Information Systems and e-Business Management (2023) 21:437–470
https://doi.org/10.1007/s10257-023-00634-2

ORIGINAL ARTICLE

A developed distributed ledger technology architectural layer framework for decentralized governance implementation in virtual enterprise

Bokolo Anthony Jnr.[1]

Received: 20 August 2022 / Revised: 20 December 2022 / Accepted: 3 March 2023 /
Published online: 17 March 2023

Abstract

Distributed Ledger technology (DLT) has recently emerged as a disruptive system with a wide range of applicability, with prospect to improve societal interactions at large. In virtual enterprise (VE) context researchers and practitioners have started to investigate the deployment of DLT to automate the processing of data and implementation of decisions to support the provision of digital services. Although academic interest in this domain is growing, a practical analysis of DLT from a governance perspective is still lacking to date. Accordingly, this study aims to fill this gap and provide implications related to decentralized governance of DLT. This article develops an architectural governance-by-design framework that defines the governance of DLT as a combination of architectural layers and governance of DLT dimensions. Design science is employed, and IOTA tangle an open-source DLT which employs a decentralized asynchronous network is deployed to evaluate the applicability of the developed architectural governance-by-design framework through qualitative interviews and literature inquiry. The findings confirm the developed architectural governance-by-design framework and offer a shared discussion and insight surrounding the topic of governance of DLT. The findings also identify limitations associated with governance of DLT solutions and proposes policy recommendations to be used as guidelines for practitioners to improve the adoption of DLT to accelerate VE digitalization.

Keywords Information systems · e-Business management · Emerging technologies · Disruptive technologies · Distributed ledger technology governance · Virtual enterprise

✉ Bokolo Anthony Jnr.
anthony.bokolo@ife.no

[1] Department of Applied Data Science, Institute for Energy Technology, Os Alle 5, 1777 Halden, Norway

1 Introduction

There is now much interest among researchers, policymakers, practitioners, and enterprises in the use of emerging technologies such as artificial intelligence (AI), big data, industry 4.0, Internet of Things (IoT), distributed ledger technologies (DLT), digital twins, and so on, to address societal issues and achieve sustainability goals (Schulz et al. 2020; Anthony Jnr 2022a). Besides AI and big data, so-called DLT such as blockchain can help provide potential solutions to virtual enterprise (VE). VE comprises a coalition of organizations aimed at attaining a shared goal in an approach that aligns to a common consensus (Browne and Zhang 1999). VEs have emerged among companies to leverage the capability of their individual competences and resources to attain real business value (Jagdev and Thoben 2001; Anthony Jnr and Abbas Petersen 2021). Presently, VE now employs DLT since it provides a decentralized, immutable record of data transactions that uses pre-programmed protocols, algorithms, and state-of-the-art cryptography to automatically execute, monitor, and authenticate transactions without depending on a central third party (Schmeiss et al. 2019). Typically, DLT allows actors (called nodes) within a decentralized system to transact digital assets based on a Peer-to-Peer (P2P) network and storing these data or transactions in a distributed approach across the network. These transactions are validated within the distributed network by employing a consensus mechanism that allows node users to validate transactions which updates the registry within the entire network (Allessie et al. 2019).

Generally, DLT such as blockchain are adopted in different areas such as banking and fintech, e-government, healthcare, chain supply management, notarial services, education to be integrated with other emerging technologies such as AI, IoT and machine-to-machine (M2M) applications, cloud computing, digital twin, big data, etc. (Anthony Jnr 2021). DLT deployment in VE has resulted in re-engineering the way business processes, data, and digitalized assets are shared, verified, accessed, and secured. Depending on the context of usage, the governance of DLT have been established as being significant to support data driven services in enterprise (Atzori 2017). Even the European Parliament Resolution (2016/2007 INI) has highlighted the potential of emerging technologies such as DLT to positively contribute to societal and economic development (europa.eu 2016). While this resolution is not obligatory for Member States or European countries, it however represents a significant recognition of DLT in institutional level. The resolution also encouraged institutions to test DLT based solutions after sufficient impact evaluation, with a view of improving the quality of data driven and digital services provided to end users in accordance with EU data protection act (europa.eu 2016; Atzori 2017). Likewise, the European Commission also started the EU blockchain observatory and forum in 2018 to support DLT development (Gloerich et al. 2020).

Additionally, like any software DLT need to be occasional maintained, updated, and scaled-up to improve the security of the entire distributed network. Thereby modifying the distributed ledger's source code which may involves coordination between stakeholders such as the software developers, miners, users, etc. (Reshef Kera 2020). Also, DLT platforms and cryptocurrency communities have little or no structure on how to coordinate consensus processes and resolve differences at times. Plausibly, this could influence the future adoption of DLT but most notably poses significant risks to potential users. This also leads to increasing concern for regulators, particularly in financial sectors where any threat to trust and stability in the economic environment are of utmost importance (Zachariadis et al. 2019). Paradoxically, DLT is adopted to improve the governance of other digital platforms but who governs these DLT adopted in VE (Anthony Jnr 2022b). Moreover, understanding how DLT are governed is necessary to come up with recommendations for policymakers (Pelt et al. 2021).

According to the literature, it is not only challenging for stakeholders to understand how the governance of DLT work but some actors are not even aware that they are stakeholders themselves in the decisions making related to the use of DLT (Pelt et al. 2021). But the governance of DLT often entails many contributors due to the decentralized nature of DLT, has calls for architectural framework to operationalize the mechanisms deployed by DLT (Liu et al. 2019). Therefore, this research will examine the following research questions:

- What are the governance dimensions to be considered in improving the operationalization of DLT in VE?
- What are the architectural layers needed to improve the governance of DLT adoption in VE?

Therefore, this study aims to improve the understanding on the governance of DLT by developing an architectural governance-by-design framework that *captures the governance dimensions* and *architectural layers* required for the governance of DLT to guide enterprises, users, regulators, and other pertinent stakeholders to understand the governance of DLT in a structured approach. The architectural governance-by-design framework can help practitioners and researchers to operationalize the governance methods for the future development and deployment of decentralized platforms. The architectural governance-by-design framework can be employed as a maturity model for VE to benchmark and understand the degree of governance in different DLTs. Additionally, findings from this study provides focal insights about the present DLT governance challenges and recommendations from an architectural perspective. The rest of this article is organized as follows. Section 2 introduces the literature review. Section 3 presents the methodology employed in this study. Section 4 presents the findings. Section 5 provides discussion and implications. Section 6 concludes this article.

2 Literature review

This section provides a theoretical background and review of the review on the state-of-the-art of DLT and need for examining the governance of DLT in VE.

2.1 Overview of DLT adoption in VE

Recently the idea that human or established agencies can now be substituted by trusting responsibility with machines has drawn considerable policy, business, and scholarly interest, especially during the last two decades. Similar to the World Wide Web (WWW) hypertext protocols integrated into the Internet infrastructure enabled the flow of information from different directories, DLT not only build on these basics but offers the promise of decentralized environment for participation, interaction, and innovation (Savirimuthu 2019). As noted, DLT comprises of a system of decentralized ledger transactions that is powered by pre-programmed algorithms, protocols, and advanced cryptography to achieve an automated consensus regarding the actuality and evolution of transactions. It offers an immutable history of transactions which are visible to all actors, without the intervention of a third party to guarantee trust between exchange partners by examining and validating transactions (Chen et al. 2020).

DLT enables a decentralized architecture that allows multiple actors that do not trust (or know) each other to interact securely under fixed conditions (Schmeiss et al. 2019). While the precise technical approach may vary from use case to use case, most DLT solutions have a distributed ledger and smart contracts (Lai et al. 2021). DLT employs a new paradigm of decentralization on large-scale in which human influence is reduced and trust shifts from the human or central organization towards an open-source code. In such a distributed architecture the DLT code is open source as such can be review by any actor within the distributed network as it not owned nor regulated by any single body. Thus, data are instantaneously kept by all node users, thus guaranteeing proper redundancy (Atzori 2015). The usefulness of DLT has been acknowledged by VE globally, aimed to transform their current products and services as well as their internal operations, and to develop innovative business models. DLT can help decrease barriers created by data silos to facilitate interactions in VE and creation of value-added services (Savirimuthu 2019).

Thus, since 2017, there have been increasing efforts by VE in different sectors such as energy, insurance, mobility, banking, entertainment, health care, etc., to deploy DLT powered services (Rajnak and Puschmann 2020). Fintech enterprise such as Ripple, for instance, aim to modernize international payments with the use of DLT. Established enterprises such as Deutsche Bank are beginning to adopt DLT across their product/service portfolios, and well-known technology companies such as Facebook have introduced their own cryptocurrency Libra (Schmeiss et al. 2019). Likewise, projects such as Provenance (2022) and IBM Blockchain (2022) promote distributed monitoring and accountability in supply chains and logistics while others such as Ripple (2022) provide scalable, efficient settlement applications for cross-border exchanges (Zook and Blankenship 2018). However, DLT such as blockchain has been criticized for having privacy, high operation costs and governance issues. Presently, solutions are evolving to address the initial shortcomings of blockchain with new technical functionalities.

2.2 Theoretical background on governance of DLT

Governance refers to processes of administration, undertaken by either government, organizations, markets, or networks, over territories (Lumineau et al. 2021). Governance has been perceived as the way in which values, rules, norms, and actions are designed, imposed, and regulated (Anthony Jr 2018). This entails drawing up policies and continually checking if those policies are being correctly being adhered to (Ziolkowski et al. 2020). Governance describes the decision-making processes or formal/informal rules of a system established (Jnr et al. 2020). These rules vary from code (such as smart contracts), laws (for example fees for malicious actors), processes (what must be accomplished when a certain event occurs) or assigning of responsibilities (who should do what). Ziolkowski et al. (2020) added that governance describes how powers and responsibilities are aligned between actors, specifies accountability, and stipulates how the decision-making process is performed. According to the literature (Seyedsayamdost and Vanderwal 2020), governance involves the mechanism employed by individuals and institutions to manage shared affairs (Jr et al. 2017). It aims at initiating compliance, along with informal arrangements that individuals and institutions either have agreed to or recognize to be in their interest or to address global challenges (Seyedsayamdost and Vanderwal 2020).

To conceptualize the governance of DLT, this study is inspired by the IT governance perspective as proposed by Weill (2004), since DLT can be seen as an IT innovation. According to Weill (2004), IT governance stipulates the decision rights and accountability framework to promote appropriate behavior in the use of IT. Based on the definition from Weill (2004), IT governance comprise of three key dimensions which are *accountability, decision rights, and incentives* (Beck et al. 2018). In addition, Weill and Ross (2005) suggested three IT governance methods which entails *decision-making structures, alignment processes*, and *formal communications*. The decision-making structures helps to form a decision-making committee within an enterprise. Whereas the alignment processes describe the management practices as related to governance decisions and implementation (e.g., exception handling, investment proposal, etc.), and lastly formal communications provide various means for involving individuals to understand the decisions. In most cases, IT governance provides high-level guidance for enterprises to better leverage IT (Liu et al. 2019; Jnr 2020). Zachariadis et al. (2019) stated that IT governance can be seen as the set of mechanisms employed to ensure the delivery of IT capabilities for an enterprise.

Due to governance issues associated with emerging technologies, over the years there have been concerns about the adoption of DLT such as blockchain as an intrinsically scalable solution to address societal issues. This is partly because emerging technologies has complex governance structures (Liu et al. 2019; Schulz et al. 2020). The complexity of legislating governance processes in DLT such as in the Bitcoin community has resulted to periodic crises in collective control and action. Depending on the number of miners and users who install the newer software release, the complete system can end up with two different DLT which can lead to confusion among contributors and later cause risk for the token value (Zachariadis et al. 2019), thereby impacting the economic gains for stakeholders. The persistent paradox of DLT is that although it is based on a distributed infrastructure, its governance often comprised of easy majority voting mechanisms that is potentially susceptible to lobbyists (for instance investors) and/or the power of some active contributors. This implies that the governance structures have a seemingly intrinsic degree of centralization. *DLT's openness is consequently both its strength and its weakness with decision-rights, as its available to any user*. Furthermore, the governance of DLT platform process in VE comprises of 7 processes as discussed in Table 1.

2.2.1 Governance mode for DLT platforms in VE

In this study governance of DLT refers to the complete control including structures, policies, and processes which could be applied to digital assets to support right decision making in VE. DLT being a new technology that disrupt many conventional norms (e.g., eliminating the central mediator), have not yet specified a standardized governance method (Paik et al. 2019). The governance of a method of DLT platforms incorporates a different procedures and rules that may be applied either as *on-chain and/or off-chain mode* (Reyes et al. 2017; Liu et al. 2019; Smit et al. 2020; Dursun and Üstündağ 2021). In comparison off-chain governance is described by De Filippi and McMullen (2019) as external applications that exist outside of the DLT platform, but however influence the development and operations of the distributed ledger. The governance rules initiated by off-chain systems are not automatically executed but a third-party authority is mostly required for oversight or enforcement (Liu et al. 2019). Accordingly, off-chain governance is usually executed through procedures and rules that are not as formalized and rigid as those of a code-based platform. Reyes (2021) stated that the off-chain governance offers a mechanism where individuals oversee the code, without their actions being defined by it. Though, it enables the DLT platform to react smoothly and quick to unpredicted situations as compared to on-chain governance.

Generally, on-chain governance refers to efforts to hard code governance procedures into the consensus algorithms employed to confirm transactions conducted within the DLT protocol (Reijers et al. 2016; De Filippi and McMullen 2019). Smit et al. (2020) mentioned that according to Erhsam (2017) the on-chain governance starts when "a participant" proposes a code update to implement update to the governance structure of the DLT platform. Next, the "distributed network participants" then vote on the submitted updates within the DLT platform, and if approved, the update will initially be integrated and deployed on a test network. After a certain period, a final vote will take place, and the code update approved will be fully executed within the main network. This approach is termed a "self-amending ledger" and improves a user's power to exert control on the distributed network (Ehrsam 2017). Overall, the difference of on-chain and off-chain governance is presented in Table 2.

In this study both on-chain and off-chain initiatives are suggested as a respond to some of the above problems faced by each governance mode in VE. The on-chain and off-chain governance will aid in addressing the governance issues faced by VE (*for DSR step* 2).

Table 1 Governance of DLT platform process

DLT platform process	Description
Voting	In DLT voting is commonly employed as a conflict resolution method to decide governance decisions, which can be executed either off-chain or on-chain. Users and node operators are the predominant actors in a voting process to establish or veto on-chain activities (such as the approval of proposals, assessment of historical transactions, and the election of certain roles). However, a major issue of executing voting in blockchain is that at times individuals lack technical expertise on how they can cast their votes in the DLT platform (Liu et al. 2019)
Forking	After the execution of the voting process for proposed improvement from all stakeholders, forking is performed to fulfill accepted proposals. It comprises of two types of upgrades (soft forks and hard forks). The soft forks describe the backward-compatible software improvements to a DLT platform whereas the hard forks refer to the backward-incompatible software improvements that all actors need to discard in the previous version (Liu et al. 2019)
Consensus protocol	The consensus protocol indicates how contributors behave when interacting with a DLT platform. The on-chain protocol is autonomously implemented by DLT stakeholders. The consensus protocols can be seen as a shared concept of authority in a DLT platform. In particular, the consensus protocol defines the capabilities, authority, and responsibility of different roles of stakeholders within the DLT platform (Liu et al. 2019). Also, the consensus protocol aids to find a democratic reconciling medium to protect the interests of all stakeholders through a cascaded voting stage. Although there are still concerns as related to low voter participation, lack of technical knowledge of voters on suggestion proposals, etc. (Dursun and Üstündağ 2021)
Incentive mechanism	The incentive mechanism is also important for DLT governance as it controls the distribution token in a permissionless DLT platforms. The incentive is considered as a motivational determinant that influences stakeholders' participation (Liu et al. 2019). For example, miners need fees, developers need control on execution of changes in the DLT as well as increase the distributed network realization, and users want high security and low usage costs, investors anticipate for growing asset values (Dursun and Üstündağ 2021)

Table 1 (continued)

DLT platform process	Description
Transaction filter and participation permission	Transactions are mainly the data entries within the DLT. In DLT such as blockchain block validators are seen as having the ability to manually filter the transactions towards ensuring data source and data quality. The governance of DLT can be permissioned or permissionless. In permissioned DLT governance may include existing centralized decision-making approaches as only a few stakeholders are engaged in the decision making. Meanwhile, in a permissioned DLT the roles are more of delegated than elected. On the contrary, governance is much complex in a permissionless DLT where there is greater level of decentralization. In this case, efficient negotiation and voting mechanisms are considerable for the stakeholders to reach consensus (Liu et al. 2019). In certain DLT, particularly permissioned DLT, new users are authenticated before joining the distributed network
Source code management and sharding	The current transparency of DLT source code may alter the governance of DLT platforms. This is because the code of many permissionless DLT platforms (such as., Bitcoin, Ethereum) are visible to the community, to accept updates and standardize the development process. Nonetheless, such openness permits the copying of the code which decreases the complexity of forking associated to competing with the original DLT (Liu et al. 2019). Also, debate on Sharding technique determines how a DLT platform is created, involving how contributors are partitioned to various shards and how data is stored
Security of Governance	Securing the DLT is difficult due to different components in the DLT. However, DLT usually employs pseudonymous and occasionally completely anonymous users' identities, and the roles of stakeholders may not be obvious. Also, the DLT must be resilient to security attacks which can exploit the security weakness. Hence, security control procedures such as blacklist abuse reporting, and not considering votes of banned users should exist (Dursun and Üstündağ 2021)

2.2.2 Actors involved in governance of DLT in virtual enterprise

In the context of this study, an actor refers to any individual or entity that directly or indirectly interacts with the operational state of the DLT platform. Actors are grouped according to the role they play within any system. In the governance of DLT an individual can simultaneously take the roles of multiple actors and operate within one layer. Equally, a specific role can be accomplished by multiple actors within the same time (Brioschi 2021). Actors involved in the governance of DLT ranges from technical perspective includes the *software developers* who debug and maintain the

Table 2 Main difference of on-chain governance and off-chain governance

Strategies	On-chain governance	Off-chain governance
Operationalization	On-chain governance provides a consistent implementation process which possibly increases fairness and coordination while concurrently aids quick decision making	Overall, off-chain governance is similar to the traditional social governing model such as direct democracy
Consensus mechanism	The developers determine which proposals are established (Smit et al. 2020). Then, it depends on the miners who jointly have at least half the computing power to carry out the proposed change with the DLT platform, which can be realized as a form of voting (Reyes 2021)	It involves business entities, users, miners, and core developers in a process that is mainly based on human collaborations for consensus on proposed changes within the DLT software which is updated manually as seen in Ethereum and Bitcoin improvement proposal models
Centralization	The on-chain governance is comparatively less centralized and entails mainstream actors that may lack the financial power or technical knowledge into decisions process	Off-chain standards are centralized due to the involvement of dominant actors but excludes some ordinary users that lack the financial power or technical knowledge to influence network decisions
Deployment	On-chain governance centers on the decision-making procedure that are codified to a DLT to ensure that all successive interactions should adhere to pre-defined rules (Liu et al. 2019)	As being performed outside of the distributed ledger network with many stakeholders involved, it may be time consuming
Speed	It however runs faster and can achieve radical changes quickly (Erhsam 2017)	It is mostly slow with lack of auditability owing to off-chain governance data (Dursun and Üstündağ 2021)
Maintainability	Are achievable without necessary employing a hard fork facilitating a self-amendment of governance rules within the distributed ledger	In some extraordinary situations, such as the DAO hack, off-chain governance has been employed to update a DLT's protocol for economic and not for technical reason (De Filippi and McMullen 2019)
Sovereignty	The consensus is usually attained via voting via the protocol. The voting results are algorithmically managed, and their automated execution are coded directly into the algorithmic protocol, for example some on-chain governance models, are Dfinity, Decred (Dursun and Üstündağ 2021), and Tezos (Smit et al. 2020)	Off-chain governance channels can be carried out in external platforms such as GitHub, Reddit, and Twitter (Liu et al. 2019). But off-chain governance may introduce the challenge of personal sovereignty (where powerful individuals dominate the decision-making processes) (Reyes 2021)
Flexibility	There is the risk that it becomes challenging to implement changes as the governance structure has been hardcoded (Ehrsam 2017), and it becomes harder to update changes once instituted (Dursun and Üstündağ 2021)	Off-chain governance is challenging to enforce due to its social constituent (De Filippi and McMullen 2019)

code, to *miners* who run the code needed for validating transactions within the distributed ledger, to *users* who via their digital wallets, buy, store and transfer value or digital assets in the form of Bitcoin (Zachariadis et al. 2019; Anthony Jnr 2022a). Generally, other actors involved in the governance of DLT in VE may comprise of *end user, regulator, business owner, investor, admin/operator, and supplier* (Lima 2018). These actors are regarded as the key shareholders involved in the governance of DLT in VE. In general, they are responsible for technical implementations and codification of the DLT platform for real-world application (Anthony Jnr 2021). The main actors are described in Table 3.

Table 3 depicts possible actors involved in the governance of DLT in VE. As stated by Anthony Jnr (2022a) the operationalization of DLT is greatly influenced by the actors involved in the governance of DLT who participates in the decision making of the consortium toward achieving a common goal. Although researchers such as Dursun and Üstündağ (2021) augured that unnecessarily over-empowered actors such as *miners, founders, core developers,* and *proposal editors* may prioritize their interests which may lead to centralization of DLT.

2.3 Related works

As supported by the literature a few studies have explored the governance of DLT grounded on primary and secondary data. Among these studies Anthony Jnr (2022a) carried out an extensive literature review and suggested a collaborative governance model for DLT adoption in organizations. The author aimed to provides a better understanding of the governance of DLT adoption in enterprises by investigating the governance issues and control of DLT adoption in intra-organizational domain. Romano and Schmid (2021) explored recent trends and perspectives in DLT beyond Bitcoin. The research proposed some conceptual framing approaches to aid in the application context. The approach comprises of an off-chain and on-chain governance models, DLT reference architecture, and categorization of consensus protocols. Smit et al. (2020) carried out a systematic literature analysis on the decision rights and governance of blockchain and designed a blockchain lifecycle model on the governance of blockchains relating to how decision rights are structured in private and public blockchains.

Furthermore, Reshef Kera (2020) provided a testnets and sandboxes as a trading zone for blockchain governance. Data was collected from a workshop utilizing templates of smart contracts, and later questionnaires to offer evidence for better integration of regulations, natural language, and code without selecting any regulatory force or domain such as technology, market, law, or culture. Werner and Zarnekow (2020) explored the governance of blockchain-based systems. The research focused to increase the understanding of governance methods of blockchain-based systems. A case study was conducted to examine the governance mechanisms and their indications. Rikken et al. (2019) investigated the governance challenges of decentralized autonomous organizations and blockchain. The study aimed to shows the need for additional research into governance approaches for DAO platforms on permissionless DLT, connected to products and services provided.

Table 3 Roles and description of actors involved in governance of DLT in VE

Actors	Description and roles
The node operators	These are validators also referred to as "*miners*" within DLT platform. They are accountable for the creation and addition of new transactions or data entries and further safeguards the security by contributing to the consensus mechanism deployed within the DLT platform. Additionally, the node operators manage the storage of all historical ledger data, and occasionally support DLT platform updates by installing the latest software version. Their roles, decision rights, and responsibility within the DLT platform can be pre-determined either in design or chosen during operation. For instance, Dash allows shareholders who have higher than 1000 Dash tokens as "masternodes", who can vote and make decisions for the future development of Dash blockchain (Liu et al. 2019)
Users	In the governance of DLT, users are important as they eventually decide whether a DLT platform can be sustainable after a certain period. For example, when a hard fork is invoked, the distributed ledger separates into two versions. The users will then decide which version they will continue to utilize. Also, users can provide feedback critical to the survival and evolving of the DLT platform. The users are also token holders who offer proposals that form potential directions and can vote for approve or disapprove proposals (Liu et al. 2019)
Third party application providers	Comprises of oracles, gatekeepers, digital assets exchangers asset custodians, token issuers, or application programming interfaces (APIs) that supports off-chain governance (Brioschi 2021). These third-party application aid integration and alignment to wallet providers, custodians, and banks (Liu et al. 2019). They act as a bridge enabling interoperability to digital applications that connects to the DLT platform (Brioschi 2021)
Regulators	These actors refer to the auditors, governments, and court who ensure that all VE operations within the DLT ecosystem conform with existing laws and policies such as general data protection regulation (GDPR). The governments for example can influence the governance decisions made by other actors by establishing new legal constraints and restrictions. These may vary from tax regulations to prevent against money laundering, where the court will also be involved. Also, the auditors are responsible to detail all information required for future audit and provenance (Liu et al. 2019)
External actors	As mentioned by Liu et al. (2019), this are indirect stakeholders which comprises of the researcher, media, and environmentalist. They can influence or contribute towards how governance decisions are made for the development of the DLT ecosystem while they do not directly participate in the operation of the DLT platform (Liu et al. 2019). The media and environmentalist can both create social pressure which may impact stakeholders' decisions on the role of DLT to the society at large. Whereas findings from researchers published in academic venues can influence policies as related to the adoption of DLT
Developers	The developers maintain and upgrades the codes of the DLT platform. They are responsible for writing and reviewing the code that powers the technical building block of a DLT platform and its linked systems. Developers may participate voluntarily or be professionally employed by the foundation (Brioschi 2021)
Administrators	These actors provide access control to the core codebase repository and decides to add, amend, deactivate remove, and activate code to change the rules of the DLT platform. The administrators are often mostly involved in the governance process and typically have more control over of the DLT platform. Although, the role and nature of an administrator can differ greatly from one DLT platform to another. For example, in a permissioned DLT platform a dedicated entity may take the role of an administrator, whereas in comparison to an open, permissionless DLT platform there may be group of administrators as volunteer core developers instead of a formal administrator (Brioschi 2021)

Table 3 (continued)

Actors	Description and roles
The foundations	Another stakeholder is the foundations which give financial support to improve DLT development. They can also influence the governance of the DLT (Liu et al. 2019)

Additionally, Schmeiss et al. (2019) designed a governance mechanism for platform ecosystems aimed at resolving the paradox of openness via blockchain technology. The designed framework of the blockchain technology-enabled governance mechanisms can support entrepreneurs and managers alike to design and manage platform ecosystems that create value for all contributing actors. Paik et al. (2019) provided an analysis of data management in blockchain-based platforms mainly from architecture to governance. The study aimed to analyze blockchains from the perspective of a developer to highlight critical concepts and issues when integrating a blockchain into a bigger software system as a data store. Beck et al. (2018) proposed a framework and research agenda on governance within the blockchain economy. The researchers discussed the blockchain economy in line with the IT governance dimensions which comprises of accountability, decision rights, and incentives. De Filippi and McMullen (2018) examined the governance of blockchain systems in relation to distributed infrastructure. The report highlighted the need for a more human-based approach to blockchain governance that deploys both on-chain and off-chain governance. Figure 1 depicts a Venn-diagram to visualize the different streams of DLT governance research from the literature.

However, as seen in Fig. 1 the gap in knowledge is that issues related to the governance of DLT is not well researched from a practical perspective by *investigating the important governance dimensions to be considered in improving the operationalization of DLT in VE and the architectural layers needed to improve the governance of DLT adoption in VE*. Moreover, there are fewer studies that have explored the governance of DLT from the lens of virtual enterprise. This study aims to better understand and enhance the governance of DLT by develop a decentralized architectural governance-by-design framework to facilitate DLT implementation in VE based on practical cases on energy marketplace and mobility solution.

3 Methodology

In this study, the design science research (DSR) approach (Markus et al. 2002; Peffers et al. 2007) was employed which concerns the creation of meaningful artifacts which aim to resolve identified problems (Hevner and Chatterjee 2010; Gregory 2011). A DSR approach using qualitative methods in information systems was chosen to solve the practical problem specified in the research questions (see Sect. 1), of this paper (Hevner et al. 2004). Moreover, DSR is an appropriate method since this study addresses the identified problem of a lack of approach for decentralized governance of DLT by designing a meaningful artifact in the form of an architectural

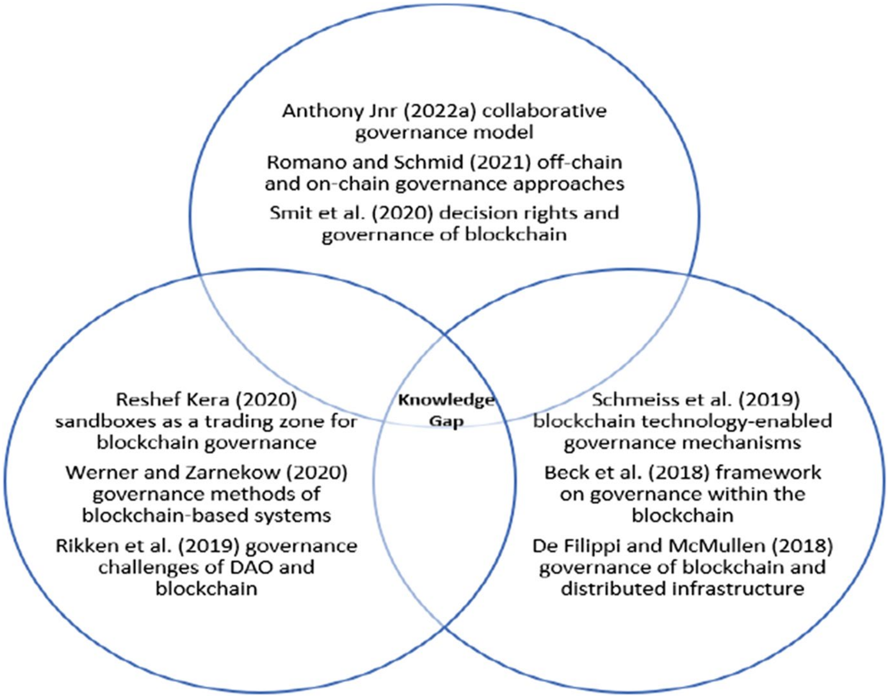

Fig. 1 Depicts a Venn-diagram of prior DLT governance studies

governance-by-design framework that captures the architectural layers and governance dimensions for DLT towards improving the governance of DLT which is not well addressed in prior studies. The aim of this study is in accordance with the criteria of DSR as suggested by Hevner and Chatterjee (2010) as an artifact is designed to solve a relevant problem and is to be preliminarily validated (Pelt et al. 2021).

The artifact (the architectural governance-by-design framework), forms two intertwined and iterative phase (the design and evaluation), to gain relevant knowledge in the implementation of DLT in VE. Hence, the design entails a sequence of research and design activities, whereas the evaluation offers new information to the refinement of the product and process (Hevner and Chatterjee 2010). Accordingly, an architectural governance-by-design framework describing the relationship between *the governance dimensions* for improving the operationalization of DLT and *the architectural layers* needed to improve the governance of DLT in VE was designed as seen in Fig. 2. According to Peffers et al. (2007), the process of DSR employed in this study is presented in Table 4.

3.1 Problem identification and solution suggestion/objective

Table 4 depicts findings in each step based on DSR approach. The procedure for step 1 specifying the current knowledge gap is discussed in Sect. 2.3 highlighting

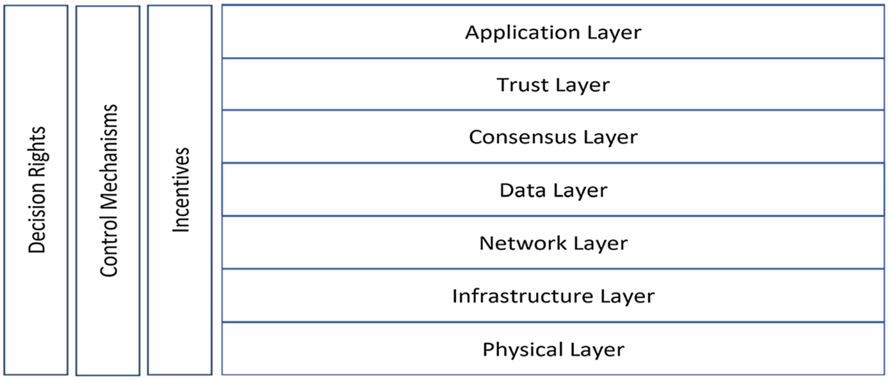

Fig. 2 Developed architectural governance-by-design framework

Table 4 DSR research procedure

Procedure steps	Outcomes
1. Problem identification	Functionalities of DLT to enable VE digitalization Enabling decentralize governance of DLT Understand how the governance of DLT works Identifying the actors or stakeholders involved in the governance of DLT Additional challenges identified during the interview sessions
2. Solution suggestion and objective	Identification of roles and description of actors involved in governance of DLT in VE Specification of governance structure, mechanisms, and mode of DLT Identification of relevant governance dimensions to be considered in improving the operationalization of DLT in VE Definition of the architectural layers needed to improve the governance of DLT adoption in VE
3. Design development	The designed artifact (architectural governance-by-design framework) for DLT represented as a model to visualize governance dimensions, architectural layers, and relevant stakeholders
4. Demonstration	Acknowledgment of the designed artifact by relevant stakeholders
5. Evaluation	Definition of use case scenarios to show the effectiveness and efficiency of the designed artifact in relation to the pre-stated problems of step 1
6. Conclusion and communication	Summary, reporting, and publication of findings

the need for investigating the important *governance dimensions* to be considered in improving the operationalization of DLT in VE and the *architectural layers* needed to improve the governance of DLT adoption in VE. In relation to step 2 the objective of the solution is specified in Sect. 2.2.1, where the architectural governance-by-design framework will comprise of both the *on-chain governance* and *off-chain governance* initiatives.

3.2 Prototype development

The IOTA driven energy marketplace and IOTA based mobility solution were developed as prototypes (Skoglund et al. 2020; Kinsella et al. 2021). The governance of theses prototypes was validated based on the developed architectural governance-by-design framework (see Fig. 2).

3.2.1 IOTA driven energy marketplace

The trading market platform is developed as part of the IOTA energy marketplace implementation in the + CityxChange smart city project, the IOTA module uses the IOTA ledger to provide *standardized APIs* for the marketplace to access required data, store agreements and to trigger payments by the IOTA ledger to ensure *auditability* (Skoglund et al. 2020; Kinsella et al. 2021). IOTA employs an IOTA proxy module use APIs to interact with the IOTA tangle to send energy and thermal power data (or hashes of them). The module exposes APIs that aids off-chain platforms to store selected data onto the IOTA tangle, therefore guaranteeing their *integrity, immutability, and auditability*. Moreover, the IOTA module is deployed within the trading market platform locally at prosumer level to collect required marketplace data which is then shared using the IOTA ledger to guarantee data *integrity and immutability*. Another component is the IOTA asset module which collects imported and exported demand and offer energy and thermal power data from the connected asset(s). For *auditability and integrity* all the data and requests shared between marketplace and IOTA asset module are stored onto tangle (Petersen et al. 2021).

Overall, the IOTA energy marketplace platform via APIs aids receiving of data directly from asset modules and off-chain platforms which then uses the IOTA tangle to read/store immutable data, i.e., energy demands and offers bids and agreed bids generated respectively by IOTA asset modules. Furthermore, to ensure governance of the platform the IOTA driven energy marketplace implementation uses a *unique digital identity for verification* of shared data. The bid manager implements *standardized data model*, *simple matching policies* and stored agreements into the tangle using the same *gateway (*Kinsella et al. 2021). The marketplace backend employs *public key encryption* and *verifies the signature* of users using *authorized public key* to guarantee *confidentiality*. Lastly, the IOTA hardware module *encapsulates collected* data into IOTA transactions via a CryptoCore.

3.2.2 IOTA based mobility solution

To achieve a DLT driven mobility system. IOTA tangle was employed to deploy a proof-of-concept electro-mobility as a service which uses data from traffic control backend provided by an infrastructure enterprise involved in the virtual enterprise consortium (Skoglund et al. 2020). To ensure governance of the platform the mobility application integrated with IOTA tangle backend retrieves, stores, and provides transport data from various data providers via APIs and makes it available in a *normalized and standardized format* (Kinsella et al. 2021). The platform also delivers data as GeoJSON objects (RFC 7946), which allows developers to easily take the data output as a standardized object format. The virtual enterprise complies with the EU issued Delegated Regulation 2017/1926 based on National Access Point (NAP) to provide data in a machine-readable format. Lastly, data is pushed to or pulled by platform using *standard communication protocols* such as Message Queuing Telemetry Transport (MQTT) and WebSocket (Petersen et al. 2021).

3.3 Demonstration

The demonstration phase of DSR shows the applicability of the artifact in business environment. Thus, step 4 involves demonstrating how the governance operations of energy marketplace and mobility solution prototypes are captured in the architectural governance-by-design framework for *on-chain* and *off-chain governance*. The framework is designed based on an extension of existing DLT based architecture and IT governance dimension suggested in the literature as seen in Sect. 3.3.1 (*DLT architectural layers*) and 3.3.2 (*governance dimensions for DLT*). Accordingly, driven by the "*DLT architectural layers*" and "*governance dimension for DLT*" the architectural governance-by-design framework is shown in Fig. 1.

Figure 2 depicts the developed architectural governance-by-design framework to facilitate governance of DLT within VE which comprises of the architectural layers and governance dimensions. The architectural governance-by-design framework also provides a unique governance framework and a research agenda for VE to assess changes to governance that may be associated with the emergence of the DLT economy.

3.3.1 DLT architectural layer

The architectural governance-by-design framework aims to facilitate the governance of DLT to share both transaction, data, and digital assets across decentralized and centralized networks. Various architectural layers are employed to easier present and described the complexities associated with governance of DLT. The developed architectural governance-by-design framework distinguishes seven layers (*application layer, trust layer, consensus layer, data layer, network layer, infrastructure layer, and physical layer*). Each of the architectural layers identified from the literature are discussed below.

a. Application layer

In VE this can be an integration between traditional applications (centralized platforms, software applications and User Interface/Graphical User Interface (UI/GUI) and apps) (Anthony Jnr 2021; Mandaroux et al. 2021), and embedded DLT such as native cryptocurrencies or decentralized applications (DApps) where most of the applications are built on (Rikken et al. 2019). The applications contain in this layer can be utilized by *off-chain* (third party systems platforms) to communicate with the *on-chain* (DLT platforms). In the context of this study, similar to prior study (Akhtar et al. 2021), this layer can comprise of a front-end UI dashboard developed using the

IOTA client-side libraries coded in JavaScript. These libraries mainly comprise of "mam.js", "@iota/core", and "iota.lib.js". Also "mam.js" known as Masked Authenticated Messaging (MAM) which is a data channels utilized for receiving and sending data to IOTA tangle infrastructure. This package supports three types of data channels for access and privacy control which encompasses public, private, and restricted mode. The MAM message works as a linked list where existing data is referenced to the subsequent data by making use of an identifier called "root" and "sideKey" (Akhtar et al. 2021).

b. Trust layer

The trust layer captures the contract scripts, programmable scripts, software code, and scripting languages running locally on the end users or hardware nodes that runs on the enterprise`s digital infrastructure ensuring security, stability, or performance improvements (Hofmann et al. 2017; Qing et al. 2020). The trust layer comprises of the program logic, rules, such as *chain code, smart contracts*, etc. The platforms deployed within the application layer calls the code and rules within the trust layer and initiate the code in the execution layer that results to the execution of a DLT transaction (Gourisetti et al. 2021). These smart contracts can be seen as computer programs which implement pre-defined commands when certain requirements are met within the DLT platform (Anthony et al. 2023).

Typically, smart contract comprises of a set of executable commands that are triggered in response to a message. When executed, these instructions may change the state of assets and produce new messages. Smart contracts are implemented in DLT using programming languages or simple interpreted scripts such as Solidity in Ethereum, Golang, etc. (Qing et al. 2020). In first-generation DLT, like Bitcoin, a basic form of smart contracts can be coded into a transaction as an executable script. In second-generation DLT, such as Ethereum, smart contracts enable storing and manipulating data within the DLT. In relation to stored procedures in databases, smart contracts guarantee that embedded data can only be handled by requesting the approved functions. Thus, smart contracts can be seen as data with rules (Paik et al. 2019).

c. Consensus layer

Consensus in distributed systems denotes the process of reaching agreement about data that are maintained and stored through a set of network participants such that the nodes share the same state at any given point in time. In the context of DLT, the consensus ensures that all the ledger replicas deployed through the distributed network are the same (ledger consistency), except perhaps for a few numbers of terminal blocks still pending a final approval (final consistency) (Romano and Schmid 2021). The DLT infrastructure is unique as its able to orchestrate both the (immutable) data layer and the protocol (rules) in a decentralized manner. Embedded within the DLT protocol, the governance of the DLT infrastructure is organized through the consensus mechanisms which is fully autonomous (Rikken et al. 2019). Therefore, the consensus layer is the core layer of any DLT platform, as it manages and validates transactions, and ensures inter/intra-DLT verification (Mandaroux et al. 2021).

Consensus layer aids distributed control, trust, and ownership. It initiates an agreement among the distributed node users and synchronizes them. It further authenticates transactions and ensures fault-tolerant and reliable operations (Gourisetti et al. 2021). The consensus layer primarily encapsulates different consensus algorithms deployed by network nodes to achieve data consistency in a distributed manner (Qing et al. 2020). Consensus in distributed systems denotes the process of reaching agreement about data that are maintained and stored through a set of network participants such that the nodes share the same state at any given point in time. In the context of DLT, the consensus ensures that all the ledger replicas deployed through the distributed network are the same (ledger consistency), except perhaps for a few numbers of terminal blocks still pending a final approval (final consistency) (Romano and Schmid 2021).

d. Data layer

The data layer involves the data stored on the distributed ledger (Hofmann et al. 2017). It comprises of a certain data structure (Qing et al. 2020). Also, in this layer data are distributed and saved across different nodes. This layer also encompasses all the data mechanisms and structures which give rise to the distributed ledger. Such as Merkle trees and linked lists which make up the ledger data structure (Romano and Schmid 2021). Thus, the process of grouping transactions into the ledger or appending transactions into the ledger, etc. are carried out in this layer (Gourisetti et al. 2021). A standard view of a data stored within the distributed ledger would require understanding different index structures (e.g., Hash table and B-tree) which are greatly enhanced for searching and retrieving data items (Paik et al. 2019). The term transaction in DLT can mean different things varying on the context. It could relate to the operation that controls the data stored on a DLT platform, including the data structure that stores the parameters employed by the operation.

e. Network layer

The network layer captures the main infrastructure needed for operation of the DLT platform. It specifies the functions and role of the distributed network nodes, the communication pattern, and how the entire DLT platform workloads get partitioned. This layer also helps to specify the modality of the participating nodes (either sporadic, continuous, or otherwise) and their capability to synchronize each other digital platforms through the exchange of information. Specifically, this layer involves the synchronization assumption which influences the design and handling of a specific consensus protocol by specifying the way and number of delays influencing message transmissions (Romano and Schmid 2021). This layer comprises of a set of software-defined rules that govern how the DLT platform operates (Brioschi 2021). It comprises of interconnected processes and actors that implement protocols that describes how participants access the DLT system, determining how data is shared within the distributed network and so on.

Furthermore, the network layer encompasses internode communication that enables decentralized peer-to-peer information transaction, and data sharing among the nodes (Mandaroux et al. 2021). Thus, this layer involves how the P2P network of nodes is constructed and shares data so that the distributed ledger can be managed (Romano and Schmid 2021). The network layer involves protocols, authentication/authorization procedures, node management, networking access methods among multiple nodes within the distributed ledger (Qing et al. 2020). When nodes transact and engage in validation and verification of transactions, such procedures are specified in this layer.

f. Infrastructure layer

This layer is analogous to the physical and virtual computers that participate as the authorized nodes within the distributed ledger. The nodes should be able of carryout cryptographic processes such as hashing and digital signature, managing the identity of other nodes and offering identity information for authorization and authentication of nodes within the network and. Therefore, processes and tools that ensure permissions, specify identity of the nodes, and facilitate access controls are captured in this layer (Gourisetti et al. 2021). For instance, to support faster and more complex queries, many DLT explorers, such as Etherscan copy the distributed ledger data to a centralized indexing server. Conversely, Hyperledger Fabric manages a purpose-built index to offer a fast identification and time-based data querying of first-class data elements. Also, Ethereum Query Language (EQL) is like an SQL-like query language which aids to provide a general-purpose query application for blockchain data. It supports queries to quickly extract information dispersed through several records within the blockchain utilizing types of objects, collections of blocks, and a binary search tree as its core language concepts. Whereas DLT such as R3 Corda's ledger data are maintained as a relational database that enable both read and write queries utilizing SQL. Lastly, BigchainDB provides an alternative design where NoSQL query language is applied to achieve read and write of DLT data (Paik et al. 2019).

g. Physical layer

Physical layer contains all physical infrastructure and hardware devices used in the enterprise operation. This layer captures the IoT devices, smart metering devices, storage devices, sensors, and communication deployed. Most of this hardware may not be able to integrate directly to the distributed ledger. In such cases, these physical devices would need to interact with the middleware to connect seamlessly to the DLT network (Gourisetti et al. 2021).

3.3.2 Governance dimensions for DLT

There has been call for more effort towards the design of governance dimensions of DLT platforms. Researchers such as Beck et al. (2018) argued that the DLT economy is dependent on the initialization of an effective governance. Therefore, Beck et al. (2018) recommended that dimensions regarding governance of DLT should be investigated. Governance dimensions are viewed as a means towards addressing the challenge of opening DLT platforms to a diverse group of actors, while guaranteeing that value is captured equally among all actors (Schmeiss et al. 2019). Therefore, building on prior studies by Weill (2004), Weill and Ross (2005), this current study conceptualizes the dimensions required for the governance of DLT. The specified dimension will serve as governance strategies needed to set rules of interaction between all stakeholders involved in the adoption of DLT in virtual enterprise. The identified three overarching governance dimensions includes *decision rights, control mechanisms, and incentives* which are all aligned with the decentralization of the deployed DLT platform.

a. Decision rights

Over the years decision-making has moved from an authoritative manner to a collaborative process, and even to delegative decision-making (Smit et al. 2020; Ziolkowski and Schwabe 2022). The decision rights or roles specify who has the power, capability, and responsibility to do what within the DLT platform. The decision rights distinguish the different roles present in the use of DLT and describe observable hierarchical structures between them (Pelt et al. 2021). These decision rights of actors determine who can define the functionalities the DLT platform and its modules should have and how these functionalities will be implemented and monitored, and which actors' interests should be prioritized (Liu et al. 2019; Zachariadis et al. 2019).

Overall, this dimension specifies how decisions are made, agreed upon, and monitored as regards to the use of DLT within the enterprise to control certain assets. Furthermore, it decides how former decisions are executed (Miscione et al. 2020; Smit et al. 2020), and this involves how decision-making processes are set in place within the enterprise as related to voting mechanisms, practices to resolve arising conflicts, and how DLT is used to facilitate organizational process (Pelt et al. 2021). The distribution of decision rights can also determine the degree of decentralization (dispersed) or centralization (small group) within the DLT platform (Liu et al. 2019; Smit et al. 2020), assessing how decision-making autonomy is concentrated (Beck et al. 2018).

b. Control mechanisms

Control mechanisms specify the rules by which actors within the DLT ecosystem interact. This requires a distinctly articulated set of principles that also allows actors to collaborate. Additionally, control mechanisms ensure accountability for specific actors and guarantee consensus in case of a dispute of interest (Schmeiss et al. 2019). The control mechanisms (formal or informal) are put in place with the virtual enterprise to ensure the good behavior of all stakeholders. In an open and decentralized environment where there is no authoritarian administration to make decisions, control mechanisms tend to be more informal collaborative procedures that promote shared beliefs and common values (Zachariadis et al. 2019).

The control mechanisms further involve guidance on the management and organizational processes that they are required to follow, administering rules, holding contributors accountable, and using metrics, etc. Accordingly, this governance dimension ensures the efficient usage of resources and monitor the complete performance of the DLT platform. Usually, control mechanisms in DLT are enacted via off-chain legal frameworks or agreements governed by institutions and on-chain smart contracts (Beck et al. 2018; Liu et al. 2019). The right to monitor decisions rights are linked to control mechanisms deployed. This implies that the virtual enterprise acquires the required tools to adopt the decentralized ledger network in relation to existing legal compliance (Bodó and Giannopoulou 2019).

c. Incentives

In using the DLT platform incentives is put in place to motivate involvement and facilitate innovative outputs within virtual enterprise. Incentives define rules of engagement and certain activities that motivate actors to make specific (inter)actions towards the deployment of DLT (Liu et al. 2019; Schmeiss et al. 2019). Incentives motivate actors to act (Beck et al. 2018). Incentive suites initiated in the enterprise influence the strategic behavior of actors and the financial gains that can be gotten from the use of DLT platform. There are basically two types of incentives (pecuniary and nonpecuniary). The pecuniary incentives relate to observable users' behavior due to financial gains or rewards that can be monetized. In contrast nonpecuniary incentives relate to observable users' behavior due to non-monetary benefits such as reputation, privileges, or visibility (Beck et al. 2018). Although, depending on the assigning of decision rights and the ownership structure in the DLT platform, it can be challenging to align interests and ensure that all partners involved maintain their competitive position as users with higher decision rights enjoy higher profits as compared to other stakeholders (Zachariadis et al. 2019).

3.4 Evaluation

Step 5 in DSR approach as seen in Table 4 involves the evaluation (Markus et al. 2002; Peffers et al. 2007; Hevner and Chatterjee 2010) where, evaluation of the artifact is carried out to assess how well the artifact performs (March and Smith 1995). Therefore, a descriptive evaluation is employed to present the artifact's suitability to the problem solution based on the governance of the IOTA driven energy marketplace and IOTA based mobility solution prototypes. The demonstration of the *architectural governance-by-design framework* (see Fig. 2) was established based on *use case scenarios*. A use case scenario is an observational approach which is employed to investigate a designed artifact in detail in its expected business environment (Davis and Dawe 2001). Use case scenario is particularly appropriate to evaluate the usefulness of a designed artifact as it can improve the robustness and strength of findings (Gilson et al. 2020).

Thus, this study employed use case scenarios to be in line with the research questions on architectural layers and governance dimensions of DLT in VE. The use case scenarios allow for the representation of different situations in one existing model. *Therefore, this phase of DSR approach helps to verify the designed artifact which is based on an extension of existing DLT based architecture and IT governance dimension suggested in the literature as seen in* Sect. 3.3.1 *(DLT architectural layers) and* 3.3.2 *(governance dimensions for DLT) identified in Step 4 of the DSR.* Qualitative interviews (Myers and Newman 2007), and literature inquiry were utilized as research methodologies to provide input for the artifact design. The qualitative interview was selected as data collection instrument because of flexibility and in gaining more practical understanding in the explored research area (Myers and Newman 2007). In this research, the qualitative interviews helped to get early information about the understandability, usefulness, operational feasibility, simplicity, and completeness of the architectural governance-by-design framework.

Overall, qualitative interview was employed to collect comprehensive information in a conversational style, and this also allows investigator(s) to ask follow-up questions. Purposive sampling was employed where the participants were deliberately selected due to their experiences and knowledge on DLT adoption. According to Barriball and While (1993), Wieringa (2014), eliciting expert opinions employing interviews is a valuable instrument to collect information from experts regarding their own opinions, experiences, practices, and perception towards evaluating the designed artifact (see Fig. 2). The qualitative data was collected through a series of interview sessions with some partners in IOTA (https://www.iota.org/) during the period of 2019–2020. A diverse group of interviewees with knowledge of DLT use for mobility and energy trading were interviewed as seen in Table 5.

Prior to performing the interview session, the interviewees were briefly notified about the need for the interview, the structure of the interview. The informants were assured of their confidentiality and the interview was not recorded. The first part of the interview focused on the background of the interviewee and their perception towards the deployment of IOTA tangle as a DLT deployed in the + CityxChange smart city project (https://cityxchange.eu/). Next, the second part of the interview involves the interviewee providing feedback (Petersen et al. 2021), to confirm the architecture layers. The interviews were between 40–60 min. The findings from the interview response were manually recorded, transcribed, and analyzed according to the content, thematic, and descriptive analysis of secondary and primary data from the qualitative interview and literature (Barriball and While 1993), by researcher(s) involved the + CityxChange smart city project to identify concepts related to the governance dimensions, architectural layers, and their relations. To ensure validity and rigor of the interview all participants work in VEs involved in the + CityxChange smart city project and have experience on the use of emerging technologies in VE. Also, as suggested by Vogelsang et al. (2013) to measure the acceptance of the framework developed. The effectiveness and efficiency of the application of the

Table 5 Demographic details of participants

Role	Education	Working experience	Responsibilities
Head of tele and infrastructure dev	Ph.D.	>10 years	Designing digital solutions based on internet of things
Project manager	Masters	<6 years	Developing emergent solutions using IOTA tangle in the areas of IoT, data integrity, verification, micro-financial transactions, data sharing, tokenization of assets, data access control, self-sovereign identity, and smart contracts
Senior technical analyst	Masters	<5 years	Deploy IOTA tangle to improve digital services and has contributed to the ideation, design and implementing of digitalization that make data usable in an efficient way
Chief architect specialist	Masters	>22 years	IT architect for transportation and sustainable mobility solutions
System developer	Bachelor	<7 years	Carryout interactive platform interface design, ubiquitous infrastructure testing, and web-based socket
System architect specialist	Masters	>12 years	User interface design for different mobility platforms
Mobile application developer	Bachelor	<7 years	Programs handheld applications for digital services such as mobility

framework in the + CityxChange smart city project was reported in Petersen et al. (2021). Overall, the respondents accepted the developed architectural governance-by-design framework emphasizing that the framework layers are useful as it aids the capturing of requirements/needs, services, businesses, applications, data, digital technologies, and physical infrastructures needed for designing and providing digital services in VE to clients.

4 Findings

Step 6 in DSR approach reports on findings from the demonstration and evaluation phase. Therefore, this final phase presents how the designed artifact is used to support the governance of the IOTA driven energy marketplace and IOTA based mobility solution.

4.1 Applicability of IOTA tangle

Basically, IOTA tangle is a Blockless Directed Acyclic Graph (DAG) based DLT (Fan et al. 2019). DAG based DLT is suggested in this study as transactions can be directly appended to a chain without waiting to be wrapped into a block in advance. Also, all new added transactions can be concurrently run-on several chains, which interconnected to create a network called "*Tangle*" (Fan et al. 2019). In this paper, it is proposed that the DAG-based DLT is an efficient solution for deploying a transactive data driven architecture. The IOTA tangle technology is used to illustrate the governance of DLT in VE. IOTA tangle has a high scalability based on the decentralized DAG-based design and no associated transaction rate limit which also guarantees that all data are encrypted and stored in the locally running *Home Nodes* (Fan et al. 2019). IOTA tangle also has high transaction speed due to the DAG data structure which uses an efficient consensus mechanism. Accordingly, transactions can be added to several chains within the tangle concurrently which speeds up the transaction rate.

IOTA has no transaction fees as tangle eliminates mining as before issuing any transaction, the node needs to approve two prior unapproved transactions (called tips), according to a tip selection algorithm before including it to the tangle and carryout a very light-weighted PoW. This implies that all contributors need to provide their computation power to sustain the network to remove the transaction fees. IOTA also supports micro-transactions unlike Bitcoin with a threshold on the least amount of a payment, individuals can send as low as "1 IOTA" which is equivalent to 0.572701 USD (as of September 10, 2018) without sending any available fee. This makes the M2M P2P micro-transaction feasible for VE, such as in the use case scenario of *IOTA driven energy marketplace for energy trading* among individuals in a local community. Respectively, this study contributes to the development of an architectural governance-by-design framework powered by DAG-based DLT. The framework differs from prior solutions in the way that it employs a lightweight, high-performance, and scalable tangle technology which is suitable for IoT devices employed in VE. This study is one of the few research projects that leverages DAG-based DLT to show how the governance of DLT such as IOTA tangle (on-chain) integrates with (off-chain) digital platforms. Thus, data was collected using qualitative interview regarding deployment of IOTA deployed in 2 different use case scenarios (*IOTA driven energy marketplace* and *IOTA based mobility solution*).

4.2 Modelling governance of DLT

The findings from the literature were employed to design the artifact (see Fig. 2) which comprises of architectural layers (*physical, infrastructure, network, data, consensus, trust, and application*), and governance of DLT dimensions (*decision rights, control mechanisms, and incentives*). The findings from the qualitative interview confirmed the identified architectural layers and governance of DLT dimensions. As such no component(s) of the developed architectural governance-by-design framework was excluded and no new component(s) was added. Furthermore, the developed architectural governance-by-design framework presented in Fig. 2 was used as a basis for the representing the findings from qualitative interviews and literature inquiry for demonstrating the practical usefulness of the architectural governance-by-design framework. The modelled findings (see Fig. 3), comprise of secondary data from the literature (Akhtar et al. 2021; Romano and Schmid 2021), and primary data from the interview on governance of DLT (IOTA tangle) are presented in ArchiMate Modeling Language (https://www.archimatetool.com/), an open-source enterprise modeling tool (see Fig. 3).

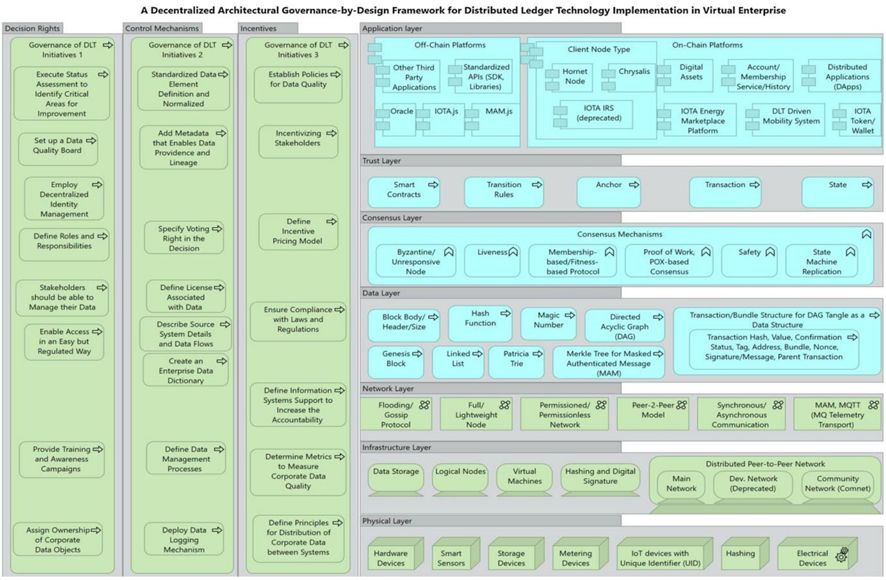

Fig. 3 Finding on the applicability of architectural governance-by-design framework

Findings from Fig. 3 presents the architectural layers and governance dimension of DLT with related initiatives to be employed within VE. Also, the finding captures the main DLT components within the identified 7 architectural layers which can be deployed to support the deployment of DLT such as IOTA tangle within VE. These findings modelled in ArchiMate provides initiatives as best practices that can be employed by practitioners and researchers for improving the decision rights, control mechanism, and allocation of incentives when implementing any DLT to improve governance of DLT in their enterprise. Furthermore, the 7 layers captures possible technological, infrastructural, business, data, and off-chain and on-chain application-based components to be deployed by a typical DLT operating in VE environment to support data driven services such as energy marketplace and smart mobility.

4.3 Challenges and recommendations of governing DLT

4.3.1 Challenges of governing DLT in VE

As one of the emerging technologies, DLT has gained widespread adoption in several sectors aimed at exploiting the features of this technology. But issues related to the regulatory, technical, and governance of DLT still remains as a key challenge that DLT platforms (particularly permissionless ones) are finding solution to address (Atzori 2017). As mentioned in the literature, the adoption of DLT in intra-organizations is still low due to the absence of a governance standards (Anthony Jnr 2022b). The governance of DLT is still an issue due to lack of liability and law compliance within decentralized open peer-to-peer networks. This is because most DLT platforms are governed by their own technical codes, irrespective of geographical borders which makes it tough to impose regulations such as GDPR stipulated by the government (Atzori 2017). As such this undermines enterprises' confidence thereby discourage them to adopt innovative systems such as DLT solutions. This demonstrates the importance of developing governance framework or standard that ensures effective interaction between legal code and technical code to lessen uncertainty and promote full compliance with government policies (Atzori 2017).

Understandably, the absence of reliable, stable governance structures and safeguards for enterprises (europa.eu 2016), along with common blockchain forks or even hard forks, may intensify uncertainty among businesses (Atzori 2017). Moreover, in permissionless DLT open governance and decentralization do not necessarily mean democratic and fair governance, nor do they essentially provide equal voting opportunities for all stakeholders. Although in theory no one controls or owns the distributed networks, adopting a true egalitarian and democratic governance is far from being achieved. Another point is grounded on the fact that the governance rules are already pre-defined by developers in the consensus mechanism employed. Achieving democracy will be much difficult due to legitimacy of procedures, and equal decision-making opportunities for all actor who access the distributed ledger. These pose risks and drawbacks for governance of permissionless DLT. Hence how can VE achieve a balance between individual ethos, innovation, and the wider public interest in the use of DLT such as blockchain (Atzori 2017).

4.3.2 Recommendations of governing DLT in VE

Resolution of common issues, creation of value, and cost saving are a few of the goals that push organizations to establish consortiums (Brioschi 2021), termed as *virtual enterprise* (Anthony Jnr and Abbas Petersen 2021). Although presently most enterprise DLT based platforms are provided and managed by private solution provider. The adoption of DLT in most VE depends on consensus mechanisms that offer the right incentives for nodes to ensure DLT integrity (Beck et al. 2018). The software protocol of DLT includes requirement on how transactions are executed, at what speed new transactions of data are added to the ledger, and what the size of these newly added data. Individuals implement these actions by specifying how updates are made to the DLT software protocol. These software updates must be managed, and this is where DLT governance comes in. Accordingly, to improve the governance of DLT the procedures employed should be simple and use fewer steps and tools. The less complex approach to govern DLT might increase the number of contributors and decrease the time and resources needed for the governance process. Besides a flexible governance model should be followed as an impulsive change in the governance approach might be risky since it is harder to revert the faulty decisions once established (Dursun and Üstündağ 2021).

The time required for determining a change and employing it to the distributed network should be reasonable, and proposals suggested by other actors to the developers should not be conflicted or incompatible with the current governance to avoid conflicts. Hence, there should be fairness and decisions should not violate the ultimate goals of the DLT eco-system and participating in the decision process should be open to as many stakeholders as possible. Nevertheless, the influences of actors linked to decision making must be relative to their roles and measures of their digital assets. Centralization which led to inequity in voting power within the distributed network should be prevented as it is an obstacle to fair governance of DLT. Voting based consensus in the distributed ledger must also handle to balance power without violating another person's right (Dursun and Üstündağ 2021). Likewise, most users with less technical knowledge may be reluctant or refrain to participate in the decision-making process or may just follow the experts or majority instead of suggesting and endorsing the best alternatives for the DLT platform. This occurrence might cause permissionless DLT to be easily dominated or controlled by a few group members. This may result to mining monopolies and potentially centralization (Dursun and Üstündağ 2021).

5 Discussion and implications

5.1 Discussion

Virtual enterprise comprises of organizations that collaborate to contribute tangible and intangible resources to provide digital service (Anthony Jnr and Abbas Petersen 2021), that influence their common future. These enterprises now adopt emerging technologies such as DLT but are faced with governance issues when decisions are made regarding the deployment of DLT (Anthony Jnr 2022a). Similarly, the rise of DLT platforms such as permissionless, permissioned, and hybrid has resulted in the need for governance approach to orchestrate the infrastructures, technologies, and actors involved in the deployment of DLT in making enterprise process smarter. Exiting governance models for DLT employs a lengthy process which depend on the involvement of multiple stakeholders who decide changes needed for the deployment of DLT in VE. These approaches usually result in decreasing the decentralized nature of DLT. Moreover, its often unclear how decisions are made regarding evolvement of these DLT platforms. Governance comprises the system by which an institution is controlled and operates, and the structures by which it, and its people, are held to accountable (Brioschi 2021). In the context of this study the governance of DLT refers to all contributors and decision makers that exist outside of the technological platform, but nevertheless influence its operations and development.

Findings from this study suggest for the inclusion of decision rights, control mechanisms, and incentives as governance initiatives analogous with results from Meier et al. (2021) where the authors stated that governance initiatives are essential for the successful deployment of DLT and for their potential to interact, integrate, adapt, and change. This is because the governance of DLT is the method by which design changes are executed and regulated within the DLT platform (Meier et al. 2021). As such the governance of DLT aids the ability of DLT platforms to adapt and evolve to change as this is essential for the long-term success and viability of the distributed ledger network (Smit et al. 2020). Besides, findings from the modelling in ArchiMate highlights the main DLT components and initiatives required for re-enforcing decentralized governance of DLT in VE. This finding is similar with results from Schmeiss et al. (2019) where the researchers designed a governance approach for platform ecosystems to support stakeholders alike to design and manage platform ecosystems that create value. From a practical standpoint, findings from this article offer an overview and structure of governance mechanisms for DLT developments that could inspire businesses to consider decision rights, control mechanisms, and incentives more explicitly in their design of DLT-based solutions. This is analogous with findings presented by Beck et al. (2018) who proposed a framework in line with the IT governance dimensions which comprises of accountability, decision rights, and incentives.

Furthermore, this article identifies potential challenges, recommendation, and initiatives to be employed regarding governance of DLT policies grounded on data from the literature and qualitative interview. Using the seven architectural layers and three governance dimensions of DLT, an architectural governance-by-design framework is developed to foster DLT communication legacy platforms. Our findings are consistent with Brioschi (2021), who highlighted that DLT governance involves endogenous coded rules that operate within the DLT codebase (on-chain) and exogenous rules at the social or institutional level (off-chain) governance enforced outside of the DLT platform such as national laws and regulations. Findings from this study suggest that the decentralized architectural governance-by-design framework offers an easy-to-understand approach as an ecosystem which allows the management of different actors, digital systems, and infrastructures via high-level user-friendly model. IOTA tangle is employed to show the applicability of the developed formwork based on two use cases (IOTA driven energy marketplace and IOTA based mobility solution). The developed framework is a response to the call for research on the topic on governance of DLT.

Furthermore, the findings presented in this research can help structure the design phase of DLT platforms, considering the governance of DLT as a perspective which is mostly overlooked in early stages of DLT design. This is similar to results from Romano and Schmid (2021) who proposed some conceptual framing approaches for off-chain and on-chain governance models, reference architecture, and categorization of consensus protocols. Findings from Dursun and Üstündağ (2021) mentioned that a commonly established governance of DLT is given by Pelt et al. (2021) as the process of achieving the control, direction, and coordination of stakeholders within the environment of a given DLT project to which they mutually contribute. Pelt et al. (2021) posited the governance of DLT as the means of achieving the control, direction, and coordination of stakeholders within the context of a given DLT system to which they all jointly contribute. The significance for DLT governance is that DLT like Bitcoin have no formal organization or legal and physical entity accountable that manages the distributed network and is responsible for its overall deployment (Zachariadis et al. 2019). Further findings from Dursun and Üstündağ (2021) added that governance of DLT focuses on keeping the distributed ledger platform running by considering the consensus, incentives, information flow, and structure of actors as related to decision-making process, state, protocol rules, roles, membership, ledger history, and incentives.

5.2 Practical implications

Over the years, DLT has been employed in achieving trust, security, and integrity for VE and is highly acknowledged as a disruptive technology. However, the deployment of DLT is faced with governance barriers which impedes the widespread use of DLT in VE. The governance of DLT is important as it will ensure the safe, proper use, and evolution of this emerging technology. Yet, practical evidence related to the governance of DLT are limited. In this article, an architectural governance-by-design framework is developed which comprises of different architectural layers (*physical, infrastructure, network, data, consensus, trust, and application*), and governance dimensions (*decision rights, control mechanisms, and incentives*). Based on academic literature and qualitative interviews the governance of DLT is contextualized and designed in ArchiMate modeling language. The findings show how the governance of DLT can be actualized in VE based on the developed framework. As the main contribution, this study recommends a few initiatives to improve the governance of DLT. For proof of concept, the developed framework is practically applied on IOTA driven energy marketplace and IOTA based mobility solution. Finally, this study concludes that DLT such as IOTA is a useful solution for implementing digitalized infrastructure in VE.

The application layer in Fig. 3 shows a representation of how IOTA tangle-based application, integrates, and communicates with between applications within the decentralized networks (on-chain) and external environments (off-chain).

While raw data produced in real-time (e.g., hardware devices, IoT sensors, smart sensors, etc.) originating from an external system within the enterprise could directly be brought into the distributed network. Practically, these generated data will go through some processing steps in an external data storage before it is transmitted to the on-chain in the form of metadata to IOTA tangle. Standardized APIs and oracle captured in the application layer (as seen in Fig. 3), connects to data source or external systems to provide data feeds. Typically, oracles have both off-chain and on-chain components, and it can either be a server or a human who periodically sends data from an external system or off-chain source to IOTA tangle as a set of transactions. However, one of the main issues of using DLT as a storage component is that DLT's physical and logical layers encompass of several types of data structures as compared to conventional databases. Consequently, the format of data between DLT and traditional databases are different. Thus, an extra effort is usually needed to address these differences (Paik et al. 2019).

5.3 Research implications

Currently, there has been little attention paid to design governance framework for DLT-based data sharing ecosystems in virtual enterprise domain. While prior studies have researched a range of governance concerns related to data on DLT. Existing governance approaches are more focused on general information strategy or data management of businesses. Also, due to the complexity associated with the deployment and operationalization of DLT platforms (Dursun and Üstündağ 2021). Scholars and practitioners have called for research on the design of governance methods in organizations. Accordingly, there is need for a novel governance framework for DLT-based application. The findings from this study provides a common understanding and discussion surrounding the governance of DLT and further develop an architectural governance-by-design framework. The framework may support practitioners such as data custodians and stewards in providing best practice on adhering to governmental stipulated standards such as GDPR. The developed framework can help practitioners and managers alike to deploy and manage DLT platform ecosystems.

From a theoretical viewpoint, the findings tried to provide an overview of the state-of-the-art on governance of DLT. Implications from this study suggest that an effective governance mechanism of DLT supports increased openness when different actors within the virtual enterprise collaborate to produce innovative product sand digital services. It supports a DLT platform-based ecosystems that fosters the creation of an open system, especially in the case of public DLT, where access to the distributed network is not limited guaranteeing a transparent and fair value creation for all actors. The outcome of this research presents an artifact that can be used to improve the governance of DLT and further provides a comprehensive documentation of the design process for developing the framework which can be valuable for other researchers interested in the development of an architectural artifacts.

6 Conclusion

The irregular nature of codebase and technological updates among core developers and diverse interest of stakeholders has resulted to governance issue which appears to impede the wider deployment of DLT in in enterprise contexts (Bokolo 2022). Governance of DLT refers to the processes and structures that are designed to guarantee the development and deployment of DLT platforms which are ethically responsibilities and compliant to legal regulations (Liu et al. 2019). Therefore, this study aims to explore the governance of DLT. The findings present DLT adoption in VE, overview and prior studies that explored governance of DLT, and different governance approaches for DLT. Most importantly an architectural governance-by-design framework was developed that defines the governance of DLT as a combination of architecture layers (physical, infrastructure, network, data, consensus, trust, and application), and governance dimensions (decision rights, control mechanisms, and incentives).

Data was collected grounded on academic literature and qualitative interview to evaluate the applicability of the architectural governance-by-design framework. A few limitations were recognized within this study. The first limitation is that the only IOTA tangle-based DAG was employed in this study as other DLT were not considered. Secondly primary data was used from only two use case scenarios. Overall, this study has opened interesting new areas for further study. Hence, further research needs to be conducted aiming at exploring the deployment of other DLTs within the framework such as Holochain, Blockchain, Hashgraph, etc. To get more insight of the governance of DLT, further work will involve the collection of data from more enterprises that adopt DLT in their organizational process using surveys, focus groups, and interviews.

Acknowledgements The author is grateful to Department of Computer Science, Norwegian University of Science and Technology (NTNU) and project partners in the +CityxChange smart city project (https://cityxchange.eu/) which is funded by the European Union's Horizon 2020 Research and Innovation Programme under the Smart Cities and Communities topic with Grant Agreement No. 824260.

Funding Open access funding provided by Institute for Energy Technology.

References

Akhtar MM, Rizvi DR, Ahad MA, Kanhere SS, Amjad M, Coviello G (2021) Efficient data communication using distributed ledger technology and iota-enabled internet of things for a future machine-to-machine economy. Sensors 21(13):4354

Allessie D, Janssen M, Ubacht J, Cunningham S, Van der Harst G (2019) The consequences of blockchain architectures for the governance of public services: a case study of the movement of excise goods under duty exemptions. Inf Polity 24(4):487–499

Anthony B Jr (2018) Using green IT governance as a catalyst to improve sustainable practices adoption: a contingency theory perspective. Int J Bus Contin Risk Manag 8(2):124–157

Anthony Jnr B (2021) Distributed ledger and decentralised technology adoption for smart digital transition in collaborative enterprise. Enterp Inf Syst. https://doi.org/10.1080/17517575.2021.1989494

Anthony Jnr B (2022a) Toward a collaborative governance model for distributed ledger technology adoption in organizations. Environ Syst Decis 42(2):276–294

Anthony Jnr B (2022b) Investigating the decentralized governance of distributed ledger infrastructure implementation in extended enterprises. J Knowl Econ. https://doi.org/10.1007/s13132-022-01079-7

Anthony B (2023) Deployment of distributed ledger and decentralized technology for transition to smart industries. Environ Syst Decis. https://doi.org/10.1007/s10669-023-09902-5

Anthony Jnr B, Abbas Petersen S (2021) Examining the digitalisation of virtual enterprises amidst the COVID-19 pandemic: a systematic and meta-analysis. Enterp Inf Syst 15(5):617–650

Atzori M (2015) Blockchain technology and decentralized governance: is the state still necessary? Available at SSRN 2709713.

Atzori, M (2017) Blockchain governance and the role of trust service providers: the TrustedChain® network. Available at SSRN 2972837

Barriball KL, While A (1993) Collecting data using a semi-structured interview: a discussion paper. J Adv Nurs 18(10):328–335

Beck R, Müller-Bloch C, King JL (2018) Governance in the blockchain economy: a framework and research agenda. J Assoc Inf Syst 19(10):1

Bodó B, Giannopoulou A (2019) The logics of technology decentralization—the case of distributed ledger technologies. In: Blockchain and web, 3

Bokolo AJ (2022) Exploring interoperability of distributed Ledger and Decentralized Technology adoption in virtual enterprises. Inf Syst e-Bus Manag. https://doi.org/10.1007/s10257-022-00561-8

Brioschi M (2021) Governance of blockchain and DLT projects: an analysis of Spunta Banca DLT

Browne J, Zhang J (1999) Extended and virtual enterprises—similarities and differences. Int J Agil Manag Syst 1(1):30–36

Chen S, Liu X, Yan J, Hu G, Shi Y (2020) Processes, benefits, and challenges for adoption of blockchain technologies in food supply chains: a thematic analysis. Inf Syst e-Bus Manag 19:1–27

Davis L, Dawe M (2001) Collaborative design with use case scenarios. In: Proceedings of the 1st ACM/IEEE-CS joint conference on digital libraries, pp 146–147

De Filippi P, McMullen G (2018) Governance of blockchain systems: Governance of and by Distributed Infrastructure. Doctoral dissertation, Blockchain Research Institute and COALA

De Filippi P, McMullen G (2019) Governance of blockchain systems: governance of and by the infrastructure. In: COALA & blockchain research institute big idea whitepaper

Dursun T, Üstündağ BB (2021) A novel framework for policy based on-chain governance of blockchain networks. Inf Process Manag 58(4):102556

Ehrsam F (2017) Blockchain governance: programming our future. Haettu osoitteesta: https://medium.com/@FEhrsam/blockchain-governance-programming-our-future-c3bfe30f2d74

europa.eu (2016) Document 52016IP0228-European Parliament resolution of 26 May 2016 on virtual currencies (2016/2007(INI)). Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016IP0228

Fan C, Khazaei H, Chen Y, Musilek P (2019) Towards a scalable DAG-based distributed ledger for smart communities. In: 2019 IEEE 5th world forum on Internet of Things (WF-IoT), pp 177–182

Gilson F, Galster M, Georis F (2020) Generating use case scenarios from user stories. In: Proceedings of the international conference on software and system processes, pp 31–40

Gloerich I, DeWaal M, Ferri G, Cila N, Karpinski T (2020) The city as a license implications of Blockchain and distributed ledgers for urban governance. Front Sustain Cities 2:56

Gourisetti SNG, Cali Ü, Choo KKR, Escobar E, Gorog C, Lee A, Lima C, Mylrea M, Pasetti M, Rahimi F, Reddi R, Sani AS (2021) Standardization of the distributed ledger technology cybersecurity stack for power and energy applications. Sustain Energy Grids Netw 28:100553
Gregory RW (2011) Design science research and the grounded theory method: characteristics, differences, and complementary uses. In: Theory-guided modeling and empiricism in information systems research. Physica-Verlag HD, pp 111–127
Hevner A, Chatterjee S (2010) Design science research in information systems. In: Design research in information systems. Springer, Boston, pp 9–22
Hevner AR, March ST, Park J, Ram S (2004) Design science in information systems research. MIS Q 28:75–105
Hofmann F, Wurster S, Ron E, Böhmecke-Schwafert M (2017) The immutability concept of blockchains and benefits of early standardization. In: 2017 ITU kaleidoscope: challenges for a data-driven society (ITU K). IEEE, pp 1–8
IBM Blockchain (2022) IBM blockchain website. https://www.ibm.com/blockchain/
Jagdev HS, Thoben KD (2001) Anatomy of enterprise collaborations. Prod Plan Control 12(5):437–451
Jnr BA (2020) Examining the role of green IT/IS innovation in collaborative enterprise-implications in an emerging economy. Technol Soc 62:101301
Jnr BA, Majid MA, Romli A (2020) A generic study on Green IT/IS practice development in collaborative enterprise: insights from a developing country. J Eng Technol Manag 55:101555
Jr BA, Majid MA, Romli A (2017) A Green information technology governance framework for eco-environmental risk mitigation. Prog Ind Ecol Int J 11(1):30–48
Kinsella S, Shams A, Helfert M, Ahlers D, Alloush I, Pourzolfaghar Z Bokolo AJ, Petersen SA (2021) D1.3: report and catalogue on the ICT data integration and interoperability. https://cityxchange.eu/wp-content/uploads/2021/05/D1.3-Report-and-catalogue-on-the-ICT-data-integration-and-interoperability-final-submitted.pdf
Lai JY, Wang J, Chiu YH (2021) Evaluating blockchain technology for reducing supply chain risks. Inf Syst e-Bus Manag 19:1–23
Lima C (2018) Blockchain GDPR privacy by design. In: IEEE blockchain group
Liu X, Sun SX, Huang G (2019) Decentralized services computing paradigm for blockchain-based data governance: programmability, interoperability, and intelligence. IEEE Trans Serv Comput 13(2):343–355
Lumineau F, Wang W, Schilke O (2021) Blockchain governance—a new way of organizing collaborations? Organ Sci 32(2):500–521
Mandaroux R, Dong C, Li G (2021) A European emissions trading system powered by distributed ledger technology: an evaluation framework. Sustainability 13(4):2106
March ST, Smith GF (1995) Design and natural science research on information technology. Decis Support Syst 15(4):251–266
Markus ML, Majchrzak A, Gasser L (2002) A design theory for systems that support emergent knowledge processes. MIS Q 26:179–212
Meier P, Beinke JH, Fitte C, Teuteberg F (2021) Generating design knowledge for blockchain-based access control to personal health records. IseB 19(1):13–41
Miscione G, Ziolkowski R, Schwabe G (2020) Decision problems in blockchain systems: old wine in new bottles of walking in someone else shoes? J Manag Inf Syst 37(2):316–348
Myers MD, Newman M (2007) The qualitative interview in IS research: examining the craft. Inf Organ 17(1):2–26
Paik HY, Xu X, Bandara HD, Lee SU, Lo SK (2019) Analysis of data management in blockchain-based systems: from architecture to governance. IEEE Access 7:186091–186107
Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S (2007) A design science research methodology for information systems research. J Manag Inf Syst 24(3):45–77
Pelt RV, Jansen S, Baars D, Overbeek S (2021) Defining blockchain governance: a framework for analysis and comparison. Inf Syst Manag 38(1):21–41
Petersen SA, Bokolo AJ, Ahlers D, Shams A, Helfert M, Alloush I, Pourzolfaghar Z (2021) D1.2: report on the architecture for the ICT ecosystem. https://cityxchange.eu/wp-content/uploads/2021/02/D1.2-Report-on-the-architecture-for-the-ICT-ecosystem-submitted.pdf. Accessed 20 Feb 2022
Provenance (2022) Provenance white paper. https://www.provenance.org/whitepaper
Qing S, Liu X, Zheng H (2020) An assessment framework for distributed ledger technology in financial application. In: Proceedings of the 2nd ACM international symposium on blockchain and secure critical infrastructure, pp 161–170

Rajnak V, Puschmann T (2020) The impact of blockchain on business models in banking. Inf Syst e-Bus Manag 19:1–53
Reijers W, O'Brolcháin F, Haynes P (2016) Governance in blockchain technologies & social contract theories. Ledger 1:134–151
Reshef Kera D (2020) Sandboxes and testnets as "trading zones" for blockchain governance. In: International congress on blockchain and applications. Springer, Cham, pp 3–12
Reyes CL (2021) (Un) Corporate crypto-governance. Russ J Econ L 88:135
Reyes CL, Geslevich Packin N, Edwards BP (2017) Distributed governance. Wm & Mary l Rev Online 59:1
Rikken O, Janssen M, Kwee Z (2019) Governance challenges of blockchain and decentralized autonomous organizations. Inf Rmation Polity 24(4):397–417
Ripple (2022) Ripple website. https://ripple.com/
Romano D, Schmid G (2021) Beyond bitcoin: recent trends and perspectives in distributed ledger technology. Cryptography 5(4):36
Savirimuthu J (2019) Blockchain regulation and governance in Europe, by Michèle Finck the Blockchain and the New Architecture of Trust, by Kevin Werbach
Schmeiss J, Hoelzle K, Tech RP (2019) Designing governance mechanisms in platform ecosystems: addressing the paradox of openness through blockchain technology. Calif Manag Rev 62(1):121–143
Schulz KA, Gstrein OJ, Zwitter AJ (2020) Exploring the governance and implementation of sustainable development initiatives through blockchain technology. Futures 122:102611
Seyedsayamdost E, Vanderwal P (2020) From good governance to governance for good: blockchain for social impact. J Int Dev 32(6):943–960
Skoglund TR, Eljueidi M, Nati N (2020) D2.5 seamless eMobility system including user interface. +CityxChange Project Deliverable. https://cityxchange.eu/wp-content/uploads/2020/06/D2.5-Seamless-eMobility-system-including-user-interface.pdf. Accessed 20 Feb 2022
Smit K, el Mansouri J, Saïd S, van Meerten J, Leewis S (2020) Decision rights and governance within the Blockchain domain: a literature analysis. In: Twenty-fourth Pacific Asia conference on information systems, Dubai, UAE
Vogelsang K, Steinhüser M, Hoppe U (2013) A qualitative approach to examine technology acceptance. In: Thirty fourth international conference on information systems, Milan, pp 1–16
Weill P (2004) Don't just lead, govern: how top-performing firms govern IT. MIS Q Exec 3(1):1–17
Weill P, Ross J (2005) A matrixed approach to designing IT governance. MIT Sloan Manag Rev 46(2):26
Werner J, Zarnekow R (2020) Governance of Blockchain-based platforms. In: Wirtschaftsinformatik (Zentrale Tracks), pp 128–141
Wieringa R (2014) Empirical research methods for technology validation: scaling up to practice. J Syst Softw 95:19–31
Zachariadis M, Hileman G, Scott SV (2019) Governance and control in distributed ledgers: understanding the challenges facing blockchain technology in financial services. Inf Organ 29(2):105–117
Ziolkowski R, Schwabe G (2022) Mine, yours,… ours? Managing stakeholder conflicts in an enterprise blockchain consortium. HICSS
Ziolkowski R, Miscione G, Schwabe G (2020) Decision problems in blockchain governance: old wine in new bottles or walking in someone else's shoes? J Manag Inf Syst 37(2):316–348
Zook MA, Blankenship J (2018) New spaces of disruption? The failures of Bitcoin and the rhetorical power of algorithmic governance. Geoforum 96:248–255