aggregation in the first place.

Another "fix" was reported by The Block Ledger, through its products Luca+ and Ledgerium. The solution reportedly reads invoices directly from the user's email inbox, automatically inputting them into the user's accounting platform, thus eliminating manual data entry (either paper based or PDF based). Reported cost savings amount to at least 70% -- from AUD 31 per paper invoice and AUD 28 per PDF invoice to approximately AUD 9 (Mehmood et al, 2019; The Block Ledger, 2019).

b. DATA INTEGRITY

Solutions identified for data integrity partially overlapped with those for manual data generation, since a number of use cases showed reduction in the error-proneness of the data following data entry automation. This was the case of T-Mining and DLT Labs.

According to Loudon Owen (2019) from DLT Labs, data with mistakes used to be recorded, but that was no longer the case under the new IoT-based system. Moreover, Walmart now knows how error-prone its data is and was, which previously was not the case. "From my perspective, they had 0 data integrity, and now 100 (...) they have moved to in-effect, actionable data."

Another example of improvements in data integrity is provided by Request (2018a: 13), which set up its system in such a manner that the outstanding balance of trade receivables is automatically recorded in the accounting software, thus enabling intrinsic validation/auditing. This prevents wrongful recordings (Request, 2018a: 19).

c. REPORTING COSTS

Figure Technologies (2020: 20) reported through their subsidiary, Provenance Blockchain, Inc. that a potential reduction in reporting costs estimated in 100 to 150 bps or USD 30 to 45 billion annually could be achieved. Reportedly, "real time transparency of underlying collateral eliminates reliance on monthly remittance reports, allowing for continuous pricing and eliminating information asymmetry."

Another example of a reduction in reporting costs was given by Pacio, who introduced a software named TARI® (Target Average Rate Index) which "turn[s] financial data into reports." This provides "actionable business improvement insight" in real-time thanks to blockchain (Pacio, 2019d: 5), and has resulted in "an average improvement in unit output of 40+% boosting net profit by an average of 96%" in the businesses applied (Pacio, 2019b: 5).

A fall in reporting costs is also anticipated by Auditchain, though the product is expected to be commercially released in 2021. The company claims to be able to offer real-time reporting, rather than "providing an audit opinion on historic information" months after the fact (Auditchain, 2019a).

d. DATA REDUNDANCY

According to DLT Labs, Walmart and its carriers now have a shared, automated record of payments due, which has minimized the costs of the bookkeeping process which, until now, was both lengthy and duplicative. T-Mining reported having achieved a similar accomplishment.

Similarly, Request (2018a: 13, 19) stated that accounting and invoicing systems can be based on a single set of facts imposed from below, instead of being determined by high level accounting data ((internal, invoices, reports, tax). This eliminates reconciliation within companies but also between companies. This is reported as particularly important for intra-group transactions, which "are estimated to be more than 30% of international business flows" (ibid: 20).

e. PROVENANCE

As previously discussed, both DLT Labs/Walmart and T-Mining reported being able to achieve an unprecedented level of granularity, using GPS technology to have knowledge of the whereabouts of every carrier or shipment in real time. Walmart had also increased its provenance query abilities in its collaboration with IBM, which allowed the firm to be able to reduce the time necessary to search for the origin of a mango from almost 7 days to 2.2 seconds (Himoff, 2019).

Another entity with provenance query capacities is SkyCell. SkyCell executes international shipments within 20 days, with containers that protect their cargo from extreme temperatures, ranging from -30°C to -70°C (SkyCell, 2018a). The firm implemented a system of IoT sensors in each container. These sensors "collect data during the whole trip," which "is uploaded to the SkyCell database once the container passes one of the numerous gateways. This creates a near real-time visibility of the shipment status and condition as well as an alarm function if a shipment is at risk and needs an intervention by a relevant stakeholder" (Groeneveld, 2019a).

SkyCell's blockchain-based monitoring software reportedly managed to reduce the number of temperature deviations in its shipping containers to 0.1% -- versus a market average of 8.5% (Smart Containers Group, 2018: 19; see also Groeneveld, 2019a). Since the software used allows the container to "recharge automatically when placed in a cold room or reefer truck" (SkyCell, 2018a), this has enabled a reduction in fuel usage, making CO_2 emissions drop by almost 20 tons relative to the baseline (SkyCell, 2018a; 2018b).

2. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

a. DISCREPANCIES AND DISPUTES

A number of use cases reported a reduction in the number and costs of disputes. Luca+ estimated that the switch from paper invoicing to electronic invoicing through their system produced savings of 20% in dispute management: from AUD 4 to AUD 3.2 per invoice approximately (The Block Ledger, 2019). The mechanism behind these savings were not specified.

Even larger cost reductions appear to have resulted from the "single source of truth" entailed by DLT systems. *DLT Labs* explained that, to the complexity of the invoicing system (170 variables times 70 carriers) one should add that each party keeps a separate account, each using separate accounting systems and practices, which makes reconciliation practically impossible. In this context, companies are subject to many different pressures: lack of trust, the desire not to lose a business counterpart, the desire not to "look greedy," and the tendency to try to "scratch every last penny."

This created difficult situations, as Walmart is the "largest company in the world by revenue," but not by profit, which meant it could not afford the luxury to authorize overpayments. Hence, payments are only authorized if they pass a strict -- and largely manual -- verification process: there is a "zero tolerance policy for discrepancies between payment and the calculations." Aside from long waiting periods, discrepancies with the calculations of the carriers were inevitable. This used to lead to costly dispute resolution processes and, often, business termination.

Following the implementation of the DLT-based TEA system, this is no longer an issue, as the calculations are the same for carriers and Walmart. The satisfaction of the carriers is reportedly illustrated by the fact that carriers "started using the same [system] in rail transportation and ocean shipping," aside from the lower number of disputes and longer business relationship duration attributed to the higher trust. This is a consequence that Ledgerium has also reported: smart contracts' increase transparency (Mehmood et al, 2019).

b. PROCESSING, INVOICE GENERATION AND SETTLEMENT ISSUES

Request (2018b: 13) claimed that processing an invoice would be inexpensive using Request, as well as faster (even real-time) and more accurate. *DLT Labs* also reported

large savings in invoice processing, although it also did not provide figures specifying the extent of the savings.

Luca+ reported that their product allows one to see "the stage in fulfilment of each invoice, including when it [has] been paid." It also allows one to "estimate future cash flows, while also providing information on (…) clients, including average payment times and missed payments" (The Block Ledger, n.d.).

Finally, the fact that smart contracts can execute a transaction on their own, thus reducing the need for intermediaries was highlighted by both Ledgerium (Mehmood et al, 2019) and DLT Labs.

c. PAYMENT MATTERS

DLT Labs reported a significant reduction in Walmart's overpayment and underpayment frequency, as well as in the time required to execute a payment. As a result, factoring costs fell for the carriers, since timely payment means the carrier no longer is required to take out expense bridge loans. They are thus willing to be awarded contracts at a comparative discount, resulting in a win-win situation. Figures were not provided, however.

In a similar fashion, T-Mining reported an increase in payment speed from many months to 60-90 days, as well as an optimization of port calls that led to companies being waived the payment of port call fees. Reportedly, this also allowed to free up working capital at the client-side (Sluijs, 2020a; 2020b).

Regarding payment speed, Request (2018a: 13) stated that while it does not contribute to the calculation of the days sales outstanding (DSO), "it improves a company's DSO by giving a reason to the customers to pay their invoices on time (with a reputation system)." The firm also explained that for online payments[30] they charge between 0.5% and 0.1% (and expect to charge 0.05% in the future), which is far less than the 1% to 7% fees charged by third parties such as Paypal, Bitpay and Stripe (Request , 2018b: 8, 11, 15) and has a dramatic impact on the bottom line.

Luca+ estimated a 58% cost-saving in payment and cash management through the usage of their system: from AUD 7.7 to AUD 3.2 per invoice (The Block Ledger, 2019). The firm also claimed to eliminate the possibility of missing payments, duplicate payments or payments in error (The Block Ledger, n.d.).

[30] As of 21 February, 2020, USD 780.000 had already been transacted through Request (Mazurel, 2020b).

Moreover, Luca+ reportedly uses its foundation of TEA to calculate and report credit-risk metrics based on the facts of invoices triggered and payments made. This feature allows third parties wishing to offer an invoice financing service to calculate risk based on fact-based past performance, unlike incumbent financing companies (Mehmood et al, 2019). PayPie (2018) and Request (2018b: 14) also plan to offer a financing service, though they would be of the factoring type. Figure Technologies (2020: 20) reported offering a similar credit risk rating mechanism.

Finally, Figure Technologies (2020: 20) estimated potential savings for global markets ranging from USD 6 billion to USD 9 billion in deal costs, due to instantaneous payments. This is expected to replace the current status quo of payments taking weeks, having legal documents "come from a smart contract tied to the collateral and resulting loans, saving significant fees" and causing the many events of the various agents in the deal-making process (e.g. custodian and payee agent) to collapse into one: the blockchain as the single source of truth.

3. FRAUD AND AUDITING

a. FRAUD AND AGENCY PROBLEMS

Improvements in the fight against fraud and inadequate agent behavior were reported qualitatively, namely without providing figures. Luca+, for instance, reported that it validates who the sender is, so that the user can be confident that the invoices received are genuine, rather than a scam or fraud (The Block Ledger, 2019).

Similarly, Request (2018a: 13) indicated that there is "no risk of fraudulent invoices as the system records the identities of both parties. We outperform the use of sampling as we don't check a sample of invoices anymore but all the requests automatically." Pacio (2019d: 5) also claimed that the product they offer is fraud proof.

b. AUDIT NATURE

Mehmood et al (2019) report that the application of Luca+ and Ledgerium transformed the audit enquiry process known as confirmation: "obtaining and evaluating a direct communication from a third party in response to a request for information about a particular item affecting financial statement assertions."

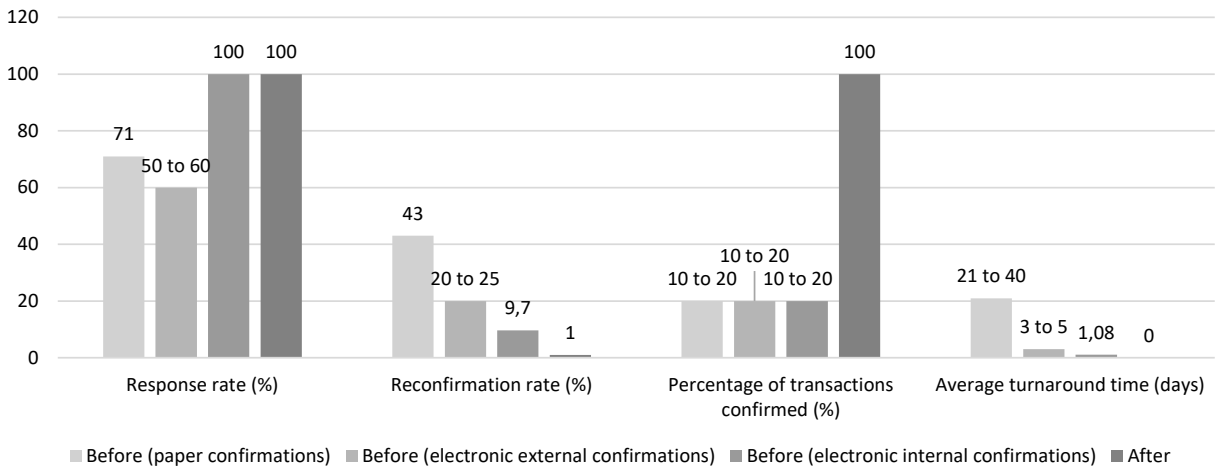

Figure 1: Benefits reported by Ledgerium (Mehmood et al, 2019).

Request (2018a: 18), without quoting actual numbers with benefits achieved, pointed out that better audits require that "a supplier debt must not remain pending for payment more than a certain number of years." Smart audits enabled by Request "can detect the old requests unpaid and flag them as invoices to be reversed" (ibid). Similarly, Pacio (2019d: 5), without providing figures, also claimed significant cost-reductions would result from the usage of their platform.

c. *AUDIT SAMPLING*

Request (2018a: 14) reported that the sample of invoices checked – to verify whether the invoice concerned the company under audit and whether the invoice was booked in the correct account and fiscal year – amounted to 100%, thus achieving total population sampling.

d. *AUDIT FREQUENCY*

While we were unable to find cases of changes in audit frequency -- either a reduction in the frequency with which they are necessary, or achieving the goal of never-ending, real-time audits -- expected improvements were claimed.

According to Ledgerium, most businesses cannot afford a regular audit, which makes it difficult to attract investors. The "universal bookkeeping function" of blockchain would reduce the needed frequency of audits. Moreover, a credit mechanism through the Blockchain would reduce the risk of mistrust between companies (Mehmood et al, 2019). PayPie (2018) proposes a similar credit risk assessment system.

4. SECURITY AND CONFIDENTIALITY

a. SECURITY (MUTABILITY)

Improvements in security, though not the central benefit indicated by the use cases identified, were reported, however only qualitatively. Companies regularly indicated that, under the DLT-based TEA system, the record of all transactions is immutable (see Request, 2018a: 15).

While the main value immutability adds to security is self-explanatory -- tampering is not possible and it is not possible to reverse transactions (Hildebrand, 2018) --, other benefits of immutability were identified. For instance, Figure Technologies (2020: 20) noticed that the costs of qualified custody and associated needs (administrative costs for the warehouse, cost of the payee agent, servicing platform and personnel) would significantly drop with a blockchain-based immutable chain of custody: the estimated annual benefit for the global market ranged USD 15 million to USD 37.5 million.

SkyCell also explained that introducing immutability also improves IoT security. Containers are equipped with a smart card chip holding its own digital identity. Using "banking-grade hardware security modules to generate digital identities, also called keys, for each container" together with blockchain, achievement of a tamper-proof identity was reported (Groeneveld, 2019a).

b. CONFIDENTIALITY

Most of the use cases identified had a gatekeeping function that allowed the network operator to only let trusted parties in. Corda resorted to partial visibility of transactions: each node can only see some transactions (those in which the node is a stakeholder). In fact, the tension between confidentiality and transparency is precisely the driver behind R3 Corda's node-to-node approach (Brown, 2018: 6; see also Mohanty, 2018: 42).

Solutions using Hyperledger, such as DLT Labs, embrace a solution consisting of confidential channels. However, this comes at the cost of requiring a trusted intermediary for moving assets between channels (Greenspan, 2018).

V. DISCUSSION: ECONOMIC VIABILITY

The research necessary to survey the preceding cases and the solutions implemented for each gap led to identifying a number of issues that are worth further discussion. These issues all pertain to the economic viability of blockchained TEA systems, and include: (a) the merits of adding a blockchain layer to the system, (b) the primary sectors/environments in which it is reasonable to expect thriving TEA systems, and (c) the scalability problem undertakings face.

The issues of scalability and commercial deployment are encompassed in the greater question of economic viability in general. TEA conceptualizes, and blockchain implements, an immutable single source of truth, which is less error and fraud prone, more auditable and with certain security advantages. Yet blockchain is also beset with scalability issues, as well as its own distinct security, redundancy and cost issues. Blockchain technology can provide data storage, timestamping, an authentication scheme and a way to achieve data persistence. However, other technologies can also provide each of these solutions. An important issue is which of the (or which combination of) technologies is most *efficient* at doing so, and whether the answer to that question is context-dependent.

Currently deployed use cases constitute evidence for an efficient solution for each "pinch point." In this context, although our survey of use cases is neither exhaustive nor representative, we identify patterns in architectural choices.

It is thus highly suggestive that a substantial number of commercially deployed use cases resort to blockchain only in part (sometimes not at all). Recapitulating, R3 Corda uses a non-blockchained DLT, Request/Gilded only resort to blockchain partially (with data storage occuring on IPFS); ThoughtWorks advocates usage of blockchain only in part (Barrit et al, 2019), Pacio resorts to "post-blockchain" Distributed Hash Technology, etc.

Yet, our goal in this paper regards triple entry accounting. While our assumption was that progress in recent decades is within blockchain, this is challengeable. We should inquire whether blockchain is the universal panacea to all things, including TEA, or whether it is "just the flavour of the month."

We must then ask what makes TEA economically viable, which we can answer by going back to the writings of one of the "oracles" of triple-entry. Todd Boyle had envisioned a system that would fix reconciliation costs (both when the parties were in agreement and when not), reduce rigidities of secondary systems, minimize bookkeeping, invoicing and

billing costs, and minimize errors: a shared transaction repository. Efficiency effects were furthermore achieved due to the elimination of redundant recordkeeping.

However, Boyle (1999; 2000e; 2000g; 2003b; 2003h; 2003l) had pointed out that, in order for this to be economically viable, the system would have to, ideally:

- display a degree of flexibility, allowing the reversal of transactions and the permission of entry of unposted information. That is, allow for unfinished business transactions, not requiring balanced books except for an identifier of the anticipated, future related entries;
- be secure;
- enable settlement and payment (to compete with banks); and
- not require an impossible leap to universal adoption, but rather offer benefits linearly, with each new use.

One could also add:

- enable not just payments, but also bidding and offers (Boyle, 2003j);
- be scalable without sacrificing throughput and latency (Barrit et al, 2019; Pacio, 2020);
- be affordable and easy to use (Boyle, 2003c; Pacio, 2020);
- be compliant with regulations (Pacio, 2020);
- be supported by the emergence of agreed standards (Request, 2018a: 25); and
- have "transitional facilities" that allow one to adopt the system without need for an abrupt abandonment of current CDEA, ERP and legacy systems (Boyle, 2000g);[31]
- integrate the communication aspects of contract formation and performance (Grigg, 2010).

While blockchain optimists may believe that this technology is capable of achieving all of this, this potential remains to be demonstrated. Moreover, blockchain technology in particular and DLT in general suffer from the "redundancy paradox:" to eliminate redundant recordkeeping (two parties recording independently the same transaction in their books) redundancy in record *copying* is introduced (replication throughout a large

[31] This is recognized and intended by Auditchain (2019a), Luca+ (The Block Ledger, n.d.) and Pacio (2020).

community of nodes).[32] This reveals that there is a trade-off between the costs of one and the other.

As far as security is concerned, blockchain does seem to attain a relative security of transactions thanks to immutability and decentralized consensus. This also removes the security-agency problem of needing a trusted network operator. However, there are also trade-offs between types of security: vulnerability to attacks (e.g. 51% attacks) are a factor. The requirement of trust is not completely removed, but shifted to oracles and curators (Arruñada, 2017: 66), as well as to whatever concentration of power may arise in the blockchain's governance mechanism (e.g. mining pools). Permissioned blockchains may solve some of this, but in turn introduce the need to trust gatekeepers and exclude the possibility of a mass market for small players (Grigg, 2017a: 8), and so on. Hence, new propositions are hard to evaluate on theoretical grounds, and a dynamic market in TEA and blockchain proposals is useful for shaking out what works and what does not.

Furthermore, security is also connected to immutability. As we established, immutability is very important for posted transactions, but actual business processes also require to keep an account of many 'unposted,' tentative transactions (Boyle, 2003h; 2003l). It needs to be shown that blockchain-based systems are capable of achieving the optimal degree of flexibility.

This is related to the intricacies of business reality. The triple-entry design can be achieved more easily with the very narrow scope of pure payments (e.g. Grigg's Ricardo Payment System, Nakamoto's Bitcoin). The wider vision of Todd Boyle, the REA community and others includes aspects such as invoicing and delivery cycles, which involves much more complexity. While triple-entry has the potential to ground a complex accounting edifice in solid facts, the ability to deploy such a complex application remains to be seen.

There is also the challenge of regulatory reception (Auditchain, 2018), since it is crucial for business adoption whether the usage of this technology smoothes operations or makes them more complex, from a legal point of view. The challenge is thus to design a system that is cost-efficient in relation to all of these dimensions. It appears from our research that the greatest savings achieved through DLT-based TEA systems are accomplished through time savings in reconciliation and transaction processing, whereas the greatest expenses are computing costs and system set-up costs, but a more detailed review of costs and benefits is necessary.

In order to realize this, each TEA operator listed in Appendix B was approached with the request to share cost-benefit data. This would have allowed us to undertake comparative

[32] This is the flipside of the "decentralization paradox:" a centralized view of transaction records is delivered through an attempted *decentralized* consensus over validation (Grigg, 2019b).

cost-benefit analyses between use cases, but not one TEA operator was in a position to "open their books," i.e. show the actual cost-benefit figures. Business confidentiality is certainly one reason in some cases, but for others it appears a business case has yet to be established.

We however have anecdotal evidence that the single truth benefits are substantial to the point that they outweigh the costs of setting up and running a TEA system. Two notable examples stand out. One, Loudon Owen (2019) at DLT Labs noted that now, with their single truth TEA system effectively eliminating disputes -- a constant prior condition -- freight carriers were willing to accept less payment in exchange for delivering freight to Walmart Canada, indicating large cost savings through the new system. Two, Christiaan Sluijs (2020a; 2020b) at T-Mining referenced optimized port calls and a waiving of the upfront charging of port call fees as a consequence of the increased payment speed and the enhanced predictability afforded by the introduction of IoT-informed single source of truth in shipping. In spite of these telling examples, at the present we must leave the verdict open whether the hard costs of running an applied TEA are indeed offset by the efficiency effects of a single truth operation between multiple players. As such, also the extrapolated public welfare impact of TEA applications has yet to be delineated.

a. DIFFERENCES IN COST DIFFERENCES

In this paper, we have attempted to provide an overview of not only the benefits of DLT-based TEA, but also its costs. But just like we are qualifying our statements regarding the former, we must do the same for the latter. For readability purposes, we offer a number of caveats here, rather than interrupting the flow of the text above.

We stated that blockchain replaces redundancy in record *keeping* with redundancy in record *copying*, there being thus a trade-off. While this is accurate, one should note that the copying and storage costs of exact copies, proven by hash indexing are essentially free in the age of free and automated net and terabytes storage. In contrast, mismatching records lead to "human reconciliation nightmares."

We also discussed the risk of 51%. In spite of being worth discussing, this is mostly a minor theoretical risk, next to insider attacks and outright theft, which are "the meat and butter" of blockchain security, just as with ordinary business.

We pointed out that even though DLT-based TEA would facilitate the auditing of transactions, auditors would require new, more elevated skill sets such as reading code to detect potential fraud. This is true in static analysis. However, in a dynamic environment one would expect an institution to arise, such as an auditing standard for smart contracts. In practice, the competitive process matches challenges with adaptation.

The competitive process is also relevant to another of our statements, specifically that delays serve a (nefarious) purpose in gaining an advantage by concealing information. Once again, it is accurate to state that delays may enable gains (or the avoidance of losses) in certain scenarios, but, over time, it is reasonable to expect the advantages of real time delivery of information to other parts of the business/market to eat away those who want to "time" their market.

We should qualify our statements on immutability in a similar manner. We argued that un-doing "immutable" blocks could require a fork with high costs attached. However, this is only absent the emergence of a dispute resolution process which is presumably less costly and less disruptive than a fork.

Finally, acknowledging the tentative character of many entries in books due to unfinished business processes is in a sense a solved (or solvable) problem already. As Corda, for instance, is a sequence of states in what is best thought of as a private micro-chain, the participants can simply wind back on agreement or on order, and restart the signing.

b. WINNERS AND LOSERS

While the "economic viability" at the micro level is one matter, the introduction of a new TEA system at the macro level produces a host of winners and losers. For instance, "paper pushers" such as office clerks processing transactions lose from TEA. This constitutes a risk to bookkeepers and low level accountants doing checking and reconciliations. However, accountants processing data to provide useful information, converting this information to knowledge that can guide decision-making and making such decisions[33] are not in jeopardy.

Lawyers are also partially at risk, especially with Ricardian contracts in place. Again, however, this applies particularly to lawyers "pushing paper around" and generating "paper pushing fees." This would not be the case for those concentrating on serving their clients and reducing their costs.

Note, however, that in spite of the myth that lawyers will be replaced by smart contracts, this is hardly so. Not even a Ricardian smart contract is really a contract, since the written document (paper contract, smart contract, Ricardian contract, etc.) can be the leading instrument or document evidencing the contract, but the real contract is a virtual construct found in court. That is, the judge says what the contract is, including most information presented and excluding some. Hence, the contract in its broad sense may

[33] Stages 3, 4 and 5 of Elliot's (in Boyle, 2009) 5 stages of accounting contributions to the information value chain.

include material such as website documentation and author pronouncements. This is contrary to some widespread beliefs about law and blockchain.

The providers of platform services, on the other hand, appear to be the winners in the TEA landscape, in addition to the platform users.

A further question is begged: In the race to build a viable TEA system, which horse leads the pack? This question is hard to answer without access to the firms' books. Even in the face of reported successes, one should not hurry to the conclusion that a general cost-efficiency quantum leap has been achieved. Cases focused on fixing a particular pinch point on a particular client are probably better fitted to deliver concrete solutions in less time. But that does not necessarily mean that one solution fits all. We cannot state with certainty that a golden chalice has been found: no breakthrough has been achieved that developers can fix the trilemma, and offer an affordable, user-friendly, regulation-compliant, commercially deployed solution non-specific to an industry, all at once.

Finally, two matters regarding the "TEA race" are worth noting. First, a number of the featured horses are slow out of the gate: some use cases are not accomplishing the milestones that they should be achieving, according to the roadmaps published in their websites or whitepapers.

This is reflected in Table 1, which shows that a large number of the TEA cases surveyed have not yet managed to reach the stage of commercial deployment. This also means our findings should be taken with prudence, since to "check many boxes" in the list of possible features is "easier said than done." In other words, if TEA systems that have not been launched yet are perceived to have architectural advantages over those that are already in the market, this could be an unfair perception, based on the fact that it is easier to announce a feature in a white paper than to materialize it in a commercially deployed, usable, cost-effective and user-friendly manner. Furthermore, the commercial deployment of a platform does not necessarily mean that apps within the platform are currently at use.

Second, one may identify two different "types" of teams in the race: On the one hand, there are pinch point-oriented software companies venturing into TEA territory without much of a legacy accounting background. On the other hand there are accounting practitioners, seeking to integrate the novel DLT into their practice. Similarly, a distinction may also be made between theory-driven undertakings aimed at faithfully implementing Todd Boyle and Ian Grigg's vision, and production-oriented projects looking to solve specific business problems, no matter that they end up converging with TEA in the end. It remains to be seen whether the bottom-up or the top-down approach will be the one to reach global scale.

c. PRIME TARGET SECTORS

The costs and benefits of TEA projects will not be the same across the whole spectrum of industry sectors. Thus, it is reasonable to expect TEA to be more useful in certain industry sectors than the others. The question thus arises: in what areas is TEA thriving?

Based on our explorations, we answer with the following hypothesis. One expect TEA to thrive when the following conditions are met:

- an ongoing "thread" of transaction;
- a myriad of players with a strong benefit in collaborating on shared and confirmed data records; or a single entity with complex internal records that can benefit from point by point signing;
- large inefficiencies in transaction recording and reconciliation generating an opportunity to enhance the system with for example an IoT oracle ("strong needs for integration"; Boyle, 2001e); or
- transactions are purely electronic -- thus not needing IoT oracles nor external payments processors providing uncertain and unreliable proofs, which renders a less expensive system.

Two types of sectors display these characteristics in a sufficient manner. First, the industries of e-payment, e-commerce and online financial services. Logging into the system would just require a computer, which makes it relatively cheap for participants. Based on our experience, we expect TEA projects in this industry sector to be deliberate attempts at building a TEA system. Second, logistics and supply chains (Boyle, 1999; 2001e; Boyle, 2003h; Dunn et al, 2016: 576; Haugen and McCarthym 2000):[34] the need to conduct numerous payments depending on numerous factors and with large inefficiencies in transaction recording and reconciliation creates an ideal opportunity for TEA systems with IoT oracles. We expect a number of these undertakings to reunite the architectural features of a TEA system without necessarily constituting a deliberate attempt to fulfill the vision of Todd Boyle, Ian Grigg or William McCarthy.

d. SCALABILITY: VITALIK'S TRILEMMA

The quest for cost-efficiency possesses many dimensions. One of the most well-known ones is Vitalik Buterin's Scalability Trilemma, which consists in the trade-offs in architectural choices faced when designing a blockchain. In essence, it is stated that it is

[34] For an argument against the application of blockchains and/or DLTs to supply chains, see Maunier (2019).

not possible to maximize all three characteristics at once: scalability, security and decentralization.[35] Although the trilemma was described in the context of blockchain, it is supposed to constitute a challenge for all systems, underpinned by blockchain or not.

In practice, many systems fail much before those the performance of those three metrics cannot keep increasing, as they do not deal with usability/UX/convenience, onboarding costs, clear benefits to users and basic fun factors. It is furthermore unclear that it is impossible to "square" (i.e. solve) the trilemma. For instance, a Ricardian contract is secure, scalable and decentralized.

The trilemma does nevertheless point to possible trade-offs. As such, it could also apply to blockchained TEA use cases. Hence, solving for Vitalik's trilemma, or at least finding viable work-arounds, continues to shape the field of TEA applications. Whether expanding TEA systems over multiple platforms of user groups, in the context of TEA systems with a myriad of functions, scalability presents a formidable challenge (Request, 2018a: 25). As such, scalability represents a pinch point within a pinch point, and the golden chalice belongs to those who find a suitable "fix."

Balanc3 was one of the early and well-resourced attempts to develop a general TEA accounting system. Developed by ConsenSys in 2015/16, the platform was an attempt to build a "triple-entry accounting system" consisting of a "trustless solution to invoicing, accounting, documentation, and payment processes for small and large businesses." It used "ESign, IPFS (a decentralized storage platform), and the Ethereum blockchain to construct, store, manage, and digitally sign documents. Also, invoicing through smart contracts [would] automatically process and record payments in real time" (Balanc3, 2016). However, by 2018, the term "triple-entry accounting" was no longer featured in the firm's website (Balanc3, 2018; Pacio, 2018b: 6), which only displayed a more modest description of Balanc3 as an Ethereum-based open platform to manage digital assets (Pacio, 2018b: 6), possibly signalling that they had given up in their attempt at TEA. The project was finally shut down in early 2019 (Zheng, 2019).

Scalability was reported to have been one of Balanc3's key problems, which was attributable to Ethereum.[36] David Hartley, CEO of Pacio, commented: "in our view, they had no chance of ever achieving their original objectives using Ethereum as the platform -- no way could the transaction volume required for TEA to be adopted at scale. Ethereum 2 might get closer, but still will fall far short of meeting world needs."

Some of the TEA use cases surveyed have a clear focus on scalability, as for example Pacio (2018a), who will integrate its Pacio Integrated Business Suite in an open-economy

[35] According to Samani (2018) "latency" constitutes a fourth underlying dimension.

[36] Many others have criticized the scalability of Ethereum, see Mohanty (2018: 41).

platform named Tender, which in turn is expected to feature "virtually unlimited scalability." However, it is unclear how a number of use cases address or plan to address the problem of scalability.

Overall, we have identified five different approaches to the trilemma, namely a maximization of the three characteristics (the categories can overlap to an extent). First, embracing the trilemma in a classic manner and prioritizing scalability within its terms through architectural choices. Second, permissioned blockchains solutions (also embracing the trilemma). Third, "many-chains" solutions. Fourth, second-layer or off-chain approaches. Fifth, non-blockchain solutions. A sixth group could comprise immature projects without a clearly defined approach for the moment. None of these approaches, however, constitute complete workarounds to the trilemma.

i. PRIORITIZING SCALABILITY

The choice of many use cases is not to "solve" the trilemma but, rather, to embrace it and prioritize scalability. This is shown by the fact that the majority of TEA cases opted for a PoS or dPoS system. Proof-of-Work (PoW) systems, such as used by Bitcoin, comprise the most widely used consensus mechanisms, are *designed to have*[37] decentralized *block production*. Proof-of-Stake (PoS) systems, instead, are not so decentralized in that regard, and achieve further scalability, though also at the cost of security: they are vulnerable to nothing-at-stake attacks (Samani, 2018).

Delegated PoS (dPoS) mechanisms embrace block production centralization even further and are even more able to offer scalability and low latency (Samani, 2018) -- though at the cost of the same vulnerabilities that apply to all voting systems. Ledgerium claims to have very high scalability (Ledgerium, n.d.), and uses Proof of Authority (PoA), a variant of PoS which, together with dPoS, are the main consensus mechanisms in EOS.IO. Auditchain, and Figure Technologies also resort to PoS or dPoS (Tobin, 2020).[38] Naturally, these are not "solutions" to the trilemma, but only to the scalability component at the expense of the others, which even further validates the trilemma. Furthermore, they constitute viable paths only under certain conditions. For instance, Tobin (2020) from Provenance Blockchain explained that most PoS systems start to break down after 25 nodes -- such is one of the constraints on the pBFT algorithms --. Provenance uses only 12.

[37] However, systems designed to have decentralized block creation may end up developing mining "pools," as the Bitcoin case shows.

[38] Request and Gilded will move to PoS when Ethereum does, a move scheduled for the future (Mazurel, 2020b).

ii. PERMISSIONED BLOCKCHAINS

Using permissioned blockchains, where viable, is another solution of choice, that allows to achieve higher throughput and performance than permissionless blockchains (Tobin, 2020). Naturally, this is also not a complete workaround to the trilemma, as decentralization is admittedly sacrificed in part.[39] DLT Labs is an example of this approach that has been able to go to scale. DLT Labs uses Hyperledger, designed for private blockchains, and uses its own consensus mechanisms (Raft and Kafka). This is not a one-size-fits all solution, however, since the set of participants is limited to participants in a part of Walmart's supply chain. Moreover, note that Raft and Kafka are not byzantine fault tolerant (BFT; Le Hors, 2019).[40]

It is possibly worth mentioning that many (not all) entities that desire or might benefit from TEA are in the regulated sector. As such, they have to answer to auditors, regulators, shareholders, lawsuits and the like. In this context they are worried about doing any business with a partner that might be considered by their stakeholders to be unreliable. For these use cases, private/permissioned blockchains where someone has the answers to who/what/where/why/whether questions may be better than PoW/PoS/dPoS, etc. This is simply because companies cannot have discussions with other formal businesses about these "partners" and are therefore unable do trade as they need to.

iii. MANY CHAINS APPROACH

The "many chains" approach consists of smaller, interoperable chains with their own sets of validators. Each individual chain may be centralized, but the system is decentralized overall. This allows for high scalability with low latency, though the reported drawback is security, since security increases with value and this system reduces the value of each chain (Samani, 2018). Corda's micro-chain approach is one such example. Cosmos is also a prime example of the many chains approach, and most of the Pacio system was intended to be built on Cosmos. This decision, which superseded the initial choice of EOS (Pacio, 2018a), was later abandoned as well, however, partly because achieving scalability was still more costly (in terms of fees and compliance with eventual regulatory

[39] In terms of permission to transact, but not in terms of data viewing permissions.
Note that these blockchains also enable group dispute resolution relying on a single (centralized) party.

[40] Which is not a problem per se, as being a partner of Walmart is sufficient to assume a modicum of respect for one's transacting partners.

requirements) than with the alternative ecosystem that Pacio finally chose: Holochain (Hartley, 2020).

The many chains approach can be regarded as a variant of the off-chain approach.

iv. OFF-CHAIN APPROACH

A number of the cases identified are resorting to the blockchain in a partial manner only. Thus, when the blockchain is not efficient, i.e. the trilemma is too much of a problem, the blockchain is simply not used. Since (in principle) the trilemma applies to blockchained systems only, this avoids the blockchain altogether. For example, while Request's version 1 was a protocol built onto the Ethereum blockchain, which it used for data storage and timestamping, the version 2 replaced Ethereum with IPFS for storage purposes. Request reported that this has significantly decreased transaction costs and increased scalability.[41]

An example of this approach is also provided by Auditchain, which only stores hash values in the blockchain. Source data, instead, is stored off-chain. This avoids overloading the blockchain with excessive information (Auditchain, 2019a). Provenance Blockchain also reported that it does not store the entirety of the documents on the blockchain (Tobin, 2020). Pacio, PayPie and SkyCell also resort to similar solutions.

v. ABANDONING BLOCKCHAIN (FOR OTHER DLTS)

If building parts of the TEA system off-chain is an alternative, the same goes for building the system fully in a non-blockchained ecosystem. R3 Corda is the main example of a DLT-based TEA solution that is not based on blockchain: despite Corda's technology is blockchain-inspired and in the same industry category than blockchain (DLT systems), it is technically not a blockchain due to the lack of a proper chain of blocks.

Similarly, after abandoning the initial choices for EOS and Cosmos, Pacio decided to build parts of its system in the Holochain -- which is not a blockchain, but uses DHT or Distributed Hash Table technology (Pacio, 2019c: 4). This was reportedly meant to

[41] However, it is somewhat unclear to what extent this constitutes a full workaround to the trilemma: the original version of Balanc3 also included usage of IPFS (Ward and Lundkvist, 2016: 7:03, 13:24-14:24).

achieve scalability, and then again to storing data outside the DHT for further speed and usability.[42]

Nonetheless, even non-blockchain DLT systems may display scalability issues.

Corda achieves high scalability by not using a gossip protocol. A blockchain's maximum throughput is constrained by the slowest node processing transactions, but as Corda's nodes only see a tiny fraction of the total transaction, they are able to achieve significant scale. Nonetheless, Corda performs worse than a blockchain when a node has to verify a large set of previously unseen transactions at a short notice. As explained by Greenspan (2018):

> *"Nodes have to verify transactions that might not be relevant to them, but in so doing, they prepay the cost of checking any future transaction that might come in. While Corda nodes are less busy overall, they run the risk of needing to do a huge amount of work at a moment's notice (...) when a Corda node processes a transaction, it must download and verify all of that transaction's ancestors, apart from those it has seen before. So if the family tree is deep, new incoming transactions may have a large number of ancestors that need to be verified, triggering Corda's scalability problem" (Greenspan, 2018).*

Upon consultation regarding this particular issue, Richard Gendal Brown (2020b), CTO of R3 Corda, agreed with this criticism in principle but pointed out that Corda's experience to date shows that this is a very rare situation:

> *"This is because many use-cases do not actually have long chains of transactions (...) Most business scenarios are between parties who affirmatively sign transactions to agree to be bound by them and so the history of those [transactions] is irrelevant to the question of whether they are valid (...) In the cases where you do need to walk back down the chain it is for situations such as bearer-tokens or contracts where one party has a unilateral right to force a change (eg exercise an option). But true bearer tokens are rare in the regulated space and for the latter example, the chain is rarely more than two or three [transactions] deep."*

[42] "Since DHT storage is inefficient for querying in terms of speed and usability, apps with querying or reporting needs, can roll out their data into high performance scalable local SQL database where the global part is read-only and is meant to be joined with other app data to deliver services to users." (Pacio, 2019d: 13)

However, Corda's particular experience may not be representative of other undertakings and thus, some TEA start-ups may not find a node-to-node mechanism superior to a gossip protocol. Whether the activity is outside (arguably invoices, package locations, contracts, offers, acceptances, ownership and rights) or inside of financially regulated territory may play a large role in this.

CONCLUSION

In this paper, we set out to achieve a number of goals. First, identify a number of gaps in current accounting practice. Second, we match them with theoretical solutions DLT-based TEA systems could offer. Third, we review the actual implementation of those solutions in the use cases surveyed.

In the course of researching current applications, we uncovered a number of findings:

1. Security is not the top benefit of DLT-based TEA. Efficiency is.
2. DLT developers are, with innovative TEA applications, breaking new accounting ground, many of which are commercially deployed.
3. The efficiency effects may surpass the input costs of building and operating a TEA system, presumably based on DLT. In particular, given the incorporation of a counterparty-agreed view of the facts, in effect the single truth of the transaction, a common shared ledger (augmented with IoT oracles) will collect and present those facts to parties. Therefore, it will reduce friction between parties by lowering costs related to reconciliation and management of risks.
4. The challenge for many use cases is to jump from proof-of-concept to production while achieving scalability, user-friendliness, cost-effectiveness, security, trustlessness, as well as adjusting the system privacy and rigidity to business needs, without sacrificing throughput and latency.
5. Logistics, finance and supply chain management are prime sectors in which the success of TEA systems is most likely, particularly when dealing with production-, transaction- and trade-oriented applications.

We believe these goals have been met. Nonetheless, this study is subject to limitations. Notably, we have not exhausted the universe of TEA applications and, since we resorted to purposive sampling, the possibility of extrapolation beyond the cases under review is restricted. Furthermore, the universe of technology and applications is under constant and rapid change, which also places a temporal restriction on the validity of our conclusions.

FUTURE RESEARCH

Future research could be oriented at providing exhaustive cost-benefit data, while duly mindful of business confidentiality. This would reflect the maturity of each particular TEA model implemented. Leading TEA applications should be surveyed on particular cost and benefit factors, in order to obtain a systematic overview of their individual viability.

Other potential lines of research that could be pursued are surveying use cases that were not deliberately built to constitute a TEA system, but effectively constitute or otherwise converge on a TEA system. Furthermore, exploring the potential for convergence between currently existing TEA use cases and firms attempting to implement distributed repositories underpinned by the REA ontology.

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APPENDIX A: ACRONYMS

B2B	Business-to-business
CDEA	Classic double-entry accounting
DBT	Distributed Book Technology
DJT	Distributed Journal Technology
DLT	Distributed Ledger Technology
G2G	Government to Government
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
OeDBTR	Open-edi Distributed Business Transaction Repository
PTR	Public Transaction Repository
REA	Resources, Events, Agents
STR	Shared Transaction Repository
TEA	Triple-entry accounting
TEB	Triple-entry bookkeeping

APPENDIX B

Our investigation identified the following blockchain-based TEA cases (self-denominated as such or not).

***Currently operational DLT TEA examples*:**

DLT Labs: "DL Asset Track" is a "blockchain-based freight and payment network" (DLT Labs, 2019). It is a platform that manages, records and verifies payments in a shared accounting ledger for Walmart Canada and carriers, involving smart contracts and IoT oracles, billed to date "the world's largest full production blockchain solution for industrial application" (ibid). DLT Labs piloted a platform on behalf of Walmart Canada with an initial number of trucking companies (e.g. Bison Transport), in view of on-boarding the remainder of the 70 trucking companies delivering goods to Walmart's 400 retail stores across Canada, by February, 2020.

Gilded + Request: Request (previously Request Network) is a non-profit foundation, which set up a decentralized network for payment requests using Ethereum[43] and working with open-source technology. Within Request (2018b), a participant built a real-time triple-entry accounting solution: Gilded (Ryan, 2019; see also Pacio, 2018b: 2).[18]

Luca+: It is an e-invoicing application within the greater Ledgerium project. The application replaces manual entry in accounting by automatically retrieving invoices from the users' email and uploading them to the immutable accounting platform that is shared between suppliers and customers. Payment reminders are used to improve speed. It is also possible to connect the application to 74 banks in order to integrate a payment solution and to input more information in the system. (The Block Ledger, n.d.)

PayPie: It is an Ethereum-based, decentralized real time accounting platform aimed at achieving increased accuracy in credit risks score. Both the firm's whitepaper (PayPie, 2018: 5) and Pacio (2018: 9) consider it a TEA use case.

R3 Corda: Corda is a joint venture between R3 (a "distributed database technology company") and numerous banks and financial institutions. It is a TEA platform with many particularities, such as having smart (and Ricardian) contracts written in Java and Kotlin

[43] V2 of the protocol does not use Ethereum to store the data. IPFS is used for that purpose. Ethereum is used for a trustable timestamp of a payment request, for proof of existence of a request and to detect payment changes. (Request, 2019)

(i.e. "industry-standard language"; Mohanty, 2018: 42) and as having a peer-to-peer (node-to-node) mechanism.[44] Ian Grigg notably participated in the creation of R3 Corda (Brown, 2018; see also Mohanty, 2018: 48). A number of applications with a TEA component have been formed within Corda:

- Fusion LenderComm: this application, developed by Finastra, allows to handle syndicated loans through the Corda DLT. It is focused on increasing the reliability of information on the lendee and on the transactions with the bank, through immutability and decreased redundancy. This facilitates the task of the bank, who acts as an agent with regards to other financial institutions in order to spread the risk --and better enables these to resort to the secondary market. (R3, 2018)
- BlockProvenance: …
- Digiledge Invoice Discounting Platform: …
- GuildOne: …
- Ripe.io: …
- Digital Ventures: Siam Commercial Bank's B2P is a Corda-based application allowing "buyers, their suppliers and banks to share purchase orders, goods receipts and invoices on a distributed ledger, based on agreed data protection policies, to enable automation of the entire procure-to-pay process." Processing time savings of 50% and general savings in dollar terms of 70% are reported in this process (R3, 2019).
- Spunta project: … (trial only, not yet deployed)
- Synechron: … (trial only, not yet deployed)

ThoughtWorks + VAKT: VAKT (2018), in partnership with ThoughtWorks, has developed a secure, real-time blockchain-based digital platform for post-transaction management of physical energy commodities. "The platform manages physical energy transactions from trade entry to final settlement, eliminating reconciliation and paper-based processes." To set up their system, VAKT collaborated with global software consultancy ThoughtWorks

[44] In spite of the literature being divided on the nature of Corda, it appears that the correct way to categorize it would be as a *non-blockchained DLT TEA* platform. Corda's white paper advertises Corda not only as a TEA use case, but also as an -- admittedly different -- "blockchain platform" (Brown, 2018). However, Grigg (2017b) himself stated that R3 has "stripped out many things," so that Corda "is not a blockchain at all." It is not blockchain because, essentially, there is no chain of blocks. Corda developer Debajani Mohanty (2018: 42) also calls Corda a 'blockchain-*inspired* (open source) DLT.' However, some have even questioned whether it is DLT in the first place (Lønsetteig, 2017).

and the system is underpinned by JPMorgan's Quorum private distributed ledger[20] [21] [22] (VAKT, 2018).

T-Mining: the company specializes in blockchain logistics and supply chain solutions for the maritime sector in general and port logistics in particular. Rather than offering a platform, the firm offers a smart contract *framework*, that allows to synchronize, speed up and improve the accuracy of invoicing, payment, communication, container release, etc. Within this framework, T-Mining is collaborating with a Dutch company in the port of Rotterdam in a project that has an important accounting/invoicing component.

TradeLens: TradeLens is a system jointly owned and developed by shipping company Maersk GTD and IBM. For any given shipment, "as many as 30 independent parties and 100 people, generating up to 200 exchanges of information" are involved, from a port to a customs authority. TradeLens uses blockchain technology for tracking customs documentation on goods that are shipped internationally providing stakeholders access to details pertaining to any given shipment. The operation promises to save third-party logistics (3PLs) an average of 30 minutes of emails, phone calls and manual EDI entry on every shipment, equating to hundreds of thousands of dollars per year. By switching from paper-based trade and manual document-handling to the TradeLens system, the operation promises an efficiency increase of "up to 15%." 10 million shipping events are now registered in the system every week.

***Yet-to-be-deployed use cases*:**

AB Fingertips Suite: The Accounting Blockchain is an accounting solution developed by a team dedicated to fixing inefficiencies in the accounting sector, with commitment to TEA (Accounting Blockchain, 2018: 6). The project is however not yet operational and their technological approach is still unclear (Pacio, 2018b: 8).

Auditchain: Auditchain (2018: 3) is a layer 2 protocol ecosystem developing what purports to be the first decentralized continuous audit and real time financial reporting solution. Auditchain leads and bears the costs of the DCARPE (Decentralized Continuous Audit & Reporting Protocol Ecosystem) Alliance, a global consortium pushing for interoperable standards. Hence, Auditchain does not offer its own shared transaction repository, which connects the sets of books of two parties. While it is not TEA in this sense, Jason Meyers (2020) --founder of Auditchain and originally inspired by Grigg's TEA (Auditchain, 2019b)-- argues that Auditchain still constitutes the only comprehensive TEA solution, because [1] it develops the protocol ecosystem in which such a solution may be implemented, [2]

it develops the only comprehensive solution properly dedicated to accounting, (100% testing) auditing and (real time) reporting and disclosure, and [3] the hash value referring to all the transaction data (invoice, date, payment date and time, etc.) *is* the third entry which requires a triple-signed receipt (see also Pacio, 2018b: 6).

bBiller: this Australian company specializes "in blockchain solutions for global supply chain participants" (bBiller, 2019) and has the objective of establishing a payment system that achieves democratization and disintermediation globally, built on Hyperledger. The project is still not fully operational and faces a number of difficulties "gaining sufficient scale (size of the network of users) for their triple entry accounting and supplier/customer linkages to be viable or useful, and then the issues of Ethereum scaling if that success should occur" (Pacio, 2018b: 7). Pacio (2018b: 9) classifies it as a TEA use case.

Fizcal: a Belize-based company specializes in software solutions for accounting. In 2017, Fizcal put out a paid press release claiming to be the first firm in the market to develop "a fully decentralised triple entry framework for bookkeeping and accounting."[45] Pacio (2018: 9) also considers its app a TEA use case. However, the inactivity in the firm's social media for the past semester suggests the project is not operational.

Ledgerium + Block Ledger: the Ledgerium (Mehmood et al, 2019) project aims to create a consortium-based blockchain network, running on Ethereum and with the particularity that the objective is to "launch products that utilise the blockchain from day 1" (ibid). For this reason, the project is not yet fully operational (ibid). Both Ledgerium's own whitepaper (ibid) and Pacio (2018: 2, 9) consider Ledgerium a TEA use case.

Open-Transactions: Open-Transactions is a collaborative project by a community of volunteers to implement a prototype notary server, a financial cryptography library and a free-software toolkit implementing the OTX protocol. The project proposes the use of (Grigg-style) "triple-signed receipts in order to prevent the notary from changing a user's balance without his signature, or falsifying any of his transactions" (Odom, 2015: 6). Franco (2014: 240) also considers Open-Transactions a TEA use case.[28]

Pacio + Tender: this is an envisioned TEA system based on Holochain and using a standardised semantic data standard, called SSIM, created by Pacio and Tender themselves. Pacio's whitepaper (Pacio, 2019b: 3) asserts that there are seven prerequisites that constitute the essential elements of a TEA system.[46] It appears,

[45] https://news.bitcoin.com/pr-fizcal-brings-accounting-blockchain-initial-coin-offering/

[46] Namely "an immutable (...) transaction to be a shared part of the record of both entities involved in a monetary transaction; a way for the TEA transaction to be made visible to anybody with a need or right to see it, but optionally to remain private otherwise, according to entity preference; a way for each party to the transaction to be uniquely and immutably identified – a universal unique immutable Id; scalability (...); compliance with financial regulations; affordability (...); ease of use." (Pacio, 2019b: 3)

however, that fulfilling this list is not a prerequisite to have a TEA system. Rather, it seems that fulfilling it enables *successful* implementation of a TEA system, in Pacio's view.

Provenance (Figure Technologies): Provenance is a project by Figure Technologies to eliminate inefficiencies in the financial industry. The goal is to make risk rating, lending -- loan origination, servicing, financing and selling-- and loan securitization quicker, cheaper and more efficient through a blockchain-based settlement and smart contract network (Figure Technologies, 2020). Board member Anthony Pompliano (2019) stated that the firm has a blockchained TEA use case.

SkyCell: SkyCell is a provider of temperature-controlled containers to transport pharmaceutical goods. With an infrastructure of IoT sensors and gateways, their smart containers offer security and compliance: no container is cleared for usage unless software indicates its perfect condition. SkyCell declined to participate in our data collection interviews or emails.

Many other projects also spoke of TEA but we were not provided with sufficient detail by time of publication.

References

AB (2018) “Accounting Blockchain Whitepaper.” Accounting Blockchain Whitepaper. Available at https://portal.theaccountingblockchain.io/pdfs/whitepaper.pdf (10/01/2020)

AB (2019) “The Accounting Blockchain.” Accounting Blockchain. Available at https://www.theaccountingblockchain.io/ (28/01/2020)

Alawadhi, A.; Ames, B.; Maciel de Aquino, C. E.; Arthúrsdóttir, M.; Brennan, G.; Brown-Liburd, H. L.; Bumgarner, N.; Byrnes, P.; Criste, T. R.; Ghosh; S.; Gross, J. A.; Gullkvist, B.; Hardy, C.; Jónsson, H. M.; Lasslet, G.; Medinets, A.; Moon, D.; Miyaki, E. H.; Sigolo, N.; Sigurjónsson, S.; Stewart, T. R.; Teeter, T.; Vasarhelyi, M. A.; Warren, J. D. (2015) “Audit Analytics and Continuous Audit: Looking Toward the Future.” American Institute of Certified Public Accountants. AICPA: New York.

Alsaqa, Z. H.; Hussein, A. I.; Mahmood, S. M. (2019) “The Impact of Blockchain on Accounting Information Systems.” Journal of Information Technology Management, 11(3), 62-80.

Andersen, N. (2016) “Blockchain Technology: A game-changer in accounting?” Deloitte. Available at https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Innovation/Blockchain_A%20game-changer%20in%20accounting.pdf (27/12/2019)

Arruñada, C. (2017) “Blockchain's Struggle to Deliver Impersonal Exchange.” Minnesota Journal of Law, Science & Technology, 19, 55-105.

Ashton, R. H.; Willingham, J. J.; Elliott, R. K. (1987) “An Empirical Analysis of Audit Delay.” Journal of Accounting Research, 25(2), 275.

Aste, T.; Tasca, P.; Di Matteo, T. (2017) “Blockchain Technologies: The Foreseeable Impact on Society and Industry.” Computer, 50(9), 18-28.

Auditchain (2018) “Auditchain: Decentralized Continuous Audit & Reporting Protocol Ecosystem.” Auditchain Whitepaper. Available at https://auditchain.com/Auditchain-Whitepaper.pdf (10/01/2020)

Auditchain (2019a) “Frequently Asked Questions.” Auditchain. Available at https://auditchain.com/faq/ (28/01/2020)

Auditchain (2019b) “Jason Meyers.” Auditchain. Available at https://auditchain.com/jason-meyers/ (28/01/2020)

Balanc3 (2016) “The Smart Contract Powered Triple-Entry Accounting System.” Balanc3. Available at http://web.archive.org/web/20161128011202/http://balanc3.net/ (09/01/2020)

Balanc3 (2018) “Financial Management for Digital Assets.” Balanc3. Available at https://web.archive.org/web/20180901222334/https://www.balanc3.net/ (09/01/2020)

Baran, P. (1964) “On Distributed Communications Networks.” IEEE transactions on Communications Systems, 12(1), 1-9.

Barrit, J.; Sheth, S.; Vile, A. (2019) “From PoC to Production: Implementing an Enterprise Blockchain Solution.” Vakt and ThoughtWorks. Available at https://files.thoughtworks.com/pdfs/vakt-tw-poc-to-production.pdf (29/01/2020)

bBiller (2019) “BBILLER™.” The Brew. Available at https://www.fhcbrx.org/?page_id=143 (10/01/2020)

BBC (2020) “Wirecard: Scandal-hit Firm Files for Insolvency.” *BBC*. Available at https://www.bbc.com/news/business-53176003 (21/08/2020)

Bible, W.; Raphael, J.; Taylor, P.; Oris Valiente, I. (2017) “Blockchain Technology and Its Potential Impact on the Audit and Assurance Profession.” Deloitte, Chartered Professional Accountants of Canada (CPA Canada), Association of International Certified Professional Accountants, University of Waterloo Centre for Information Integrity and Information System Assurance (UWCISA).

Bits n Coins (2019) “The Many Facts Pointing to Ian Grigg Being Satoshi.” *Bits n Coins*. Available at https://www.bitscoins.net/the-many-facts-pointing-to-ian-grigg-being-satoshi/ (12/02/2020)

Boyle, T. (1999) “Differentiating between web-based GLs.” *GL Dialtone*. Available at https://linas.org/mirrors/www.gldialtone.com/2001.07.14/journalbus.htm (22/01/2020)

Boyle, T. (2000a) “CDEA General Ledger Schema.” *Ledgerism*. Available at https://web.archive.org/web/20071001201740/http://www.ledgerism.net/GLSchema1.txt (17/01/2020)

Boyle, T. (2000b) “Draft Schema for General Ledger.” *Ledgerism*. Available at http://web.archive.org/web/20051003224536/http://ledgerism.net/GLSchemaDraft1.txt (08/02/2020)

Boyle, T. (2000c) "FAQ." *GL Dialtone*. Available at http://web.archive.org/web/20000827165329/http://www.gldialtone.com/PTR-FAQ.txt (11/02/2020)

Boyle, T. (2000d) "Re: Company centric view ends. Data goes to the Net." http://linas.org/mirrors/www.gldialtone.com/2001.07.14/ToddREAPost.htm

Boyle, T. (2000e) "The Public Transaction Repository (PTR) project." *GL Dialtone*. Available at http://web.archive.org/web/20000622133330/http://www.gldialtone.com/PTR.htm (17/01/2020)

Boyle, T. (2000f) "Webledger." *GL Dialtone*. Available at http://web.archive.org/web/20000610172851/GLDialtone.com/webledger.htm (17/01/2020)

Boyle, T. (2000g) "WebLedger Architectures; Ending Data Duplication." *GL Dialtone*. Available at http://web.archive.org/web/20000829141221/http://www.gldialtone.com/endredundancy.htm (17/01/2020)

Boyle, T. (2000h) WebLedger Discussion Forum. *GL Dialtone*. Available at http://web.archive.org/web/20000623204427/http://www.rosehill.net/cgi-bin/dnewsweb.exe?cmd=xover&group=webaccounting.design&utag= (12/02/2020)

Boyle, T. (2001a) "Consistent Accounting Recognition by Parties in Ecommerce." *Ledgerism*. Available at http://web.archive.org/web/20050209061623/http://ledgerism.net/consistent_accounting.htm (08/02/2020)

Boyle, T. (2001b) "RE: Initial Draft of CPP-CPA Specification." Available at http://lists.ebxml.org/archives/ebxml-bp/200101/msg00089.html (17/01/2020)

Boyle, T. (2001c) "Resume." *GL Dialtone*. Available at http://web.archive.org/web/20010120224200fw_/http://www.gldialtone.com/resume.htm (12/02/2020)

Boyle, T. (2001d) "Services." *GL Dialtone*. Available at http://web.archive.org/web/20010120224200fw_/http://www.gldialtone.com/services.htm (12/02/2020)

Boyle, T. (2001e) "The Shared Transaction Repository (STR) Accountant's Explanation." *GL Dialtone*. Available at

http://linas.org/mirrors/www.gldialtone.com/2001.07.14/STRaccountant.htm (11/02/2020)

Boyle, T. (2001f) "The Shared Transaction Repository (STR) ver. 0.60 spec." *GL Dialtone*. Available at http://linas.org/mirrors/www.gldialtone.com/2001.07.14/STR.htm (17/01/2020)

Boyle, T. (2001g) "The WebLedger era has arrived." Available at http://linas.org/mirrors/www.gldialtone.com/2001.07.14/ (17/01/2020)

Boyle, T. (2002a) "End-to-end principle in ledger relations?" *Ledgerism*. Available at http://web.archive.org/web/20060518034443/http://www.ledgerism.net/end2end.htm (11/02/2020)

Boyle, T. (2002b) "General Ledger Information Entities (GLIEs) library – Requirements." *Ledgerism*. Available at http://web.archive.org/web/20060101203128/http://www.ledgerism.net/requirementsGLIES.htm (11/02/2020)

Boyle, T. (2002c) "Inter-ledger Semantics and Methods." Available at http://web.archive.org/web/20050211110419/http://ledgerism.net/inter-ledger-requirementsVer0p23.htm (11/02/2020)

Boyle, T. (2003a) "Accounting Hypercubes on the Internet." *Ledgerism*. Available at http://web.archive.org/web/20060102014117/http://www.ledgerism.net/hypercub.htm (11/02/2020)

Boyle, T. (2003b) "The AR/AP Cloud." *Ledgerism*. Available at http://web.archive.org/web/20060101213250/http://www.ledgerism.net/arapcloud.htm (11/02/2020)

Boyle, T. (2003c) "Automatic Reconciliation." *Ledgerism*. Available at http://web.archive.org/web/20050204064722/http://ledgerism.net/AutoReconciliation.htm (08/02/2020)

Boyle, T. (2003d) "Empirical Reputation Metrics." *Ledgerism*. Available at http://web.archive.org/web/20060106140404/http://ledgerism.net/reputation.htm (11/02/2020)

Boyle, T. (2003e) "File-Based Commerce (FBC) Architecture ver. 0.31 spec. Business Requirements Viewpoint." *Ledgerism*. Available at http://web.archive.org/web/20050211111755/http://ledgerism.net/fbc.htm (08/02/2020)

Boyle, T. (2003f) "General Ledgerism." *Ledgerism*. Available at http://web.archive.org/web/20060425114848/http://ledgerism.net/ (08/02/2020)

Boyle, T. (2003g) "GLT and GLR: Conceptual Architecture for General Ledgers." *Ledgerism*. Available at http://web.archive.org/web/20060629093406/http://ledgerism.net/GLT-GLR.htm (17/01/2020)

Boyle, T. (2003h) "Ledger Ontology." *Ledgerism*. Available at http://web.archive.org/web/20080209023044/http://ledgerism.net:80/LedgerOntology.htm (11/02/2020)

Boyle, T. (2003i) "The Illiquidity of Cash. Nonquantified Multiparty Barter." *Ledgerism*. Available at http://web.archive.org/web/20060102013434/http://www.ledgerism.net/nonquantified.htm (17/02/2020)

Boyle, T. (2003j) "Shared Transaction Repository (STR) ... a High Level Software Specification." *Ledgerism*. Available at http://web.archive.org/web/20060102052824/http://www.ledgerism.net/STR.htm (17/01/2020)

Boyle, T. (2003k) "The Argument to Abolish Double-Entry Accounting and Abolish the Assets=Liabilities + Owner's Equity Equation." *Ledgerism*. Available at http://web.archive.org/web/20031208235246/http://ledgerism.net/GLSchema2.txt (08/02/2020)

Boyle, T. (2003l) "Uniform Economic Event Notification (UEEN) ver .05." *Ledgerism*. Available at http://web.archive.org/web/20050830154015/http://ledgerism.net/UEEN05.htm (08/02/2020)

Boyle, T. (2009) "Todd on Audits V: Why on Why?" In Grigg, I. (2009) *Financial Cryptography*. Available at http://financialcryptography.com/mt/archives/001187.html (18/01/2021)

Buterin, V. (2017) "The Meaning of Decentralization." Medium. Available at https://medium.com/@VitalikButerin/the-meaning-of-decentralization-a0c92b76a274#.tt97tzspw (25/01/2020)

Brown, R. G. (2015) "How to Explain the Value of Replicated, Shared Ledgers from First Principles." *Richard Gendal Brown: Thoughts on the Future of Finance.* Available at https://gendal.me/2015/04/27/how-to-explain-the-value-of-replicated-shared-ledgers-from-first-principles/ (12/02/2020)

Brown, R. G. (2016) "On Distributed Databases and Distributed Ledgers." *Richard Gendal Brown: Thoughts on the Future of Finance.* Available at https://gendal.me/2016/11/08/on-distributed-databases-and-distributed-ledgers/ (26/01/2020)

Brown, R. G. (2018) "The Corda Platform: An Introduction." R3 Corda Whitepaper. Available at https://www.r3.com/wp-content/uploads/2019/06/corda-platform-whitepaper.pdf (06/01/2020)

Brown, R. G. (2020a) Personal Communication. January 27, 2020.

Brown, R. G. (2020b) Personal Communication. February 23, 2020.

Buchman, E. (2020) Personal Communication. January 7, 2020.

Byeongju, H. (2018) "An Introduction on Traditional Double Entry Bookkeeping of Korea." *8th World Congress of Korean Studies*.

Cai, C. W. (2019) "Triple-entry Accounting with Blockchain: How far Have we Come?" *Accounting & Finance*. Accounting and Finance Association of Australia and New Zealand.

Campbell, H. F. (2004) "A Multiple Account Framework for Cost–Benefit Analysis." Evaluation and Program Planning, 28(1), 23-32.

Carlyle, J. (2020) "How "Public-permissioned" Blockchains are not an Oxymoron." *R3.* Available at https://www.r3.com/blog/how-public-permissioned-blockchains-are-not-an-oxymoron/ (27/02/2020)

Chandler, A. D. (1977) "The Visible Hand: Managerial Revolution in American Business." Harvard University Press: Harvard.

CIIA (2019) "Why Audits Take Longer Than the Time Allocated." Chartered Institute of Internal Auditors. Available at https://www.iia.org.uk/resources/delivering-internal-audit/why-audits-take-longer-than-the-time-allocated/ (06/01/2020)

CNN (2019) "Enron Fast Facts." CNN. Available at https://edition.cnn.com/2013/07/02/us/enron-fast-facts/index.html (30/12/2019)

Cocco, L.; Pinna, A.; Marchesi, M. (2017) "Banking on Blockchain: Costs Savings Thanks to the Blockchain Technology." Future Internet, 9(3), 25.

Cook, C. (2002) "Market 3.0: the Final Version." Mondovisione. Available at https://mondovisione.com/exchanges/handbook-articles/market-30-the-final-version/ (17/01/2020)

Cook, C. (2016) “Fintech 2.0.” P2P Foundation. Available at https://blog.p2pfoundation.net/fintech-2-0/2016/10/06

Consensys (2019) “Enterprise Ethereum 5 Reasons Why Enterprise Ethereum Is so Much More Than a Distributed Ledger Technology.” Available at https://consensys.net/enterprise-ethereum/best-blockchain-for-business/5-reasons-why-enterprise-ethereum-is-so-much-more-than-a-distributed-ledger-technology/

Cotrugli, B. (1573) “Della Mercatura et del Mercante Perfetto. Libri Quattro.” Available at https://archive.org/details/bub_gb_Ohloe05v0-oC (06/01/2020)

Czarnek, M.; SecondLeo (2014) “Nxt Network Energy and Cost Efficiency Analysis.” Available at https://es.scribd.com/document/254930279/Nxt-Network-Energy-and-Cost-Efficiency-Analysis (21/12/2019)

Dai, J. (2017) “Three Essays on Audit Technology: Audit 4.0, Blockchain and Audit App.” Doctoral dissertation within the Doctor of Philosophy Graduate Program of The State University of New Jersey.

Damodaran, A. (2009) “The Dark Side of Valuation: Valuing Young, Distressed, and Complex Businesses.” FT Press: New Jersey.

Diffie, W.; Hellman, M. E. (1976) “New Directions in Cryptography.” IEEE Transactions on Information Theory, 22(6), 644-654.

Di Gregorio (2017) “Blockchain: A new tool to cut costs.” Middle East Insurance Review. PricewaterhouseCoopers. Available at https://www.pwc.com/m1/en/media-centre/articles/blockchain-new-tool-to-cut-costs.html (06/01/2020)

DLT Labs (2019) “Walmart Canada and DLT Labs™ Launch World's Largest Full Production Blockchain Solution for Industrial Application.” *CISION PR Newswire*. Available at https://www.prnewswire.com/news-releases/Walmart-canada-and-dlt-labs--launch-worlds-largest-full-production-blockchain-solution-for-industrial-application-300958198.html (09/01/2020)

Dorris, B. (2018) “Report to the Nations: 2018 Global Study on Occupational Fraud and Abuse.” Available at https://s3-us-west-2.amazonaws.com/acfepublic/2018-report-to-the-nations.pdf (07/01/2020)

Dowlat, S. (2018) “ICO Quality: Development & Trading.” *Medium*. Available at http://web.archive.org/web/20191111120039/https://medium.com/@sherwin.dowlat/ico-quality-development-trading-e4fef28df04f (06/02/2020)

Dunn, D.; Gerard, G. J.; Grabski, S. V. (2016) "Resources-Events-Agents Design Theory: A Revolutionary Approach to Enterprise System Design." Communications for the Association for Information Systems, 38, 554-595.

Edwards, J. D. (1960) "Early Bookkeeping and its Development into Accounting." *Business History Review*, 34(04), 446–458.

El-Halaby, S.; Hussainey, K. (2016) "Contributions of Early Muslim Scholars to Originality of Bookkeeping-system." *Corporate Ownership and Control*, 13(3), 543-560.

ESMA (2016) "The Distributed Ledger Technology Applied to Securities Markets." European Securities and Markets Authority Discussion Paper.

EY (2019) "Total Cost of Ownership for Blockchain Solutions." Amendment of Fundamental Cost of Ownership for Private Blockchain Solutions, With Updated Information on Public Blockchain Deployment Options and Updated Conclusions. Ernst & Young. Available at https://www.ey.com/Publication/vwLUAssets/ey-total-cost-of-ownership-for-blockchain-solutions/$File/ey-total-cost-of-ownership-for-blockchain-solutions.pdf (23/12/2019)

Mehmood, F.; Cheah, I.; Golash, R.; Ma, L. (2019) "Ledgerium Whitepaper, Version 2.2." Ledgerium. Available at https://whitepaper.ledgerium.io (28/01/2019)

Fanning, K.; Centers, D. P. (2016) "Blockchain and Its Coming Impact on Financial Services." Journal of Corporate Accounting & Finance, 27(5), 53–57.

Figure Technologies (2020) "Provenance: Creating the Future of Finance." Provenance Whitepaper. Available at https://provenance.io/documents/Provenance%20Whitepaper%20-%202020.pdf (28/01/2020)

Fino, J. (2018) "Regulation Forces up FTSE 100 Audit Fees." Institute of Chartered Accountants in England and Wales. Available at https://economia.icaew.com/news/september-2018/regulation-forces-up-ftse-100-audit-fees (14/12/2019).

Forfirm (n.d.) "Comparison of Ethereum, Hyperledger Fabric and Corda." https://www.forfirm.com/comparison-of-ethereum-hyperledger-fabric-and-corda/

Franco, P. (2014) "Understanding Bitcoin: Cryptography, Engineering and Economics." Wiley: Chichester (UK).

Ge, J. (2005) "会计 英语" (Accounting English). Available at http://abook.cn/pdf/H-0535.0101.pdf (18/02/2020)

Gee, J.; Button, M. (2019) “The Financial Cost of Fraud 2019: The Latest Data From Around the World.” Crowe Clark Whitehill.

Ginigoada Foundation (2017) “Introduction to Bookkeeping: A Flexible Learning Course.” Available at http://oasis.col.org/bitstream/handle/11599/2749/2017_Ginigoada-Bisnis-Foundation_Introduction-to-Bookkeeping_.pdf (18/02/2020)

Glassnode (2021a) “Bitcoin: Number of Active Addresses (30d Moving Average).” *Glassnode Studio*. Available at https://studio.glassnode.com/metrics?a=BTC&ct=linear&m=addresses.ActiveCount&mAvg=30&zoom=all (19/01/2021)

Glassnode (2021b) “Ethereum: Number of Active Addresses (30d Moving Average).” *Glassnode Studio*. Available at https://studio.glassnode.com/metrics?a=ETH&ct=linear&m=addresses.ActiveCount&mAvg=30&zoom=all (19/01/2021)

Golan, E.; Krissoff, B.; Kuchler, F.; Nelson, K.; Price, G.; Calvin, L. (2003) “Traceability in the US Food Supply: Dead End or Superhighway?” Choices, 18(2), 17-20.

Goethe, J. W. (1824) “Wilhelm Meister's Apprenticeship and Travels,” Volume I. English Translation (1840). Lea and Blanchard: Philadelphia.

Gopal, C. R. (2009) “Accounting for Managers.” New Age International: Delhi.

Grange, E. (2016) “Mesh World P2P Simulation Hypothesis.” DelphiTools. Available at https://www.delphitools.info/DWSH/ (25/01/2020)

Greenspan, G. (2018) “R3 Corda: Deep Dive and Technical Review.” *MultiChain*. Available at https://www.multichain.com/blog/2018/05/r3-corda-deep-dive-and-technical-review/ (01/02/2020)

Grigg, I.; Howland, G. (1997) “Executive Summary of the SOX TM Protocol.” *Systemics*. Available at www.systemics.com/docs/sox/execsummary.html (11/01/2021)

Grigg, I. (2001) “Financial Cryptography in 7 Layers.” *International Conference on Financial Cryptography*, 332-348.

Grigg, I. (2003) “The Evolution of the Internet Financial System.” *Systemics*. Available at www.systemics.com/docs/ricardo/ifs.html (11/01/2021)

Grigg, I. (2004) “The Ricardian Contract.” Systemics Inc. Available at https://iang.org/papers/ricardian_contract.html (19/12/2019)

Grigg, I. (2005) “Triple entry accounting.” Systemics Inc. Available at https://iang.org/papers/triple_entry.html (19/12/2019)

Grigg, I. (2010) “The Baby Back Ribbed Theory of Architecture.” *Financial Cryptography*. Available at http://financialcryptography.com/mt/archives/001247.html (18/01/2021)

Grigg, I. (2011) “Is Bitcoin a Triple Entry System?” *Financial Cryptography*. Available at http://financialcryptography.com/mt/archives/001325.html (22/01/2020)

Grigg, I. (2014) “Who Invented the Shared Repository Idea: Bitcoin, Boyle and History.” *Financial Cryptography*. Available at http://financialcryptography.com/mt/archives/001469.html (17/01/2020)

Grigg, I. (2016a) “In a Nutshell: Ian Grigg’s Ricardian Contracts and Digital Assets Prehistory” (Crain, B. F.; Roy, M., interviewers). *Bits on Blocks: Thoughts on Blockchain Technology*. Available at https://bitsonblocks.net/2016/11/22/in-a-nutshell-ian-griggs-ricardian-contracts-and-digital-assets-prehistory/ (22/01/2020)

Grigg, I. (2016b) “Satoshi is Dead - Long Live Satoshi - Team Leader Comes Out.” *Financial Cryptography*. Available at http://financialcryptography.com/mt/archives/001593.html (12/02/2020)

Grigg, I. (2016c) “@tomerkantor Nope - I am not a member of the team.” *Twitter Post*. Available at https://twitter.com/iang_fc/status/727068366129655810

Grigg, I. (2016d) “Yup - Todd Boyle’s concept could not work without a server, a quorum or a blockchain. That’s why it’s called triple entry.” Twitter Post. Available at https://twitter.com/iang_fc/status/775234399847710720 (26/01/2020)

Grigg, I. (2017a) “EOS: An Introduction.” EOS Whitepaper. Available at https://whitepaperdatabase.com/eos-whitepaper (10/01/2020)

Grigg, I. (2017b) “Interview with Ian Grigg” (Louv, J., Interviewer). Internet of Agreements. Available at http://internetofagreements.com/2017/12/25/interview-ian-grigg/ (09/01/2020)

Grigg, I. (2017c) “My thanks to Todd Boyle, originator of the concept of triple entry, for pointing out this video by Bill McCarthy https://t.co/rwGAZZaHfo.” Twitter Post. Available at https://twitter.com/iang_fc/status/939258799654924288 (25/01/2020)

Grigg, I. (2017d) “Oddly, Yuji called it 3E bookkeeping, we called it 3E accounting, and arguably we should have reversed.” Twitter Post. Available at https://twitter.com/iang_fc/status/880691386735112192 (25/01/2020)

Grigg, I. (2017e) ““But it’s not modelled there, it’s only modelled up in the cloud.” HOLYSMOKINMUDDERODUKS! That’s triple entry accounting at the triple A.”

Twitter Post. Available at https://twitter.com/iang_fc/status/939243253060329475 (25/01/2020)

Grigg, I. (2017f) "Wildest dream: REA (triple entry accounting) is the Golden Spike that brings the conventional industry together with wild-eyed blockchain…" Twitter Post. Available at https://twitter.com/iang_fc/status/939256814314622976 (25/01/2020)

Grigg, I. (2018) "Independently, @cjenscook invented something to STR similar for oil trading. Also someone (Eric Hughes?) postulated the "we all share a common ledger" idea on cypherpunks, but couldn't make it work technically." *Twitter Post*. Available at https://twitter.com/iang_fc/status/1035845304556417025 (12/02/2020)

Grigg, I. (2019a) "It's tricky - term was coined 20 years ago by Todd Boyle. My paper was 2004 or so. Oddly - paper is "3E accounting" but techniques are really bookkeeping. Yuri Ijiri's work was originally labelled "triple entry bookkeeping" but is really accounting… Confusion abounds…" Twitter Post. Available at https://twitter.com/iang_fc/status/1182660123245928449 (25/01/2020)

Grigg, I. (2019b) "Fundamentally, yes - Bitcoin design delivers a unique single (centralised?) view of the records, by means of a decentralised consensus over validation. Triple entry suggests there be 3 copies, but it doesn't stop you at 3000, as long as Alice and Bob have one, Borg has 2998." Twitter Post. Available at https://twitter.com/iang_fc/status/1211239320050384897 (14/02/2020)

Grigg, I. (2019c) "Triple Entry Accounting was theorised originally by Todd Boyle, who wrote of its application & implementation in the 1990s. My team implemented it independently. In 2004 I wrote the paper, thinking we'd discovered it de novo. An example of science moving in parallel, in mass." Twitter Post. Available at https://twitter.com/iang_fc/status/1103047183287418885 (25/01/2020)

Grigg, I. (2019d) "Triple entry accounting was about creating facts. Nominally for accounting, also useful for cash. Bitcoin showed a way to do 3E without a single center. Corda showed a way to do 3E with selected notaries. I'm working with 3E by communities. The future is triple entry." Twitter Post. Available at https://twitter.com/iang_fc/status/1103046077954097158 (25/01/2020)

Grigg, I. (2020) "Thoughts on Momentum Accounting." Financial Cryptography. Available at http://financialcryptography.com/mt/archives/001655.html#more (22/01/2020)

Gröblacher, M.; Mizdraković, V. (2019) "Triple-entry Bookkeeping: History and Benefits of the Concept." Digitization and Smart Financial Reporting, 58-61

Groeneveld (2019a) “Big Data in Pharma Cold Chain Logistics.” SkyCell. Available at https://skycell.ch/archives/2685 (30/01/2020)

Hambiralovic, M.; Karlsson, R. (2018) “Blockchain Accounting in a Triple-Entry System: Its Implications on the Firm and its Stakeholders, a Case Study on the Request Network.” Thesis submitted for completion of the Bachelor’s in Financial Accounting & Corporate Finance program at the Department of Business Administration of Lund University.

Hartley, D. (2020) Personal Communication. February 13, 2020.

Haugen, R.; McCarthy, W. E. (2000) “REA, a semantic model for Internet supply chain collaboration.” OOPSLA Workshop on Business Object Components: Enterprise Application Integration, OOPSLA.

Haugen, R. (2020) Personal Communication. January 20, 2020.

Hearn, M.; Brown, R. G. (2019) “Corda: A Distributed Ledger.” R3 Corda Technical Whitepaper, Version 1.0. Available at https://www.r3.com/wp-content/uploads/2019/08/corda-technical-whitepaper-August-29-2019.pdf (29/01/2020)

Helsel, B. (2018) “The Uncovering of Satoshi Nakamoto Through Literary Habits?.” *CryptoCoin Mastery*. Available at https://cryptocoinmastery.com/the-uncovering-of-satoshi-through-literary-habits/ (12/02/2020)

Hildebrand, G. (2018) “The Strikingly Simple New Way To Get Paid in Cryptocurrency.” Medium. Available at https://medium.com/gilded/the-strikingly-simple-new-way-to-get-paid-in-cryptocurrency-609ecbd8a80a (30/01/2020)

Himoff, J. (2019) “Walmart: Staying Ahead of the Industry with Blockchain Technology.” *Insolar*. Available at https://insolar.io/uploads/Case%20Study%20Walmart%20Blockchain%20Analysis.pdf (30/01/2020)

Holman, G. K. (2019) “Blockchain and eBusiness.” *LinkedIn*. Available at https://www.linkedin.com/pulse/blockchain-ebusiness-ken-holman/ (11/02/2020)

Holman, G. K. (2020a) Personal Communication. January 12, 2020.

Holman, G. K. (2020b) Personal Communication. January 17, 2020.

Holman, G. K. (2020c) Personal Communication. February 21, 2020.

Howland, G. (1996) “Development of an Open and Flexible Payment System.” Systemics. Available at www.systemics.com/docs/sox/overview.html (11/01/2021)

Hsieh, P. G. (2018) "The Intellectual Development of Yuji Ijiri." Accounting History, 23(4), 541-554.

Hughes, E. (1993a) "PROTOCOL: Encrypted Open Books." *Cypherpunks Mailing List*. Available at https://marc.info/?l=cypherpunks&m=85281390301301&w=3 (12/02/2020)

Hughes, E. (1993b) "PROTOCOL: Encrypted Open Books." *Cypherpunks Mailing List*. Available at https://marc.info/?l=cypherpunks&m=85281390300988&w=3 (12/02/2020)

Ibañez, J. I., Bayer, C. N., Tasca, P., Xu, J. (2020) "REA, Triple-entry Accounting and Blockchain: Converging Paths to Shared Ledger Systems." *Social Science Research Network (SSRN)*. Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3602207

Ibañez, J. I., Bayer, C. N., Tasca, P., Xu, J. (2021) "Triple-entry Accounting: A Typology." *Arxiv*. Cornell University. Available at https://arxiv.org/abs/2101.02632

Ibrahim, A. (2018) "Does Blockchain Mean Higher Transparency in the Financial Sector?" Revista de Contabilidad y Dirección, 27, 71-82.

ICAEW (2018) "Blockchain and the future of accountancy." Institute of Chartered Accountants in England and Wales. Available at https://www.icaew.com/technical/technology/blockchain/blockchain-articles/blockchain-and-the-accounting-perspective (27/12/2019)

IFC (2017) "Blockchain in Financial Services in Emerging Markets Part I: Current Trends." International Finance Corporation. World Bank Group. Available at https://econpapers.repec.org/paper/wbkwboper/30369.htm (06/01/2020)

ISO/IEC (2015) "Information Technology — Business Operational View — Part 4: Business Transaction Scenarios — Accounting and Economic Ontology." ISO/IEC International Standard 15944-4. Second edition 2015-04-01.

ISO (2019) "ISO/IEC CD 15944-21 [ISO/IEC CD 15944-21]." *ISO*. Available at https://www.iso.org/standard/78924.html (12/02/2020)

Hildebrand, G. (2020) "Gilded Launches the Open Finance Platform for Business." Medium. Available at https://medium.com/gilded/gilded-launches-the-open-finance-platform-for-business-5e27c86172f3 (30/01/2020)

Ijiri, Y. (1975) "Theory of Accounting Measurement." American Accounting Association: Sarasota.

Ijiri, Y. (1982) “Triple-entry Bookkeeping and Income Momentum.” American Accounting Association: Sarasota.

Ijiri, Y. (1986) “A Framework for Triple-Entry Bookkeeping.” The Accounting Review, 61(4), 745-759.

Ijiri, Y. (1989) “Momentum Accounting and Triple-entry Bookkeeping: Exploring the Dynamic Structure of Accounting Measurements.” American Accounting Association: Sarasota.

Jeffries, D. (2019) “Why Everyone Missed the Most Important Invention in the Last 500 Years.” Hackernoon. Available at https://hackernoon.com/why-everyone-missed-the-most-important-invention-in-the-last-500-years-c90b0151c169 (22/01/2020)

Ijiri, Y.; Kelly, E. C. (1980) “Multidimensional Accounting and Distributed Databases: Their Implications for Organizations and Society.” Accounting, Organizations and Society, 5(1), 115–123.

Kim, H. M.; Laskowski, M. (2018) “Towards an Ontology-Driven Blockchain Design for Supply Chain Provenance.” Intelligent Systems in Accounting, Finance and Management, 25(1), 18-27.

Kim, S.; Chandra Deka, G.; Zhang, P. (2019) “Advances in Computers: Role of Blockchain Technology in IoT Applications.” Vol. 115. Elsevier: London.

Kiviat, T. I. (2015) “Beyond Bitcoin: Issues in Regulating Blockchain Transactions.” Duke Law Journal, 65, 569-608.

Kondo, D.; Javadi, B.; Malecot, P.; Cappello, F.; Anderson, D. P. (2009) “Cost-benefit Analysis of Cloud Computing Versus Desktop Grids.” IPDPS, 9, 1-12.

Kuhn, T. S. (1996) “The Structure of Scientific Revolutions." The University of Chicago Press: Chicago.

Larimer, D.; Lee, G.; TestZ; Lavin, J.; Cox, T.; Hourt, N.; Ma, Q.; Prioriello, W. (2018) “EOS.IO Technical White Paper v2.” GitHub. Available at https://github.com/EOSIO/Documentation/blob/master/TechnicalWhitePaper.md (28/01/2020)

Ledgerium (n.d.) “Guides.” *Ledgerium*. Available at https://docs.ledgerium.io/docs (28/01/2020)

Le Hors, A. (2019) “Demystifying Hyperledger Fabric Ordering and Decentralization.” *IBM Developer*. Available at https://developer.ibm.com/articles/blockchain-hyperledger-fabric-ordering-decentralization/ (01/02/2020)

Liu, M.; Wu, K.; Xu, J. J. (2019) “How Will Blockchain Technology Impact Auditing and Accounting: Permissionless versus Permissioned Blockchain.” Current Issues in Auditing, 13(2), 19-29.

Liu, X.; Yu, T. (2019) “An Automatic Pattern Recognition Value System With Listed Banks Based on Blockchain.” *2018 IEEE 3rd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC 2018)*.

Lomax, P. S. (1918) “Significant Results of Missouri and New Mexico Commercial Education Studies.” *The School Review: A Journal of Secondary Education*, 26(2), 73-84.

Lønsetteig, A. B. (2017) “R3’s Corda Uncovered: It’s not Blockchain.” Global Trade Review. Available at https://www.gtreview.com/magazine/volume-15issue-3/r3s-corda-uncovered-not-blockchain/ (19/02/2020)

Macey, J.; Sale, H. A. (2003) “Observations on the Role of Commodification, Independence, and Governance in the Accounting Industry.” Vilanova Law Review, 48(4), 1167-1188.

Makridakis, S.; Christodoulou, K. (2019) “Blockchain: Current Challenges and Future Prospects/Applications.” Future Internet, 11, 258-274.

Martinuzzi, E. (2019) "Why Deutsche Bank's Monte Paschi Scandal Still Matters." Bloomberg. Available at https://www.bloomberg.com/opinion/articles/2019-11-11/why-deutsche-bank-s-monte-paschi-scandal-still-matters (30/12/2019)

Maunier, S. (2019)”Supply Chain is Obviously Not a Blockchain Use Case.” *Innovation in Finance*. Available at http://finnoworld.com/supply-chain-is-obviously-not-a-blockchain-use-case/ (14/02/2020)

Mazurel, R. (2020a) Personal Communication. January 24, 2020.

Mazurel, R. (2020b) Personal Communication. February 21, 2020.

McCarthy, W. E. (1982) “The REA Accounting Model: A Generalized Framework for Accounting Systems in a Shared Data Environment.” The Accounting Review, 57(3), 554-78.

McCarthy, W. E. (2001) “Re: Company Centric View Ends. Data Goes to the Net.” *GL Dialtone*. Available at http://linas.org/mirrors/www.gldialtone.com/2001.07.14/McCarthyPost.htm (11/01/2020)

McCarthy, W. E. (2016) “Accounting Is Big Data: How Research Becomes Reality.” Accounting is Big Data Conference. *American Accounting Association*. Video.

Available at https://aaahq.org/Meetings/2016/Accounting-Is-Big-Data-Conference/Video-Gallery/AIBD-Video-10-Public (12/02/2020)

McCarthy, W. E.; Holman, G. K. (2019) "Blockchain and eBusiness. The Open-edi Distributed Business Transaction Repository. ISO/IEC 15944-21 OeDBTR." *E-Invoicing Exchange Summit Singapore 2019*.

Mekić, E.; Purković, S.; Lekpek, A. (2018) "Cost Benefit Analysis of Compromising Ledger System Based on Blockchain Technology." BizInfo (Blace) Journal of Economics, Management and Informatics, 9(2), 27-38.

Meyers, J. (2020) Personal Communication. February 27, 2020.

Michael, S. (2019) "Plain Text Accounting." Plain Text Accounting. Available at https://plaintextaccounting.org (10/01/2020)

Mik, E. (2017) "Smart Contracts: Terminology, Technical limitations and Real World Complexity." Law, Innovation and Technology, 9, (2), 269-300.

Mitrokotska, A.; Rieback, M. E.; Tanenbaum, A. S. (2009) "Classifying RFID Attacks and Defenses." Information Systems Frontiers, 12(5), 491-505

Mohanty, D. (2018) "Blockchain From Concept to Execution: BitCoin, Ethereum, Quorum, Ripple, R3 Corda, Hyperledger Fabric/SawTooth/Indy, MultiChain, IOTA, CoCo." BPB Publications: New Delhi.

Murphy, K. E.; Simon, S. J. (2002) "Using Cost Benefit Analysis for Enterprise Resource Planning Project Evaluation: a Case for Including Intangibles." In Hossain, L.; Patrick, J. D. (2001) Enterprise Resource Planning: Global Opportunities and Challenges. IRM Press: Hershey.

Nakamoto, S. (2008) "Bitcoin: A Peer-to-Peer Electronic Cash System." Available at https://bitcoin.org/bitcoin.pdf (09/01/2020)

Oliveira Simoyama, F. d.: Grigg, I.; Bueno, R. L. P.; & Cavarzere de Oliveira, L. (2017) "Triple Entry Ledgers With Blockchain for Auditing." International Journal of Auditing Technology, 3(3), 163-183.

Odom, C. (2013) "Vulnerabilities." Open-Transactions. Available at http://opentransactions.org/wiki/Vulnerabilities (28/01/2020)

Odom, C. (2015) "Open-Transactions: Secure Contracts Between Untrusted Parties." Open-Transactions White Paper. Available at http://www.opentransactions.org/open-transactions.pdf (19/12/2019)

Odom, C. (2016) "FAQ." Open-Transactions. Available at http://opentransactions.org/wiki/FAQ (28/01/2020)

Owen, L. (2019) Personal Communication. November 22, 2019.

Pacio (2018a) "Pacio Technology." Pacio Whitepaper Extract. Available at https://www.pacio.io/docs/Pacio_Technology.pdf (30/01/2020)

Pacio (2018b) "Semantic Blockchain for Business Data: Competition." Pacio. Available at https://www.pacio.io/docs/PacioCompetition.pdf (09/01/2020)

Pacio (2019a) "BlockchainTech: Can Triple Entry Accounting Save the World?." Pacio. Available at https://pacio.io/2019/08/26/blockchaintech-can-triple-entry-accounting-save-the-world/ (06/01/2020)

Pacio (2019b) "Pacio White Paper." Pacio. Available at https://pacio.io/docs/PacioWhitePaper.pdf (06/01/2020)

Pacio (2019c) "Tender. Building Fair Money: Contextpaper." *Pacio*. Available at https://tender.buzz/docs/Tender.Buzz-NoTechPaper.pdf (30/01/2020)

Pacio (2019d) "Tender. Collaborative Open Economy White Paper V1.0." *Pacio*. Available at https://tender.buzz/docs/TenderEconomyWhitePaper.pdf (30/01/2020)

Pacio (2019e) "Tender. Open Source Economy - Design Paper 1.1." *Pacio*. Available at https://tender.buzz/docs/Tender.Buzz-NoTechPaper.pdf (30/01/2020)

Pacio (2020) "Pacio White Paper." *Pacio*. Available at https://pacio.io/docs/PacioWhitePaper.pdf (07/02/2020)

Pacioli, L. (1494) "Particularis de Computis et Scripturis." In Pacioli, L. Summa de Arithmetica Geometria Proportioni et Proportionalita. English translation (1995). Pacioli Society: Seattle.

Panuparb, P. (2019). "Cost-benefit Analysis of a Blockchain-based Supply Chain Finance Solution." Doctoral dissertation, Massachusetts Institute of Technology.

PayPie (2018) "Credit Risk Assessment Based on Blockchain Accounting." PayPie Whitepaper. Available at https://whitepaper.io/document/126/paypie-whitepaper (10/01/2020)

PayPie (n.d.) "Paypie." PayPie. Available at https://www.paypie.bb/ (28/01/2020)

Peters-Richardson, J. (2011) "Introduction to Accounting." Ministry of Education, Trinidad and Tobago Commonwealth of Learning. Available at http://oasis.col.org/bitstream/handle/11599/2463/2011_VUSSC_Intro-Accounting.pdf (18/02/2020)

Pompliano, A. (2019) "Funding The Future of Finance." *Off The Chain*. Available at https://offthechain.substack.com/p/funding-the-future-of-finance (19/02/2020)

Postma, J.; Helm, A. J. v. d. (2000) "La Riegola de Libro: Bookkeeping Instructions From the Mid-fifteenth Century". Accounting and History: a Selection of Papers Presented at the 8th World Congress of Accounting Historians: Madrid-Spain, 19-21 July 2000, 147-178. Asociación Española de Contabilidad y Administración de Empresas, AECA.

Powers, W.; Troubh, R. S.; Winokur, H. S. (2002) "Report of Investigation by the Special Investigative Committee of the Board of Directors of Enron Corp." Available at http://i.cnn.net/cnn/2002/LAW/02/02/enron.report/powers.report.pdf (30/12/2019)

Provenance (2015) "Blockchain: the Solution for Transparency in Product Supply Chains." Provenance Whitepaper. Project Provenance Ltd. Available at https://www.provenance.org/whitepaper (06/01/2020)

Psaila, S. (2017a) "Blockchain Technology: A Game-changer in Accounting?" Deloitte. Available at https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Innovation/Blockchain_A%20game-changer%20in%20accounting.pdf (27/12/2019)

Psaila, S. (2017b) "Blockchain: A Game Changer for Audit Processes?" Deloitte. Available at https://www2.deloitte.com/content/dam/Deloitte/mt/Documents/audit/dt_mt_article_blockchain_gamechanger-for-audit-sandro-psaila.pdf (27/12/2019)

R3 Corda (2017) "What is a UTXO?" *R3 Corda*. Available at https://www.r3.com/blog/what-is-a-uxto/ (18/02/2020)

R3 (2018) "Case Study: How Finastra is Harnessing R3's Corda Enterprise Blockchain to Open Up a New Business Line and Transform Transparency and Efficiency in the Syndicated Loan Market." *R3*. Available at https://www.ledgerinsights.com/finastra-first-live-r3-corda/ (19/02/2020)

R3 (2019) "Blockchain for Procure-to-Pay (B2P)—Faster, Cheaper Procurement for Corporates." *R3*. Available at https://www.r3.com/wp-content/uploads/2019/11/R3.SCB_.B2P_CS_2019.pdf (19/02/2020)

Request (2018a) "The concept of smart financial audits on the Blockchain." *Request Yellow Paper*. Available at https://request.network/assets/pdf/request_yellowpaper_smart_audits.pdf (29/01/2020)

Request (2018b) "The Future of Commerce: A Decentralized Network for Payment Requests." *Request Whitepaper.*

Request (2019) “Request – Version 2.0 Mainnet Released.” *Request*. Available at https://request.network/en/2019/08/19/request-version-2-0-mainnet-released/ (09/01/2020)

Rosenzweig, P. (2019) “Preliminary Observations on the Utility of Measuring Cybersecurity.” Lawfare. Available at https://www.lawfareblog.com/preliminary-observations-utility-measuring-cybersecurity (23/12/2019)

Rosner, M. T.; Kang, A. (2016) “Understanding and Regulating Twenty-First Century Payment Systems: The Ripple Case Study.” Michigan Law Review, 114(4), 649-681.

Rückeshäuser, N. (2017) “Do We Really Want Blockchain-Based Accounting? Decentralized Consensus as Enabler of Management Override of Internal Controls.” Wirtschaftsinformatik 2017 Proceedings, 16-30.

Rukhiran, M.; Netinant, P. (2018) “The House Bookkeeping Conceptual Framework for Supporting Adaptability Using Three Dimensions Layering.” *Advanced Science Letters*, 24(7), 5234-5238.

Ryan, J. (2019) “Triple-Entry Accounting and DeFi: Blockchain for accountants.” Gilded. Available at https://get.gilded.finance/blog/blockchain-for-accountants/triple-entry-accounting-and-defi (09/01/2020)

Samani, K. (2018) “Models for Scaling Trustless Computation.” *Multicoin Capital*. Available at https://multicoin.capital/2018/02/23/models-scaling-trustless-computation/ (01/02/2020)

Sangster, A. (2015) “The Earliest Known Treatise on Double Entry Bookkeeping by Marino de Raphaeli.” Accounting Historians Journal, 42(2), 1-34.

Sangster, A.; Rossi, F. (2018) “Benedetto Cotrugli on Double Entry Bookkeeping.” De Computis, Revista Española de Historia de la Contabilidad, 15(2), 22-38.

Sassone, P. G. (1988) “A Survey of Cost-benefit Methodologies for Information Systems.” Project Appraisal, 3(2), 73-84.

Schollmeier, R. (2001) “A Definition of Peer-to-peer Networking for the Classification of Peer-to-peer Architectures and Applications.” Proceedings of the First International Conference on Peer-to-Peer Computing, 101-102. IEEE.

Schwartz, E.; Thomas, S. (2018) “White Paper.” Codius Whitepaper. Ripple Labs. Available at https://github.com/codius/codius-wiki/wiki/White-Paper (30/12/2019)

Shea, R. (2015) “The Blockchain is a Journal.” *Medium*. Available at https://medium.com/@ryanshea/the-blockchain-as-a-journal-dc1715ffa8a1 (11/02/2020)

Sieber, A. (2018) “Transity - The Future of Plain Text Accounting.” *Feram*. Available at https://www.feram.io/blog/2018-06-05_transity_the_future_of_plain_text_accounting/ (11/02/2020)

Sirletti, S.; Di Pasquale, S. (2019) "Ex-Deutsche Bank, Nomura Bankers Get Jail for Paschi Roles." Bloomberg. Available at https://www.bloomberg.com/news/articles/2019-11-08/ex-deutsche-bank-nomura-bankers-get-jail-terms-for-paschi-roles (30/12/2019)

SkyCell (2018a) “Big Four Audit Company Confirms SkyCell’s Outstanding Quality Performance.” SkyCell. Available at https://skycell.ch/archives/2429 (30/01/2020)

SkyCell (2018b) “SkyCell Clients Help Reduce CO2.” SkyCell. Available at https://skycell.ch/archives/2384 (30/01/2020)

Sleeter, D. (2014) “Bitcoin is based on this writing from Todd Boyle in 2003. http://ow.ly/t5axF We collaborated during his development. #roundtable14.” *Twitter Post*. Available at https://twitter.com/DougSleeter/status/428612589795704832 (12/02/2020)

Sluijs, C. (2020a) Personal Communication. January 8, 2020.

Sluijs, C. (2020b) Personal Communication. February 24, 2020.

Smart Containers Group (2018) “Smart Containers.” Smart Containers Whitepaper. Available at https://icosbull.com/whitepapers/2710/Smart_Containers_whitepaper.pdf (28/01/2020)

Suryanto, T. (2016) “Audit Delay and Its Implication for Fraudulent Financial Reporting: A Study of Companies Listed in the Indonesian Stock Exchange.” European Research Studies, 19(1), 18-31.

Swanson, T. (2015) “A Blockchain With Emphasis on the “A”.” *Great Wall of Numbers: Business Opportunities and Challenges in Emerging Markets*. Available at https://www.ofnumbers.com/2015/07/09/a-blockchain-with-emphasis-on-the-a/ (12/02/2020)

Tanenbaum, A. S.; Van Steen, M. (2007) “Distributed Systems: Principles and Paradigms.” Prentice-Hall: New Jersey.

Tanenbaum, A. S.; Van Steen, M. (2016) “A Brief Introduction to Distributed Systems.” *Computing*, 98(10), 967-1009.

Tasca, P.; Tessone, C. J. (2018) “Taxonomy of Blockchain Technologies: Principles of Identification and Classification.” Ledger, 4, 1-39.

The Block Ledger (2019) “Luca+.” *Luca+*. Available at https://www.lucaplus.com/ (27/01/2020)

The Block Ledger (n.d.) “Support for Luca+.” *Luca+*. Available at https://lucaplus.zendesk.com/hc/en-us (28/01/2020)

Tholen, J.; Vries, D. d.; Daluz, A.; Antonovici, C. C., Brug, W. v.; Abelson, R.; Lovell, D. (2019) “Is There a Role for Blockchain in Responsible Supply Chains?” Joint document by the OECD and KPMG. OECD Global Blockchain Policy Forum.

Tobin, B. (2020) Personal Communication. February 26, 2020.

Tyra, J. M. (2014) “Triple Entry Bookkeeping With Bitcoin.” *Bitcoin Magazine*. Available at https://bitcoinmagazine.com/articles/triple-entry-bookkeeping-bitcoin-1392069656 (27/12/2019)

University of Derby (2019) “Distributed Ledger Technologies.” D*epartment of Electronics, Computing and Mathematics at the University of Derby*. Available at https://computing.derby.ac.uk/bigdatares/?page_id=487 (22/01/2020)

Vagneur, K. (2018) “Blockchain Distributed Technology: Governance, accounting and risk implications in the face of potential disruption.” University of Cambridge. Available at https://www.researchgate.net/profile/Kathryn_Vagneur/publication/325541604_Blockchain_Distributed_Technology_Governance_accounting_and_risk_implications_in_the_face_of_potential_disruption/links/5beedac5299bf1124fd6f790/Blockchain-Distributed-Technology-Governance-accounting-and-risk-implications-in-the-face-of-potential-disruption.pdf

Vagneur, K. (2020) Personal Communication. February 18, 2020.

Vaidyanathan, N. (2017) “Divided We Fall, Distributed we Stand: The Professional Accountant’s Guide to Distributed Ledgers and Blockchain.” The Association of Chartered Certified Accountants (ACCA).

VAKT (2018) “November 2018: VAKT Goes Live with World First Enterprise-grade Blockchain Platform.” VAKT. Available at https://www.vakt.com/november-2018-vakt-goes-live-with-world-first-enterprise-grade-blockchain-platform/ (09/01/2020)

Verlinden, P. (2018) “Blockchain in Logistics.” T-Mining Whitepaper. Available at https://t-mining.be/s/T-Mining-Whitepaper-v13-2lb7.pdf (10/01/2020)

Vliet, K. v. d.; Reindorp, M. J.; Fransoo, J. C. (2014) “The Price of Reverse Factoring: Financing Rtes vs. Payment Delays.” European Journal of Operational Research, 242 (2015) 842–853.

Vollmer, H. (2003). “Bookkeeping, Accounting, Calculative Practice: the Sociological Suspense of Calculation.” *Critical Perspectives on Accounting*, 14(3), 353–381.

Ward, J. S.; Lundkvist, C. (2016) “DEVCON1: Balanc3 - Triple Entry Accounting.” DEVCON1. Available at https://www.youtube.com/watch?v=NEYTypMoQv0 (30/01/2020)

Watts, R. L.; Zimmerman, J. L. (1983) “Agency Problems, Auditing, and the Theory of the Firm: Some Evidence.” The Journal of Law and Economics, 26(3), 613–633.

Vogt, G.; Dashja, E.; Birov, S. (2016) “Cost-Benefit Analysis of ICT-enabled Services: Results from 11 pilots in Public Administrations Across Europe.” empirica Schriftenreihe, 1, 1-79.

Wild, J. J.; Shaw, K. W:; Chiappetta, B. (2011) “Fundamental Accounting Principles.” McGraw-Hill/Irwin: New York.

XPRL (2019a) “Consensus”. XRP Ledger Project. Available at https://xrpl.org/consensus.html (30/12/2019)

XPRL (2019b) “Payment Channels”. XRP Ledger Project. Available at https://xrpl.org/payment-channels.html (30/12/2019)

XPRL (2019c) “Trust Lines and Issuing”. XRP Ledger Project. Available at https://xrpl.org/trust-lines-and-issuing.html (30/12/2019)

XPRL (2019d) “XRP”. XRP Ledger Project. Available at https://xrpl.org/xrp.html (30/12/2019)

XPRL (2019e) “XRP Ledger Overview”. XRP Ledger Project. Available at https://xrpl.org/xrp-ledger-overview.html (30/12/2019)

Zaid, O. A. (2004) “Accounting Systems and Recording Procedures in the Early Islamic State.” *The Accounting Historians Journal*, 31(2), 149-170.

Zhang, J. (2019) “Enterprise Blockchain Protocols: A Technical Analysis of Ethereum vs Fabric vs Corda.” Kaleido. Available at https://kaleido.io/a-technical-analysis-of-ethereum-vs-fabric-vs-corda/ (30/12/2019)

Zheng, S. (2019) “ConsenSys accounting software spoke Balanc3 is shutting down.” Yahoo Finance. Available at https://finance.yahoo.com/news/consensys-accounting-software-spoke-balanc3-204600069.html (09/01/2020)