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Decentralization and IT Governance: Exploring Issues in Blockchain and Beyond. A systematic review

Descentralización Y Gobierno De TI: Explorando Problemas En Blockchain Y Más Allá. Una Revisión Sistemática

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ABSTRACT

The emergence of blockchain technologies has sparked debates on emerging governance structures involving collaboration between multiple stakeholders. Issues have surfaced due to vulnerabilities in blockchain systems, smart contracts, and Decentralized Autonomous Organizations (DAOs). The decision-making processes around blockchain development often remain ambiguous. This article delves into the governance challenges facing blockchain undertakings in various decentralized setups through academic literature and case studies. The problems are grouped based on a system with distinct layers (infrastructure, application, corporate, and state level) and phases (creation, operation, development/crisis). Our findings highlight challenges at different layers and stages. We also identified the interconnectedness of governance in blockchain apps and infrastructure. Our study emphasizes the need for deeper exploration into DAO governance on open-access blockchains related to offered services and products. For private blockchains and other applications, traditional governance models may often be suitable. We suggest borrowing insights from the open-source domain when devising new governance frameworks.

Keywords: Blockchain, DAO, IT governance, IT oversight, open-access, smart contracts.

RESUMEN

La aparición de las tecnologías de blockchain ha generado debates sobre estructuras de gobierno emergentes que involucran la colaboración entre múltiples partes interesadas. Han surgido problemas debido a vulnerabilidades en sistemas de blockchain, contratos inteligentes y Organizaciones Autónomas Descentralizadas (DAO, por sus siglas en inglés). Los procesos de toma de decisiones en torno al desarrollo de blockchain a menudo permanecen ambiguos. Este artículo profundiza en los desafíos de gobierno que enfrentan los proyectos de blockchain en diversas configuraciones descentralizadas a través de la literatura académica y estudios de casos. Los problemas se agrupan en función de un sistema con capas distintas (infraestructura, aplicación, corporativa y estatal) y fases (creación, operación, desarrollo/crisis). Nuestros hallazgos resaltan desafíos en diferentes capas y etapas. También identificamos la interconexión del gobierno en aplicaciones de blockchain e infraestructura. Nuestro estudio enfatiza la necesidad de una exploración más profunda del gobierno de las DAO en blockchains de acceso abierto relacionados con los servicios y productos ofrecidos. Para blockchains privados y otras aplicaciones, a menudo los modelos de gobierno tradicionales pueden ser adecuados. Sugerimos tomar ideas del dominio de código abierto al diseñar nuevos marcos de gobierno.

Palabras clave: Blockchain, DAO, gobierno de TI, supervisión de TI, acceso abierto, contratos inteligentes.

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1. Introduction

About ten years back, Satoshi Nakamoto unveiled a groundbreaking concept for a decentralized, peer-to-peer platform in the Bitcoin white paper (Nakamoto, 2008). Initially meant for peer-to-peer financial exchanges, this system introduced a method for transactions that ensured data protection and integrity internally. These systems are predicted to bring transformative organizational shifts since the role of a trustworthy intermediary would be built into the system, eliminating the need for an external entity or individual. This integration is possible due to decentralized databases, cryptographic measures, and consensus approaches, resulting in features like near-permanence and continuous data storage. However, these features make it nearly impossible for an individual to alter or remove data or transactions.

Nevertheless, trust hinges on those participating in the network. Since most of these networks have open entry, many members remain unidentified. While some argue that this openness translates to a trust-minimized environment (Bahga & Madisetti, 2016; Swan, 2015), trust in the system's correct functioning remains tech-based. With the elimination of intermediary bodies, pivotal governance questions arise: What are individual responsibilities? How are changes in blockchain applications determined? Who is liable for which shortcomings? And who implements preventive actions during mishaps?

Several of these misfortunes underscored the imperative for crisis-focused governance. High-profile cases involving governance challenges include the DAO fiasco, the Parity multisig wallet compromise, and the Parity II asset freeze event. These incidents caused losses in the hundreds of millions. Solving these issues necessitated infrastructure governance due to the interwoven nature of application and infrastructure. Yet, the infrastructure's decentralized nature, lacking a single owner, posed governance complications. The absence of a central authority to enforce or halt actions sparked debates surrounding various regulatory and governance issues, prompting the U.S. Security and Exchange Commission's first formal inquiry.

The interconnected character of blockchain and DAOs makes governance complex. Governance lays out a structure for decision-making authority, incentives, and responsibilities that foster the desired utilization of resources. Governance mechanisms shape communication protocols, roles, and decision-making procedures. While blockchain is often linked to embedded, automated governance through consensus, this merely covers transactional operations and neglects broader governance issues such as system updates or addressing failures. This indicates the potential need for novel governance strategies. However, current knowledge on pertinent governance challenges remains limited. Recognizing these challenges is crucial for the technology's broader adoption.

This article's purpose is to spotlight governance hurdles in blockchain applications. Given the variety of blockchain configurations, governance is inherently tricky. Our study's foundational assumption is that each variant could face distinct challenges. Key differences arise between private blockchains and open public blockchains. Our research offers three primary insights: first, we spotlight governance issues in different blockchain setups; next, we identify diverse decentralized app categories and their governance hurdles; lastly, we categorize challenges based on different layers and phases of blockchain projects. The subsequent sections detail our research methodology, followed by literature insights. From this review, we categorize applications, leading to a blockchain governance structure. We then delve into governance challenges through this structure, culminating in our conclusions and recommendations for future research endeavors.

2. Research method

Our study amalgamated insights from academic literature and expert perspectives to pinpoint blockchain governance challenges. Adopting Kitchenham's systematic literature review method (Kitchenham et al., 2010), we meticulously analyzed a collection of 51 various sources, including academic papers, articles, blogs, and transcripts, encompassing more than 850 pages. Initial literature scouting commenced between December 2018 and February 2019 on scholar.google.com, using search terms "blockchain" combined with "governance."

Supplementing the literary review, we sought insights from four blockchain veterans to deeply understand prevalent governance issues and strategies to address them. Our interviewee selection emphasized individuals with hands-on experience in steering blockchain initiatives. Given the nascent emphasis on blockchain's hands-on governance, the pool of such experts remains small. Our chosen experts comprised an industry professional from Swarm City focusing on decentralized application development, another expert specializing in decentralized consensus mechanisms, and two researchers—one from academia and the other representing a non-profit organization. Both researchers delve into various blockchain facets, with a special interest in blockchain and smart contract governance. Our study also plotted the growth trajectory of DAOs over time.

While numerous sources broach the twin themes of blockchain and governance, frequently cited works typically lean towards envisioning blockchain's potential in reshaping state governance frameworks or evaluating decentralized platforms as radical political instruments. Atzori's study (2017) questions blockchain's capability to oversee extensive social interactions and potentially bypass traditional central entities. On the other hand, Jia & Zhang (2017) stress that state laws should regulate blockchain as a technology. Hsieh and team (2018) mainly draw governance insights from cryptocurrencies rather than blockchain-based applications, while Casinoa et al. (2019) emphasize apps bolstering governance, like identity management. Contrarily, Voshmgir (2017) speculates about blockchain's disruptive potential for governance itself, and Yermack (2017) probes possible corporate governance ramifications due to blockchain. While these sources furnish partial insights, a focused study into the governance of blockchain applications remains a gap.

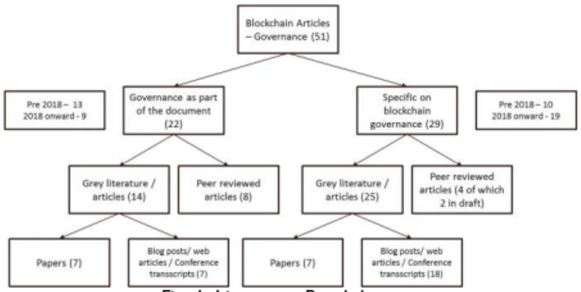

Fig. 1. Literature Breakdown

Of the 51 sources we found pertinent, a mere four were peer-reviewed articles exclusively addressing blockchain governance. Published timelines for these were: two in 2016, one in 2018, and a preliminary draft in 2019. A detailed look into the interdependence of infrastructure and applications was conspicuously absent in these pieces. Despite the surge in articles and blogs on blockchain governance, peer-reviewed literature explicitly covering blockchain governance remains sparse. Some of the freshest perspectives and dialogues on this theme originate from blockchain mainstays penning blogposts on platforms like Medium, notably from contributors such as Vlad Zamfir (2018a, 2018b) and Hareeb Qureshi (2018).

3. Literature review

3.1. Forms of blockchain: There is no one blockchain

When questions arise with regards to responsibilities, accountabilities and governance in permissioned environments, it is relatively easy to pinpoint the companies and institutions that run the infrastructure and are in control of the protocol, including elements like access right management as this is with the validating/master nodes (Peters & Panayi, 2015). As these are known it is relatively easy to adopt exist- ing governance models. When governance actions need to be executed, changes can relatively easy be implemented when needed due to limited amount and verified nodes that need to update. Their devel- opers' community is often equally transparent. Traditional approaches of governance of IT can directly be applied as a result and stakeholders can be held responsible (Post & Kas, 2019). Ripple is a clear example of a permissioned blockchain and while it is decentralized across approved nodes, like any other centralized company, it has top managers who make decisions on resource allocation and control the direction for code development (. . .) reflects a more centralized form of governance (Hsieh et al., 2018). In the permissionless environment actors, nodes, miners, users and developers are less known and reaching consensus over change becomes much harder. In itself not necessarily a negative feature. It is stated that Bitcoin's sustainability can largely be attributed to its recognition of the need for a slow evolution (Curran, 2018). A clear example of how difficult this process can be and can lead to deep division amongst actors, is the Segregated Witness (SegWit) scaling discussion in the Bitcoin network. It took several years to reach consensus and eventually, by lack of full consensus, resulted in a split (hard fork) of the network (van Wirdum, 2017). The reason this process is so difficult is due to the fact that the issue is often political and not so much technical. Bitcoin's block size debate is perhaps the most prominent example of a blockchain community facing complex governance problems that goes beyond the technical (Sclavounis, 2017). The base of this political discussion over a seemingly technical update was that the actors (miners, exchanges, nodes, users and developers), had conflicts of interest of the desired outcomes.

Although both permissioned protocols and permissionless protocols are blockchain, in the permis- sioned protocols, there is still a clear group of nodes and or owners where in the permissionless envi- ronment this group becomes fuzzy, which makes traditional governance methods in permissioned envi- ronments still valid. This calls for research into governance models on public permissionless blockchain protocols.

	Permissionless	Permissioned
Compared to traditional situations	Unknown group of users No "centralized" and fluid group of nodes running the network Development open to "anyone" Unknown of tradition (IT and Corporate) governance models are possible	Known group of users, "Centralized" group of nodes running the network. Traditional (IT and corporate) governance models possible

Fig. 2. Contrasting Permissioned and Permissionless Approaches with Conventional IT Scenarios.

3.2. Types of applications

Applications built on blockchain are referred to as decentralized Applications (dApps) (Raval, 2016). Many of these dApps are not directly integrated into the fundamental blockchain software itself; instead, they utilize core components of a specific blockchain, such as cryptocurrencies. These solutions are constructed on existing blockchains, often facilitated by external applications like wallets, as well as through the creation and deployment of smart contracts. Despite being developed on top of a blockchain, smart contracts are closely intertwined with the infrastructure, as the blockchain's infrastructure also functions as the data layer. Once a smart contract application code is deployed, it cannot be taken offline since it becomes part of the blockchain's data layer, stored within its blocks. It's worth noting that the term "smart contracts" can be misleading, as they often do not represent conventional contracts and are essentially deterministic computer code or programs executed on a blockchain (Rikken et al., 2018).

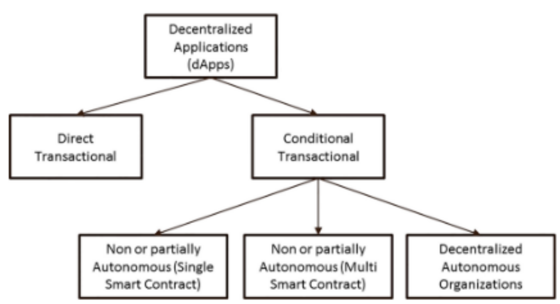

Fig. 3. App types

The classification of dApps operating on or utilizing blockchain involves four distinct types, as illustrated in Figure 3: types of dApps. These categories are as follows: direct transactional applications, conditional transactional applications encompassing single Smart Contract applications, Multi Smart Contract applications, and Decentralized Autonomous Organizations. Further details about these applications and illustrative examples are provided in Table 3: Application types – descriptions – examples. The differentiation between types of blockchains and types of applications holds significance in the analysis of governance within blockchain projects.

Table 3. Comparison per type

Application Type	Description	Examples
Direct transactional application	A direct transactional application is a type of application that allows users to make transactions directly with other users.	Wallets, Brokers, Exchanges
Conditional transaction application (single contract)	A conditional transaction application (single contract) is a type of application that allows users to make transactions based on the fulfillment of a single condition.	Escrow accounts, prediction markets
Conditional transaction application (multiple contracts)	A conditional transaction application (multiple contracts) is a type of application that allows users to make transactions based on the fulfillment of multiple conditions.	Smart contracts, decentralized exchanges
Decentralized autonomous organization	A decentralized autonomous organization (DAO) is an entity structure in which tokenholders participate in the management and decision-making of an entity. There is no central authority of a DAO; instead, power is distributed across tokenholders who collectively cast votes12.	The DAO, MakerDAO, Aragon

4. Towards a blockchain governance framework

The concept of governance in the context of blockchain is intricate, involving multiple stakeholders, and lacks a standardized framework for comprehensive comprehension. Presently, there exists no universally accepted model for understanding blockchain governance. In a broader context, governance encompasses decision-making authorities, incentives, and responsibilities that promote favorable behavior in the utilization of limited resources (Weill, 2004). Despite common assumptions, blockchain governance is frequently not entirely driven by technological enforcement or entirely self-governed. As one interviewee noted, "Mostly off-chain governance is observed. On-chain governance, which involves reaching agreements through online voting and automatically pushing updates after achieving a quorum, is in its early stages and under experimentation."

Blockchain application governance extends beyond the governance of infrastructure alone. We dissect governance into several layers, including the infrastructure layer, application layer, individual or company level, and the institutional layer. Others, like De Filippi and McMullen, have identified different layers, such as the internet layer, blockchain layer, and application layer (De Filippi & McMullen, 2018). Williamson's (1998) institutional economics framework also categorized layers with varying timelines and frequency of occurrence per layer. In this framework, lower layers tend to have shorter timelines than those above.

Furthermore, governance is dynamic, evolving over time in response to changing circumstances. New governance mechanisms might become necessary, while older ones might lose relevance. Hence, we categorize governance into different stages to highlight the evolving nature of governance. These stages and layers entail varying levels of engagement by different actors. A consensus among interviewees validates the significance of these stages and layers, as expressed through statements like "Multiple levels are indeed present," "A grid depicting levels and stages makes sense," and "Recognition of different layers and stages is crucial." These layers and stages culminate in the model depicted in Figure 4, which will be explored further in subsequent sections.

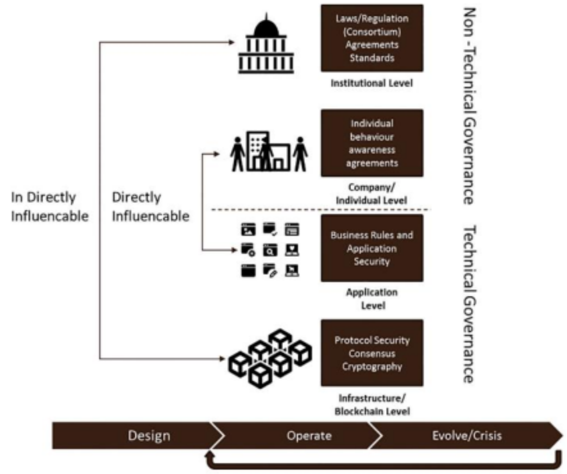

Fig. 4. Structure for Governance in Blockchain Ecosystem.

4.1. *Stages*

Blockchain governance is a dynamic entity, transitioning through multiple phases that require distinct strategies, decision-making procedures, and often diverse models. There are three distinct stages: design (or creation), operation, and evolution (or crisis) (De Filippi, 2016). These aren't sequential but instead are continuous, with the evolution/crisis stage cycling back to either design or operation. Some equate the evolution/crisis phase with transition (as per ITIL), maintenance (from A2 Data Governance), or control (in COBIT's terms).

Table 4. Stage Explanation

Stage name	Purpose of the stage	Time	Stakeholders roles/decisions
Design	Define the problem and identify potential solutions.	Before implementation.	Identify stakeholders, define their roles, and determine their level of involvement.
Operation	Implement the solution.	During implementation.	Assign tasks to stakeholders, monitor progress, and ensure that the solution is implemented as planned.
Evolvement/Crisis	Monitor the solution's performance and make necessary adjustments.	After implementation.	Evaluate the solution's effectiveness, identify areas for improvement, and make necessary changes.

Respond to unexpected events or problems.	As needed.	Identify the cause of the crisis, develop a plan to address it, and communicate with stakeholders as needed.

While most equate blockchain's automated self-governance with its consensus mechanism, this only encapsulates the operational phase. It's the evolutionary or crisis phase that's most captivating because it demands swift decisions and changes. Even though robust initial design can prevent certain issues, anticipating all potential problems is impossible. The long-term significance isn't just the initial design but the mechanisms for change (Ehrsam, 2017). Mario Laul, in the Aracon1 panel discussion, emphasized the importance of having clear protocols to modify existing ones (Choi et al., 2019).

4.2. Governance layers of blockchain project

Blockchain governance varies across different types of infrastructures. Additionally, each project stage has its governance distinctions. By categorizing governance into layers, one can simplify and better describe its intricacies. We categorize governance into four layers: infrastructure, application, corporate, and institutional.

4.2.1. Infrastructure layer

This layer is rooted in the blockchain protocol. It's distinctive because it holds both the governing rules and the immutable data layer in a decentralized fashion. The meaning of "decentralized" is, however, often a subject of debate (Walch, 2019). Two types of governance are present here: by the infrastructure (during the operation phase) and of the infrastructure. The consensus mechanism takes care of the former, enabling automated execution of protocols by nodes. Post-activation, the process runs autonomously, immune to external interference, like unplugging to halt it. Moreover, data is cemented in the blockchain, and altering it post-submission is challenging, requiring consensus from nodes. A plethora of consensus mechanisms exist, with more than 15 primary types identified, some having multiple subtypes (Cachin & Vukolic, 2017).

Concerning infrastructure evolution (or governance of the infrastructure), two primary categories emerge: on-chain and off-chain governance. Even within these broad categories, each blockchain protocol typically has its unique evolutionary mechanism. In public blockchains, decisions or protocol evolutions require a consensus from the community. Influence over this layer varies, often dependent on node counts combined with factors like CPU contributions or staked reserves, contingent on the consensus procedure.

4.2.2. Application layer

Applications can either be traditional (like centralized websites and apps) or exhibit blockchain-specific features, such as native cryptocurrencies or decentralized applications (dApps) built predominantly on a blockchain using smart contracts. The most evolved form of these is known as DAOs. A DAO is essentially a virtual organization with members or stakeholders who can manage the entity's funds and alter its code (Buterin et al., 2014). The governance structures vary among the four types of blockchain applications:

1. **Direct Transactional**: The governance can be traditional, existing off-chain in standard IT settings, or it can rely on the governance of the underlying blockchain infrastructure.
2. **Single Smart Contract Conditional Transaction**: During the operation phase, the smart contract's rules are executed by the infrastructure protocol and external cues. In terms of evolution, smart contract code in permissionless blockchains is immutable once launched. Alterations are primarily through infrastructure governance. If one needs to change non-parameter elements, the contract must be deactivated (using self-destruction commands if included in the design) and a new one initiated. Smart contracts designed with adjustable parameters in the code offer a workaround. It's crucial to regulate access to these functions, like using "modifiers" in Ethereum for function-level access. Future solutions might include "proxy functions" that link to subsequently deployable smart contracts to enhance functionality.
3. **Multi Smart Contract Conditional Transaction**: The governance of these mirrors that of single smart contract applications, but one can replace individual components (or smart contracts) without overhauling the entire app. Conventional companies or suppliers likely implement these apps, and their governance often integrates with the company layer structures. However, DAOs are distinct in this context.
4. **DAOs**: In terms of technicality and governance, DAOs resemble conditional transaction apps, consisting of one or multiple smart contracts that, once initiated, operate as dictated by their coded business rules. Human intervention is minimal, and there's no traditional company structure underpinning it.

Estimating the number of direct transactional applications is challenging. As of March 2019, dApps numbered around 2,650 (Stateofthedapps, 2019). Historically, DAO numbers were limited because they required manual coding. However, with Aragon's launch on October 30, 2018, creating a customized DAO without manual coding became feasible, causing a significant increase in DAO creations as depicted in Fig. 5.

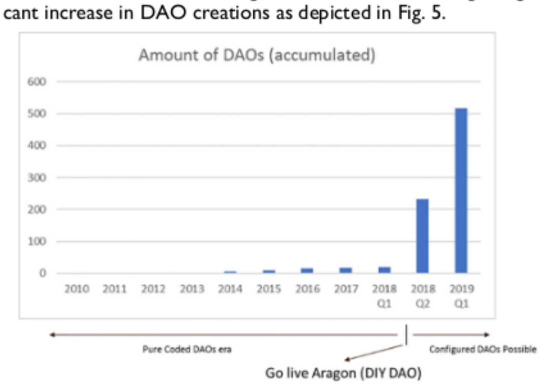

Fig. 5. Cumulative Quantity of Decentralized Autonomous Organizations (DAOs). There might be a minor overlap in the count for 2018 and 2019. Colony utilizes Aragon, and it's uncertain whether these DAOs are included in Aragon's DAO directory.

The governance of applications is intrinsically linked to infrastructure-level governance. In all application types, the governance options for data, smart contract code, and specific blockchain offerings or attributes depend on infrastructure governance actions.

4.2.3. Company layer

At the foundation of many blockchain applications are the individuals who utilize these applications and either official organizations or standalone projects that design and manage the apps. One crucial aspect of blockchain responsibility is the management of private keys. With the absence of a trusted third party in the network, this responsibility shifts back to individuals. If they lose this key, they can't engage in actions linked to that key. Although individuals bear this responsibility, the duty falls on companies or projects to educate users about this.

While governance for blockchain projects typically doesn't differ from that of other IT initiatives, there are unique scenarios where defining governance becomes intricate. Some of these situations include:

Open source projects that lack a formal organizational structure, like a definable group collaborating on platforms like GitHub.
Open-source endeavors on platforms such as GitHub that neither have an underlying formal organization nor link to a distinct individual or group. Many public permissioned blockchains are theoretically evolved this way since anyone can propose updates anonymously.
For DAOs, governance gets intricate since there's no legally recognized organization and no predefined ownership set. If users are viewed as owners, as in some DAOs, ownership is highly fluid and often hard to identify due to pseudonymity.

4.2.4. Institutional level

Blockchain transcends geographical and institutional boundaries, presenting unique challenges. With its decentralized essence and its development by potentially anonymous global contributors, pinpointing jurisdiction becomes tougher (West, 2018). This difficulty is pronounced in permissionless blockchains. Since the network operates on servers worldwide, it's often tricky to determine jurisdiction. Furthermore, each country has its stance on blockchain services and products, and even these views can vary within nations (Directorate, 2019).

A universal jurisdiction for blockchain projects is absent, and aside from a few standards like ERC20 set by the industry, global standards are sparse. Moreover, enforcing regulations becomes an uphill battle. Established institutional powers aren't naturally incorporated into the blockchain governance framework (Meijer & Ubacht, 2018). For instance, Draghi mentioned that the ECB couldn't regulate cryptocurrencies (Union, 2017). The enforcement challenge mirrors issues faced with websites like "thepiratebay", where real bans proved elusive. Only disruptive business models like Netflix and Spotify shifted user behavior. Regulatory stances differ among nations, with some needing significant reforms and others less. Currently, this has led to four distinct regulatory approaches, showcased by the regulation of Initial Coin Offerings (ICOs), a relatively straightforward product. The regulatory landscape becomes even murkier for intricate structures, especially in the context of DAOs.

5. Governance challenges

Blockchain-based projects and their implementations manifest various governance challenges, contingent upon the stages of implementation and the specific layers they occupy.

5.1. Governance challenges per stage

Design Stage: The primary challenge during the design stage is the decision between creating a custom infrastructure or opting for an existing one (van Deventer et al., 2017). This choice will reverberate throughout all subsequent layers and stages. Additionally, the design stage faces a lack of rigorous peer review. Cardano is an illustrative example: it emerged as a response to this issue, aiming to revolutionize cryptocurrency design and development through rigorous academic and peer-reviewed research (Foundation, 2019).
Operation Stage: During this stage, a critical challenge is balancing between automated and manual decisions across the infrastructure, application, and company levels. For example, the reluctance or apathy of participants when it comes to voting is a documented issue (Buterin, 2017; Vessenes, 2016). As Mario Laul pointed out: "People don't always want to be involved" (Choi et al., 2019). This sentiment was evident in the DAO incident where voting quorums were frequently unmet (DAOStats, 2016; Vessenes, 2016).
Evolve Stage: This stage is shrouded in uncertainties and unknowns. Given the nascent nature of blockchain governance, there's a dire need for both experimentation and research (Ehrsam, 2017; Qureshi, 2018). Governance during this stage might echo challenges from the operation and design phases, especially when quick decision-making is imperative in crisis situations.

5.2. Governance challenges per layer

5.2.1. Infrastructure layer

Numerous governance challenges are present in the realm of infrastructure layers, particularly within permissionless public blockchains. The need to establish effective governance for these permissionless blockchains, which aim to avoid dominance by single entities, is a critical area requiring substantial research and development (Hacker, 2019). In contrast, permissioned protocols possess limited decentralization and involve known participants, allowing for the application of conventional governance approaches to Permissioned Public and Permissioned Private blockchains (Kadiyala, 2018), although challenges persist (Oskar van Deventer et al., 2018). A relevant perspective for understanding forms of blockchain-based corporate governance involves assessing their degrees of decentralization (Hsieh et al., 2018).
Permissionless blockchains encompass a diverse array of protocols, each presenting distinct challenges, particularly those related to operational issues and infrastructure governance, which are intricately tied to the consensus mechanism employed. Unique governance challenges arise with each consensus mechanism, such as the presence of "whales" (holders of large token amounts) in proof of stake, or concentrated mining power within specific geographical regions in proof of work. In-depth analysis is necessary to comprehensively outline the advantages and drawbacks of these various consensus mechanisms.
A prevailing issue concerning consensus mechanisms pertains to the alteration of user or node bases. The primary challenge is the susceptibility of immutability to 51% attacks, wherein a group of miners controls the majority of CPU power, enabling them to perpetually construct the longest chain and manipulate transactions. While previously deemed theoretical, real-world incidents, as observed in Ethereum Classic (Moos, 2019), have demonstrated the actualization of this threat, leading to changes in transaction history and instances of double spending.
Another challenge involves the concept of mob democracy or justice (Chinyem, 2018; Qureshi, 2018), wherein decisions are influenced by majority voting rather than rationale. Balancing voting power within voting systems proves to be a difficult task. The challenge of "one man, one vote" emerged in five articles

(Berreman, 2018; Choi et al., 2019; Ehrsam, 2017; Qureshi, 2018; Steis, 2018). Additionally, the autonomous execution of transactions and code introduces another obstacle. While a notable feature of blockchain, this autonomy renders traditional governance actions obsolete—suspending applications, halting infrastructure execution, or modifying incorrect data.

It's crucial to carefully consider these challenges before opting for blockchain solutions, particularly when aligned with the application's purpose. The nature of blockchain—immutable, transparent, and permanent—has earned it the moniker of the "most hostile environment for applications" (Everts & Muller, 2018).

The governance of blockchain infrastructure also faces an array of challenges. Similar to governance via the infrastructure, mechanisms for managing evolution and crises differ significantly across blockchains and warrant thorough investigation. Several overarching challenges are discernible. In off-chain governance, conventional voting processes and stakeholder management guide decision-making for protocol updates or data alterations through customary voting mechanisms. Transparency is achieved through the publication of meeting minutes for update discussions, which theoretically allow anyone to participate. However, the technical nature of these discussions often limits participation (Curran, 2018), potentially resulting in an uneven distribution of power among developers. A mitigating factor is that nodes must adopt changes and possess the option to abstain, though this could trigger a hard fork—an outcome often viewed as unfavorable due to the potential economic repercussions for various stakeholders.

5.2.2. Application layer

With regards to challenges in the application layer we can identify various challenges per type of application.

Direct transactional applications – this type of applications doesn't build additional integrated logic in the blockchain. The challenges are not specific for blockchain but are, as these applications run on traditional infrastructure, similar to traditional applications, except specific blockchain data storage, be- ing transaction and transaction related data that is stored immutable and permanent (in permissionless blockchains) on the blockchain. Here governance challenges are one-on-one to infrastructure layer chal- lenges.

Conditional transaction application – (Single smart contract) – Challenges in these applications are challenges directly related to the infrastructure and transaction applications as well. Any change in un- derlying data structure or transactional data can influence input and outcome of smart contracts. A spe- cific challenge is in evolvement of these applications. Once deployed, the code of smart contracts cannot be altered on most permissionless blockchains. Besides governance challenges if something goes wrong with the underlying data in the infrastructure, the challenge is the impossibility of altering hard coded logic of smart contracts (Everts & Muller, 2018). Another challenge could be the length of smart con- tracts. Long smart contracts increase risk of surface attack (Everts & Muller, 2018).

Conditional transactional application – (Multi smart contracts) – Challenges in these applications are related to challenges on the infrastructure layer, the transaction applications and single smart contract applications. Additional challenges are that these applications often represent more complex products and services with multi actor environments. Examples are initiatives like Augur and Swarm City. Large part of operational governance is done by pre-defined business rules, executed by the infrastructure, but part of the decisions can be made off chain, as these applications are not fully autonomous. With evolve governance, in principle, applications like Swarm City are developed and deployed by teams with centralized governance (Beck et al., 2018). Responsibilities towards these applications pinpoint to these teams. Additional challenge is the risk of reentrancy attack as result of the modular setup.

DAO – For DAOs same challenges can be identified as with other applications and the infrastructure layer. Besides those challenges, one major additional challenge compared to other application types, is lack of traditional company structure, especially after the design stage as teams/owners become fuzzy. This might not result in governance challenges in operate stage of applications due to predefined business rules and automated execution but lies predominately in the evolve stage. As no governance for evolve or crisis management is arranged on a company level, it must be designed and embedded in the application layer. Specifically on DAOs in the evolve stage, "we need rules to change the rules" (Choi et al., 2019).

Another challenge is how to deal with unethical behavior or misuse of code. There is only one real example in this regard, "the DAO". Eventually governance actions were taken on infrastructure level clearly showing the entanglement of application and infrastructure. But also other DAO like cases, like "Swarm City", clearly demonstrate that the emergence of the blockchain economy demands rethinking of governance (Beck et al., 2018).

A challenge for governance of all blockchain applications is transparency of code base of smart con- tracts. This can lead to voting behavior for updates in these applications with malicious intends. This was witnessed in "the DAO" incident with "proposal 59" where the hacker voted in favor of an update proposal that contained flaws that he would later exploit (Slacknation, 2016). There is limited knowl- edge about the governance challenges in the evolvement phase. Most DAOs are not live yet but are in the design/test phase. As they all differ in basic design the, implemented or designed, governance models should be researched in more detail.

The high entanglement of infrastructure and application governance in blockchain also leads to an entanglement of the challenges. Some of these governance challenges might be new due to the hostile development and deployment infrastructure blockchain, but most of the challenges are not different from traditional IT application challenges. Most of the time, a clear (IT)-organization is related to the appli- cation and traditional governance actions can be taken. Only in case of DAOs, especially in evolve/crisis stage, governance challenges can differ significantly from traditional applications. Here traditional pro- cesses, roles and responsibilities appointed to identifiable human lack as result of no formal traditional organizational forms.

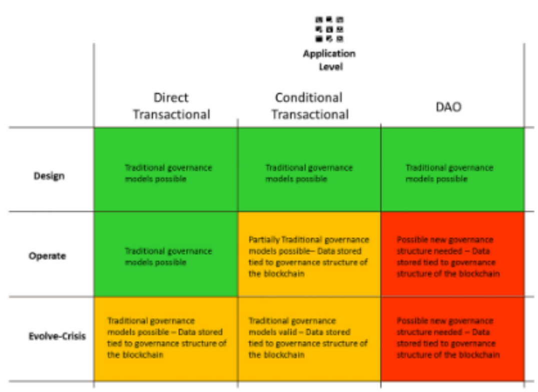

Fig. 7. Applicability Traditional Governance models: Color coding refers to suitability of traditional governance models.

5.2.3. Company layer

At the institutional layer, a significant hurdle for blockchain projects revolves around jurisdictional choice, especially when a particular company backs the application. This becomes particularly crucial if the app delivers financial or data services. Given the nascent stage of blockchain technology, laws and regulations pertaining to services like Initial Coin Offerings can evolve rapidly (Salmon, 2018), and retrospective enforcement is a possibility.

DAOs introduce additional complexity at this layer. The decentralized nature of a DAO makes it challenging to govern using conventional company-based frameworks. As DAOs aren't geographically bound, determining a suitable jurisdiction based on location is not straightforward. Further complicating the matter is the open-source nature of many DAOs, rendering it challenging to identify responsible developers. Determining jurisdiction by developer location or nationality becomes nearly impossible in such scenarios. Presently, there is no well-defined legislative framework for DAOs.

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3 Concluding on governance

The burgeoning world of blockchain technology is prompting a reevaluation of traditional governance structures. While many assert that these traditional structures are becoming obsolete or need complete redesign in the blockchain era, a nuanced view suggests that traditional governance models remain pertinent across various blockchain contexts.

Take the tragic event of the QuadrigaCX case from December 2018. The unexpected demise of its owner resulted in the loss of access to substantial funds because no one else had access to the essential password or private key. While this event might make a compelling case for creating novel governance structures at the infrastructure or application layers of blockchain technology, one could also argue that adequate traditional governance mechanisms at the company level, such as proper backup procedures, could have avoided this debacle.

The real litmus test for blockchain governance lies in the realm of public permissionless blockchains. Permissioned blockchains, with their identifiable validating nodes, fit more snugly into existing governance models. Actions like design modifications, operation, and evolution become straightforward. Standard governance models like ITIL and COBIT can even accommodate public permissionless environments in many cases. If an application on such a blockchain is constructed by identifiable entities, those entities remain responsible and accountable for that application. The only scenarios that might challenge this paradigm are extreme crisis situations, like a catastrophic failure of the underlying blockchain or unanticipated vulnerabilities, as in the Parity I incident.

The pressing governance questions emerge when applications on public permissionless blockchains are conceived and managed in a decentralized, open manner. The evolution of DAOs, for instance, is leading towards enhanced autonomy, diminishing human intervention. If such DAOs are developed in open-source environments without clear identification of their developers and operate without human oversight, the question of responsibility becomes murky. How do we govern the evolution and address potential crises of such entities?

Another layer of complexity is the inseparable link between the application and infrastructure layers. Once set in motion, the application's code and the data transactions become immutable. While traditional companies can offset the absence of technically enforceable governance with process-driven governance or clear regulations, DAOs present a conundrum. The absence of clear regulations, the potential lack of responsible parties, and the dearth of global standards lead to an array of fresh governance challenges.

However, despite these challenges, our analysis reveals that traditional governance models remain valid in many blockchain contexts. In most blockchain applications, especially those on permissioned blockchains and during the design phase of permissionless blockchains, governance can be effectively arranged outside of just the infrastructure or application layers. The key is to recognize the specific contexts and challenges, and accordingly adapt governance models, while also pushing for further research to address the unique challenges posed by blockchain technology.

Conclusions and further research

Blockchain's decentralized nature, devoid of a central trusted authority, has sparked fresh discussions on its governance approach. The inherent characteristics of blockchain, such as decentralization, immutability, absence of formal organizational setups, fluid and unidentifiable participants in permissionless blockchains, and the intertwined nature of application and infrastructure components, make governance a challenging endeavor. There's a dependency between the governance of applications and the underlying infrastructure, which often sees different stakeholder groups managing the infrastructure. This frequently leads to ineffective overarching governance actions.

By examining the governance challenges across varied blockchain types, stages of governance (design, operation, evolution/crisis), and layers (infrastructure, applications, company, institution/country), our framework emerged as an effective tool for categorizing these governance challenges. We anticipate this framework to aid in shaping blockchain governance strategies.

It's evident that applications built on permissionless blockchain protocols present novel governance challenges. For most other blockchain forms, existing governance models might suffice since accountable entities are identifiable and have direct control. In contrast, permissioned blockchains offer simpler mechanisms for updates and data revisions when compared to their permissionless counterparts. Digging deeper, as illustrated in Fig. 8, primary challenges are most evident in DAO applications during their operation and evolution/crisis phases.

This is primarily because distinguishing between users, developers, and the foundational infrastructure becomes ambiguous. Moreover, DAOs might not even have an associated organizational structure post-deployment. Governance in DAOs rests on their code and a possibly volatile user base. While this might not pose significant challenges during operations, it can lead to major complications during evolutionary or crisis situations. Determining accountability becomes a herculean task, leading to vague responsibilities. This vagueness can greatly hinder swift decision-making and governance action execution.

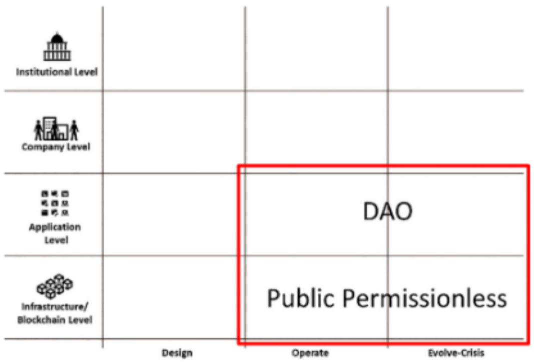

Fig. 8 Diagram emphasizes the areas where novel governance queries emerge.

When DAOs adopt an open-source model, it could drastically alter traditional roles, responsibilities, and accountability dynamics.

Given blockchain's growing stature and the increasing tilt towards autonomous applications like DAOs, there's a pressing need for further research on crafting effective governance structures. Future work should focus on devising a model that correlates the intended use and regulatory framework of the DAO with apt governance models, all while considering its integration with the underlying infrastructure.

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