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Decentralizing governance: exploring the dynamics and challenges of digital commons and DAOs

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This paper explores the intersection of decentralized governance, blockchain technology, and the digital commons through the lens of Elinor Ostrom's principles. It examines how Decentralized Autonomous Organizations (DAOs) and tokenization models present both opportunities and risks for managing digital resources in transparent, community-driven ways. The authors assess how token-based, reputation-based, and hybrid governance mechanisms—ranging from quadratic voting to Soulbound Tokens—can enhance democratic participation and accountability within blockchain ecosystems, while also recognizing their susceptibility to plutocracy, voter apathy, and collusion. Drawing on case studies such as MakerDAO, MolochDAO, Commons Stack, and Aragon, the paper critically analyzes real-world implementations of decentralized governance and the extent to which they adhere to—or deviate from—Ostrom's design principles for common-pool resource management. It highlights structural limitations in governance design, especially in the presence of unequal voting power and centralized control disguised as decentralization. The paper also critiques the socio-economic implications of blockchain's global expansion, noting how digital governance can replicate neo-colonial dynamics in the Global South and amplify state surveillance in authoritarian contexts. Further, it underscores the environmental costs of blockchain infrastructure and introduces DAOs like KlimaDAO and Regen Network as emerging experiments to align decentralized finance with sustainability goals. Ultimately, the authors propose a "dual imperative": to develop context-sensitive, inclusive governance architectures within DAOs, while pursuing international legal recognition and standards. The conclusion calls for communitarian models that fuse algorithmic rule enforcement with human-centered deliberation to protect the emancipatory potential of blockchain governance. Whether blockchain becomes a force for democratization or digital enclosure, the authors argue, will depend on how its governing architectures are designed, contested, and evolved by the communities that steward them.

KEYWORDS

digital commons, governance, blockchain, artificial intelligence, decentralized network

Introduction

A blockchain network relies on collectively managed technologies to pool and share information (Murtazashvili et al., 2022). Analyzing various models of blockchain networks present an opportunity to govern the digital commons. Based on Elinor Ostrom's definition, the digital commons can be understood as online resources that are designed and governed by a community with rules concerning access and sharing. The digital commons refer to shared online resources and spaces that are collectively created, maintained, and governed by a community, often with an emphasis on open access and collaboration. These resources can include open-source software, public datasets, freely available educational materials, and platforms for collective knowledge sharing, such as Wikipedia or Creative Commons-licensed content.

Most examples of digital commons governance through blockchain networks have occurred in the realm of finance (Vulpen and Jansen, 2023). Implementing tokenization models and smart contracts that allow token holders to participate in democratic voting processes, Decentralized Autonomous Organizations (DAOs) typically govern shared resources. Other forms of decentralized governance have been found in Aragon (Aragon Network DAO, 2012) and large Commons-Based Peer Production (CBPP) communities like Wikipedia and FLOSS projects (Rozas et al., 2021a). FLOSS (Free/Libre and Open Source Software) projects are software initiatives that follow the principles of freedom, transparency, and collaborative development involving open access to source code and non-proprietary licensing.

This paper compares the efficacy of various models and examines the extent to which the decentralized, token-based nature of blockchain networks can improve the regulation of the digital commons based on Ostrom's principles. Historically, the decentralized nature of blockchain networks has been treated as a means to democratize digital spaces by introducing multilateral forms of governance adhering to the beliefs of many users (Zwitter and Hazenberg, 2020). However, the expansion of blockchain technologies and cryptocurrencies in the developing world could also represent a new form of financial colonialism, where blockchain financialization perpetuates historical patterns of economic exploitation and dependency through digital networks. These challenges are not limited to the developing world but are also prevalent in industrialized nations, highlighting the global nature of digital inequality and the need for inclusive solutions (Robinson et al., 2015). Recent research has shed light (Dellarocas, 2010a) on the complex impacts of automated reputation and reward systems on online communities, revealing both benefits and potential drawbacks that warrant critical examination. For instance, while these systems can enhance user engagement, they may also inadvertently reinforce existing biases or create perverse incentives (de la Roche et al., 2022). While blockchain networks aim to decentralize power and increase transparency, their design often reflects the assumptions and values of their creators, prioritizing efficiency over fairness or favoring users with more technical expertise or financial resources. Yet, blockchain technology also offers opportunities for financial and social inclusion in developing countries by addressing challenges such as lack of banking infrastructure, high transaction costs, and limited access to formal financial systems.

Ostrom's principles for commons governance

Blockchain networks can be used to improve the governance of digital commons by addressing limitations to Ostrom's eight principles. (Stern, 2011) These principles include the need for clearly defined boundaries, rules fit to local circumstances, participatory decision-making, self-monitoring, environmental monitoring, sanctions, accessible modes of conflict resolution, and rights to organize.

Clearly defined boundaries allow users to know who has access to the resource and the capabilities of the resource. Without clear boundaries, it becomes difficult to prevent overuse by outsiders or to hold users accountable. Ostrom explains that rules governing the use of the resource should align with local conditions, ensuring that expectations about maintenance are realistic and appropriate to the specific environment. Resource users should actively participate in making and modifying rules. This inclusion fosters a sense of ownership and increases compliance. Monitoring should be conducted either by the users themselves or by individuals accountable to them. This helps detect rule violations early and maintain trust within the group.

When rules are violated, sanctions should be applied in a graduated manner, meaning that minor infractions receive light penalties while repeated or severe offenses result in stronger consequences. This approach balances fairness with enforcement. Accessible and low-cost mechanisms for resolving conflicts should also be available in the community. Since disagreements are inevitable, a fair and efficient system for handling disputes helps maintain group cohesion. Communities must have the right to organize their own governance systems without interference from higher authorities, which legitimizes their local management and supports autonomy. For resources that are part of larger systems, governance should be nested in multiple layers. Local groups handle local issues, while broader institutions coordinate at regional or national levels, creating a cooperative structure across scales. Together, these principles highlight the potential for sustainable, community-based resource management when systems are carefully designed and grounded in local knowledge and participation.

Existing limitations to governing the digital commons along Ostrom's principles include discrepancies in resource management, difficulty of assigning ownership over global boundaries and scalability, unequal decision-making, monitoring, and weakly enforced sanctions due to a lack of universally binding authorities (Stern, 2011). Building on Ostrom's principles, blockchain networks present an opportunity to enhance the regulation of global digital commons through decentralized governance models.

Tokenization model in decentralized governance

On blockchain networks, tokenization is used to determine users' rights to conditionally perform an action based on their ownership of an asset. These assets are tokens that function as transferable data elements on the blockchain. Tokenization allows for forms of decentralized governance that are unique to blockchain

networks, including DAOs like MolochDAO and MakerDAO. Originally created to fund Ethereum 2.0 development, MolochDAO allows token holders to vote on grant proposals, collectively funding projects that contribute to the Ethereum ecosystem (Ethereum, 2015). MolochDAO primarily funds projects that contribute to the development and sustainability of Ethereum's public goods and decentralized infrastructure. The DAO is focused on improving areas of the Ethereum ecosystem where funding through traditional venture capital or private investment is lacking.

Similarly, MakerDAO is a lending protocol and a DAO that oversees its operating protocol using the MKR governance token. Holders of MKR participate in the decentralized governance of the MakerProtocol by voting on key parameters such as stability fees (essentially the interest rate on the loan), collateral requirements, and risk management strategies. To generate the DAI stablecoin, the stablecoin that MakerDAO mints as loans, users lock Ether (ETH), or other approved collateral, in smart contracts. These contracts, known as "vaults," ensure that DAI is backed by overcollateralized assets to secure the stablecoin's value (MakerDAO's DAI, 2014). If the value of ETH drops below a critical level, the protocol liquidates the collateral to repay the outstanding DAI debt (The Maker Protocol, 2024). Users are incentivized to manage their collateral to prevent losses from liquidation penalties; the protocol benefits because overcollateralization ensures the stability and trustworthiness of DAI. As such, by making users stake ETH as collateral, MakerDAO ensures that individual users' incentives to avoid liquidation align with the protocol's goals of stability and ecosystem growth. MKR governance through the tokenization model further reinforces this alignment by ensuring risk parameters are selected to benefit both the protocol and its users ("Understanding the MakerDAO Governance Process, 2024).

The tokenization model turns users into decentralized policymakers (Sockin and Xiong, 2021). However, models like token-weighted voting can paradoxically lead to centralization and plutocracy. In token-based governance, voting power is typically proportional to token holdings. Early adopters or participants with more resources who acquired tokens at lower prices or through lower prices are more likely to gain disproportionate influence over governance decisions. This dynamic reinforces itself in a negative feedback loop, where those with more tokens can shape governance to favor policies that benefit them, further consolidating their power. When coupled with the fact that many smaller holders do not participate due to rational apathy, decision-making becomes primarily driven by a few large token holders. This consolidation of governing power creates incentives for collusion and vote-buying, as large token holders can inform cartels or delegated governance structures where they align voting interests to maintain control. Further, systems like liquid stacking governance can concentrate governance in the hands of a few large liquid stacking providers. This leads to low baseline engagement, which persists across most DAOs. In Decentraland, average voter participation per proposal was 0.79%, with median participation at 0.16% (Peña Calvín et al., 2025). Across 30,000 DAOs analyzed, 53% were inactive, with no proposals in 6 months, and voter turnout decreased as DAO size increased (Peña-Calvin et al., 2024).

Unlike traditional modes of governance, blockchain governance is often dominated by economic incentives rather than long-term sustainability. Major token holders, especially those with short-term investment horizons, may push for policies that maximize immediate token value even at the expense of long-term ecosystem health (Uzsoki and Guerdat, 2016). This can lead to the formation of a shareholder primacy model, where decisions favor token price appreciation over decentralization protocol security (The Aspen Institute, 2022).

Delegated voting model

In response to low voter participation, governance delegation allow users to delegate votes to representatives. A unique aspect of the MakerDAO ecosystem is the delegated voting model. Since not all MKR holders can actively participate in every governance decision, the MakerDAO allows MKR holders to delegate their voting power to other individuals or entities, known as delegates, who vote on their behalf. In MakerDAO, proxy delegates controlled 9.16% of voting power individually, while self-delegates required 504,514 MKR tokens to sway decisions (DAO Index, 2025). This governance model aligns with the monitoring and regulations outlined in Ostrom's principles. However, the overarching tokenization model also introduces the risk of centralization when a limited number of individuals or entities owns a comparatively large percentage of MKR. For example, in September 2018, the firm Andreessen Horowitz acquired 6% of the total MKR supply for $15 million (Crypto Fund, 2018). In December 2019, Dragonfly Capital Partners and Paradigm collectively purchased $27.5 million of MKR, approximately 5.5% of the total supply (The Maker Foundation, 2012), to influence the decentralized governance of the MakerProtocol. The involvement of these venture capital firms introduces a limitation to the decentralized, collective decision-making of the MakerDAO ecosystem, as governing power becomes concentrated within the users that possess the most tokens. While delegation tends to increase overall voting activity (Cheng et al., 2024), it reduces engagement in strategic decisions and concentrates power among delegates.

To address this, platforms like Compound and Aave have adopted delegated voting models, where token holders can assign their voting power to trusted delegates. This approach attempts to balance broad participation with effective decision-making by enabling more informed or engaged actors to vote on behalf of less active members. However, it can also lead to concentrations of power in the hands of a few high-profile delegates, raising questions about whether such models truly break from traditional hierarchies or simply reproduce them in new forms.

Uniswap has taken a different approach by establishing a governance council, a group of trusted stakeholders who guide key decisions while still deferring to community votes on major protocol changes. This hybrid model introduces a layer of institutional memory and coordination capacity, aiming to resolve issues like fragmented decision-making or procedural delays common in fully open governance structures. Yet, this too presents trade-offs. While councils can improve efficiency and provide accountability mechanisms, they may also consolidate power and limit broader community input, especially if council membership lacks rotation or transparency. The tension between

coordination and inclusivity remains a central issue for DAOs navigating governance at scale.

Mitigants to centralization on blockchain networks

Quadratic voting models

To mitigate the consolidation of governing power among the largest token holders, it is recommended to transform the tokenization model so that funding influence is nonlinearly proportional to token holdings (Quadratic Models for Understanding, 2017). In traditional token-based voting, influence is directly proportional to the number of tokens possessed by a user. A quadratic, or nonlinear, voting model would weaken the power of large token holders by introducing a cost-curve for voting. For example, Gitcoin Grants use quadratic voting to distribute funding based on community priorities (Gitcoin Grants, 2020).

In additional to a quadratic tokenization model, blockchain networks can also employ a public goods funding model that allows small contributors to have a larger collective impact. Funding is matched using a quadratic formula, where smaller donations from many people receive more weight than a large donation from a single entity. Gitcoin's quadratic funding model for Ethereum projects exemplifies this form of decentralized governing power. Gitcoin's experimentation with reputation-based and quadratic voting through its Grants program represents another innovative governance pathway. Rather than giving greater weight to those with more tokens, Gitcoin's quadratic funding mechanism amplifies the voices of smaller contributors, promoting a more democratic distribution of influence. This model reflects Ostrom's emphasis on congruence between rules and community values, as it enables more equitable resource allocation based on the breadth, not just the size, of support. At the same time, reputation systems are not immune to manipulation, and defining what constitutes meaningful participation remains a challenge, especially in anonymous or pseudonymous digital spaces.

Reputation-based voting

Unlike traditional token-based voting, reputation-based voting assigns voting power based on an individual's contributions and engagement rather than financial stake. This mitigates wealth concentration issues, ensuring that governance decisions reflect long-term community interests rather than short-term profit motives. This aligns with Ostrom's principle of collective-choice arrangements, where stakeholders actively shape the rules governing shared resources. In token-weighted governance, decision-making power is proportional to the number of governance tokens a participant holds, which often results in "whale domination," where a few large stakeholders control governance outcomes. Reputation-based voting distributes power based on trust or expertise rather than token ownership. This model incorporates on-chain activity metrics, where participants earn governance weight based on actions such as code contributions and proposal reviews. Off-chain contributions can also be incorporated through engagement in community discussions which can factor into users' reputation scores. Long-term, consistent participation is rewarded, reducing the risk of manipulation from short-term engagement spikes. Reputation-based governance establishes transparent criteria for participation and influence, ensuring that decision-makers are involved in the commons. Despite its advantages, reputation-based voting requires thorough implementation to avoid sybil attacks, as fake identities on networks can artificially inflate reputation, as well as mitigate biases in contribution assessment. Potential solutions include cryptographic identity verification and reputation decay mechanisms to prevent exclusionary governance.

Soulbound Tokens (SBTs)

Soulbound Tokens (SBTs) are non-transferable digital assets that represent personal achievements, credentials, or reputational markers. They offer an effective way to prevent governance capture in blockchain-based digital commons by ensuring that voting power is tied to participation rather than wealth. Since SBTs cannot be bought or transferred, they align governance influence with meaningful engagement rather than financial status. Governance participation is earned rather than bought, meaning long-term contributors and ecosystem stewards wield influence. Since governance is tied to non-transferable tokens, misbehavior can lead to penalties, such as losing governance privileges, which aligns with Ostrom's principle of graduated sanctions. Community members can also verify each other's contributions through on-chain records, ensuring transparency in governance. The main challenge with SBTs is privacy. If all reputational markers are public, users may be subject to tracking or discrimination. Additionally, governance systems must implement fair ways to distribute and revoke SBTs without creating centralized gatekeepers.

Rotating governance councils

Rotating governance councils involve periodically changing the individuals responsible for overseeing key governance functions in a decentralized organization. This mechanism prevents entrenched power structures by ensuring that governance responsibilities are distributed over time. By implementing fixed-term governance roles, individuals or groups cannot monopolize decision-making indefinitely. Different perspectives are introduced over time, ensuring that governance decisions reflect the evolving needs of the digital commons. By rotating governance responsibilities, different members of the community take turns ensuring fair management of shared resources, aligning with Ostrom's principle of monitoring. Moreover, since governance roles are temporary, disputes are less likely to escalate into long-term power struggles. While rotating councils can prevent centralization, they require structured transition processes to ensure continuity. Additionally, inexperienced participants may struggle with governance responsibilities, necessitating mentorship programs or staggered transitions where experienced members guide new entrants.

DAO regulations

Two prominent categories of DAOs include financial DAOs, such as MakerDAO, and digital commons governance DAOs, such as Commons Stack. Financial DAOs are primarily focused on monetary and economic activities. MakerDAO, for instance, governs the Dai stablecoin, allowing users to generate Dai through collateralized debt positions. The core function of such DAOs is to ensure financial stability, liquidity, and efficiency in decentralized financial markets. Governance in financial DAOs typically revolves around risk management, monetary policy, and maintaining stable operations within a decentralized ecosystem. In contrast, DAOs for digital commons governance, like Commons Stack, aim to support the development and sustainability of shared digital resources, open-source projects, and community-driven initiatives. These DAOs facilitate collective decision-making for resource allocation, funding, and governance of public goods. They employ mechanisms such as bonding curves and quadratic voting to ensure fair participation and long-term sustainability of digital commons, emphasizing values like collaboration and social impact rather than financial profit.

DAOs allow blockchain networks to establish a collective, decentralized decision-making process (Li and, 2022). Initially, users or community members of a blockchain network propose changes to the network's structure, operation, and strategies. Then, these proposals are refined through on-chain discussions before the core team takes the proposals to on-chain voting. As opposed to off-chain voting, where voting happens outside the blockchain on third-party platforms, on-chain voting occurs directly on the blockchain, where votes are recorded immutably in smart contracts and decisions are executed automatically based on the outcome (Jafar et al., 2022). After token holders cast their weighted votes based on their possession of tokens, the core team implements the community-approved proposals. (Commons Stack, 2024) This collective determination of digital regulation aligns with Ostrom's definition of the commons by treating digital spaces as a common-pool resource that users should regulate through collaborative, decentralized decision-making. Yet, the tokenization model raises concerns about the scope of this collective choice arrangement, as only those who own tokens can cast votes to determine the implementation of a specific structural, operational, or strategic change (Crandall, 2023). Despite blockchain networks' inclusionary, collective decision-making approach to decentralized governance, current trends suggest that blockchains are used in fewer cases as platforms for inclusion in the digital commons; blockchain networks are also being used for more exclusionary and exploitative ends. (DAO Index, 2025) As such, although DAOs allow for a relatively democratic governance model for decentralized digital commons, they yield varying results. DAOs can take initiative only when users propose changes, and DAO's enforcement of token-based voting increases the impersonalization of community-wide improvements and sanctions (Rozas et al., 2014).

The Optimism Collective's bicameral governance model is an example of how centralized decision-making can improve government efficiency. Composed of two distinct "houses", the Token House and the Citizen's House (Welcome to the Optimism Collective, 2024), the system blends token-based governance with a more curated form of public goods funding. The Token House allows for token holders to vote on protocol upgrades and technical matters, while the Citizen's House is responsible for allocating funding to public goods. The design intentionally separates financial incentives from social value, creating clearer accountability and reducing the risk of token whales dominating all governance outcomes. Both houses rely on a more curated and representative membership than what is typically found in fully decentralized DAOs, enabling faster and more focused decision-making.

Centralized or semi-centralized governance models can also promote better strategic alignment. In the case of Optimism, the presence of curated councils and working groups enables the network to set and pursue long-term objectives more coherently. Rather than relying on unpredictable token holder sentiment, Optimism can channel efforts toward its core mission of funding digital public goods. Similarly, projects like Arbitrum have begun exploring delegate councils and security councils to expedite decision-making and respond to emergencies—features that pure DAOs typically lack. These more structured models do not abandon decentralization entirely, but they temper it with mechanisms for clearer accountability, strategic leadership, and execution power.

However, DAOs are increasingly gaining attention as innovative governance structures for blockchain-based communities, yet their legal status remains ambiguous. Traditional legal frameworks struggle to accommodate DAOs, which operate without centralized control, fixed jurisdictions, or conventional corporate structures. In response, emerging DAO regulations, such as Wyoming's DAO LLC law, represent an effort to integrate DAOs into recognized legal systems. However, while such regulations provide a pathway for legitimacy, they also introduce potential challenges and tensions with decentralization.

In 2021, Wyoming became the first U.S. state to legally recognize DAOs by amending its Limited Liability Company (LLC) statutes to allow DAOs to register as LLCs. Under this framework, DAOs can obtain legal personhood, meaning they can enter contracts, own assets, and benefit from limited liability protections for their members. To qualify, a DAO must include "DAO" in its name, provide an operating agreement specifying how it operates, use smart contracts for governance, and elect to be either "member-managed" or "algorithmically managed." This legislation aims to offer DAOs the same protections and responsibilities as LLCs while acknowledging their unique decentralized nature.

One of the main challenges DAOs face is legal uncertainty, particularly concerning liability. Wyoming's DAO LLC framework provides members with limited liability protection, ensuring that individuals participating in DAO governance are not personally liable for the DAO's actions. This protection is crucial for encouraging broader participation in DAOs without fear of legal repercussions. Without legal personhood, DAOs struggle to interact with traditional entities, such as banks, courts, and regulatory bodies. The DAO LLC model grants legal standing, allowing DAOs to sign contracts and engage in litigation when necessary. This legal bridge can help DAOs integrate with mainstream financial and commercial systems while maintaining decentralized governance. By offering a legally compliant pathway, Wyoming's law could encourage more institutional adoption of DAOs. Regulatory clarity may attract traditional businesses and

investors, fostering innovation while reducing risks associated with regulatory arbitrage.

However, the requirement for a formal operating agreement and LLC registration could impose traditional corporate structures onto DAOs, potentially undermining their decentralized nature. While smart contracts may automate governance, the necessity of a legal entity and compliance with state laws could lead to centralized administrative functions that conflict with the original ethos of DAOs. Moreover, Wyoming's law only applies within its jurisdiction, raising questions about how DAOs interact with regulations in other states and countries. Because DAOs operate globally on blockchain networks, differing legal treatments across jurisdictions could lead to conflicts or regulatory arbitrage, where DAOs strategically register in the most favorable legal environments while still operating globally.

The 2023 Ooki DAO ruling set a legal precedent for DAOs. District Judge William H. Orrick ruled that Ooki DAO had illegally operated a trading platform without proper registration as a futures commission merchant (Statement of CFTC, 2024). After a $643,542 fine, Ooki DAO was shut down via default judgement by the Commodity Future Trading Commission. (Dellarocas, 2010a) Crucially, the ruling classified Ooki DAO as a "person" under the Commodity Exchange Act, increasing the regulatory and legal liabilities for DAOs (Li and, 2022). Further rulings in U.S. courts have created the possibility of contributors to DAOs facing personal liabilities, complicating DAOs' model of decentralized governance and increasing legal risks for DAO contributors (Dellarocas, 2010b).

As DAOs gain traction globally, regulatory approaches vary widely by region, reflecting different attitudes toward innovation, risk, and financial oversight. Countries like Switzerland and Singapore have positioned themselves as crypto-friendly jurisdictions, offering legal clarity and frameworks that accommodate DAOs within broader fintech ecosystems. For example, Switzerland's canton of Zug, often referred to as "Crypto Valley", has developed progressive laws that allow DAOs to register as legal entities, such as associations or foundations (Braun-Dubler et al., 2020). This legal recognition provides DAOs with the ability to enter into contracts, hold assets, and interact with traditional financial systems, while still preserving aspects of decentralization. By grounding decentralized organizations within established legal categories, Switzerland balances the innovative potential of DAOs with safeguards for legal accountability.

Singapore has taken a similarly open yet cautious approach, promoting blockchain innovation while implementing regulatory guardrails. The Monetary Authority of Singapore requires compliance with anti-money laundering and counter-terrorism financing laws, ensuring that decentralized projects operate within a transparent and regulated environment. Singapore has become a hub for Web3 startups by offering regulatory sandboxes and clear guidelines, allowing DAOs to experiment and grow within a legally secure framework. However, DAOs operating in Singapore still face challenges around defining liability and enforcing contracts, especially as their governance structures often involve global, pseudonymous participants.

In contrast, the European Union is moving toward a more comprehensive regulatory regime with the Markets in Crypto-Assets (MiCA) regulation, which will come into full effect in 2024. While MiCA is primarily focused on crypto-asset service providers and stablecoins, it sets a precedent for how decentralized projects, including DAOs, might be governed across EU member states. MiCA emphasizes consumer protection and operational transparency, which could pressure DAOs to adopt more formal structures or partner with compliant entities if they wish to serve EU users. Though MiCA does not explicitly legislate DAOs, its broad definitions and risk-based approach suggest that any organization engaging in crypto-related financial activity could be subject to oversight, even if it lacks a traditional legal identity.

DAOs are limited by the fact that most are still in their infancy (El Faqir et al., 2020), and there is a lack of tooling available for DAO development (Wang et al., 2022). Although there is currently no clear view of how a DAO designed for commons governance would operate (Vulpen and Jansen, 2015), there have been same examples of projects who claim to rely on commons-oriented perspectives, including the Commons Stack project and the Aragon DAO platform (Rozas et al., 2021b).

Commons-oriented projects

The Commons Stack is an organization that creates tools and frameworks to assist decentralized digital communities in managing shared resources (Commons Stack, 2014). Focusing on sustainable governance models that balance community goals with financial stability, the Commons Stack project founded the Token Engineering Commons (TEC) (Commons, 2021). The TEC is a project under Commons Stack and the digital token engineering community that has created a resource pool for developing public infrastructure projects. TEC uses a bonding curve model to manage resources and democratic voting for decision-making. In 2021, TEC launched as the first CommonsDAO, applying Ostrom's principles to DAO governance through the economics co-design methodology. () This model allows voters to independently develop proposals and receive feedback from members of the digital commons before it is put to vote. The Commons Stack claims that the CommonsDAO "embraces polycentric governance" by catering to the diverse needs of the commons (Commons Stack, 2013). Commons-oriented projects on blockchain networks like the Commons Stack align with Elinor Ostrom's principles for governing the commons by promoting decentralized, community-driven management of shared resources. These projects aim to prevent overuse by ensuring fair participation and sustaining collective benefits in digital public goods, such as open-source protocols, decentralized identity systems, and data-sharing networks.

Aragon is a software that allows users to create decentralized autonomous organizations on the Ethereum blockchain (Upgrading Smart Contracts, 2021). This software can be leveraged to create clubs, companies, nonprofits, and other organizations that collectively regulate finances and decision-making through its decentralized model. According to Aragon, over 1,700 organizations are built on its software, with a market cap of over $30 billion USD. (Ecosystem, 2020) Aragon consists of five offerings with two native tokens. Most significantly, the Aragon Network Token is used in platform-wide governance and can be used as a bond to create the ANJ token, which the Aragon Court uses to settle disputes. Organizations built on Aragon can use the Aragon

Court to arbitrate and reach resolutions. Similar to a centralized model, jurors are selected at random from the Aragon Network's collection of DAOs based on Aragon software. Both parties will stake ANT tokens, and after the jurors deliver their verdict, the tokens will be distributed to either party based on the vote. Jurors who vote will receive a portion of the aggregated fees, and jurors who fail to vote will lose their staked tokens (Stephen Haley, 2016). The Aragon Court sanctions misbehaving parties and members of the jury through the process of stacking tokens and removing jury members. Thus, decentralized communities can establish a form of governance through blockchain courts (Rozas and Hassan, 2022).

Collective choice and resource pooling regulation

Blockchain networks address the challenge of identifying relevant conditions in an environment as heterogeneous as global digital commons. In a blockchain context, online communities decide which proposals to recognize and how they are valued, establishing a framework to acknowledge contributions through online participation in organized methods similar to those of a participatory democracy. These interactions occur on open-source projects on platforms like GitHub, as well as community chats and forums (Seungwon Eugene Jeong, 2020). Formally established proposals, after obtaining approval through a tokenized voting process, are then codified through smart contracts (Rozas and Hassan, 2022). Initial implementations of blockchain systems did not have sufficient flexibility in its smart contracts, but current implementations have adopted tools to overcome former limitations and change smart contracts as deemed necessary through collective determination. (MakerDAO, 2020) This upgradeability of smart contracts can be seen in Aragon's DAO platform (Aragon Network DAO and Decentralized Governance,) and Open Zeppelin's tools for smart contract updating (Upgrading Smart Contracts, 2021).

Global perspective on democratization of blockchains

Despite the benefits of decentralized polycentrism through DAOs, the tokenization model, and collective choice, blockchain technology can also be weaponized against democratic intent by extending neo-colonial dynamics. (Jutel) The deployment of blockchain in developing countries may serve the interests of global financial capital, leading to new forms of economic dependency.

In the Global North, blockchain is celebrated for decentralization and empowerment (Hung, 2024). In contrast, in China, the state utilizes blockchain to reinforce governance and align with corporate interests, amplifying state power and capitalist motives. (Peña-Calvín et al., 2024) The adaptation of blockchain technology in rural China contrasts its original libertarian ideals with its current implementation as a state-controlled tool for economic and social governance. (Regen Network, 2021) In China, blockchain is integrated into national development policies, diverging from its decentralized, privacy-focused roots (The Untold Technological Revolution Sweeping Through, 2016). These initiatives often exacerbate economic and social inequalities, embedding many smallholder farmers in exploitative frameworks dominated by corporations and state surveillance (Blockchain Chicken Farm, 2015). Blockchain initiatives often increase barriers for smallholder participation, favoring corporations and large-scale farmers, and subjecting smallholders to increased scrutiny and dependency on corporate platforms. These systems also facilitate data collection by corporations and the state, reinforcing surveillance mechanisms in rural communities. This usage of blockchain technology aligns with an authoritarian capitalist model, consolidating state control and corporate interests under the guise of modernization. It is necessary to further investigate the enduring effects of blockchain implementation on local rural economies and smallholder livelihoods.

Resource allocation in Web3

Analyzing the impact of blockchain technology and Web3 on local economies and environments reveals that blockchain projects are not merely virtual systems but are intrinsically tied to physical spaces and their social, economic, and environmental dynamics (Howson et al.). Drawing on Henri Lefebvre's idea of "the production of space," (FairCoop, 2023) Howson et al. idea of "Crypto/Space" posits that Web3 projects materially and socially constitute space in manners that deviate from traditional digital software. Blockchain projects derive value and operational capacity from physical resources like energy, land, and infrastructure, while simultaneously shaping these spaces by altering their economic and regulatory landscapes. The "Crypto/Space" framework critiques the prevailing narrative that blockchain is a neutral, apolitical technology. Instead, it reveals how these projects are deeply embedded in power dynamics, often favoring speculative capital and elite actors at the expense of marginalized communities (Howson et al., 2024).

Due to the energy-intensive nature of Proof-of-Work (PoW) cryptocurrencies like Bitcoin, blockchain projects tend to exploit local resources without offering commensurate benefits to host communities in a process known as "crypto-parasitism". (Hung, 2024) Bitcoin mining, which relies on PoW consensus mechanisms, consumes vast amounts of electricity, often sourced from local grids or subsidized energy programs intended for broader community use.

Case studies from Chelan County, Washington, and Dresden, New York (Lally et al., 2010), illustrate how mining operations strain local infrastructure, increase utility costs, and produce noise pollution, disrupting everyday life. Chelan County became a hotspot for cryptocurrency mining due to its access to cheap hydroelectric power generated by the Columbia River. The area's historically low energy costs attracted several mining operations, but the influx of miners created significant challenges. Mining rigs produce significant heat and require industrial-scale cooling systems to operate efficiently. The large fans used to cool these systems generated constant, high-decibel noise, disrupting the tranquility of the surrounding neighborhoods. Moreover, sudden demand from crypto mining operations overwhelmed Chelan County's electrical grid. Mining rigs require enormous amounts

of electricity to run high-powered computers 24/7, causing the local utility infrastructure to near capacity. To accommodate these demands, the Chelan County Public Utility District (PUD) had to invest in grid upgrades, including installing new transformers and substations. These additional costs imposed financial burdens for the public utility. To manage the heightened demand and offset infrastructure costs, the PUD introduced a special rate structure for cryptocurrency miners (Chelan PUD, 2021). These higher rates aimed to prevent the costs from spilling over to residential and other commercial customers. However, local residents voiced concerns that they might indirectly subsidize mining operations if rate adjustments proved inadequate to cover the actual costs incurred by infrastructure upgrades. In response to community backlash and grid concerns, Chelan County implemented temporary moratoriums on new crypto mining operations. This allowed local officials to study the long-term impacts of these activities and establish regulations to mitigate adverse effects.

Similarly, in 2020, a decommissioned coal-fired power plant in Dresden, New York was repurposed into a natural gas-powered crypto mining facility. This facility, operated by Greenidge Generation, highlighted the environmental and infrastructural challenges associated with crypto mining. Greenidge Generation converted the plant into a facility that could both produce energy and power its cryptocurrency mining rigs. The dual-use model created additional strain on the regional energy grid, as large-scale mining operations demand a consistent and significant energy supply. The substantial power usage raised concerns about the facility's impact on energy availability for local communities and small businesses. The high energy consumption by Greenidge's mining operations raised fears of increased energy prices for local residents. While the company claimed to operate efficiently, critics argued that its heavy energy use created upward pressure on rates for the broader community. The facility drew large amounts of water from Seneca Lake for cooling, discharging heated water back into the lake. Environmental groups warned that this practice threatened local aquatic ecosystems, including fish populations and water quality (Mantius, 2022).

The events in Chelan County and Dresden illustrate the unintended consequences of large-scale cryptocurrency mining. While these operations bring investment and jobs, their significant energy demands, noise pollution, and infrastructural strain often outweigh their benefits. Both communities demonstrate the importance of proactive regulation and community engagement to address the environmental, economic, and social impacts of crypto mining.

More broadly, the carbon footprint of Bitcoin mining rivals that of entire nations, with much of the energy coming from fossil fuels. Mining operations produce e-waste from outdated hardware like ASIC units, which are discarded every 1–2 years. This waste often ends up in the Global South, exacerbating environmental degradation. Often, local communities are left to bear the brunt of these externalities, such as increased pollution, rising utility costs, and limited job creation. In order to reap the democratizing benefits of decentralized blockchain networks in the digital commons while minimizing crypto-parasitism, users must have equal input in the functions of the network, as well as with external regulatory bodies.

Virtual land grabs

Blockchain projects often acquire land under false pretenses, promising development or innovation but failing to deliver on these commitments (Howson et al., 2020). These projects use the land primarily for speculative purposes, such as securing investment, inflating asset values, or facilitating token sales. For example, Liberland, a proposed tax-free crypto nation on disputed land between Croatia and Serbia, was originally marketed as a libertarian haven, but its promises remain unrealized, and the land remains undeveloped. Similarly, Cryptoland, a planned blockchain utopia in Fiji that was heavily marketed but failed to secure the land, left investors with worthless NFTs. These land acquisitions displace local populations and often ignore existing claims or community needs. Many regulatory bodies and developers tend to frame these areas as "blank slates" for experimentation, disregarding the social and environmental costs. () As such, ethical usages of blockchain networks as a mode of digital governance requires the establishment of foundational risk-minimizing oversight secured by external regulatory bodies.

Play-to-earn gaming

"Play-to-earn" (P2E) gaming is an emerging form of digital labor that blurs the lines between work and play. P2E games monetize gameplay by integrating blockchain technology, offering players financial incentives through cryptocurrency and NFTs. *Axie Infinity*, a pioneer in P2E gaming, exemplifies this model by using digital scarcity to create value. Sky Mavis, the developer, generates revenue through transaction fees and marketplace activity. *Axie Infinity* can demonstrates how blockchain-based gaming produces new forms of labor precarity, endangering employment levels through exploitative practices (Kuo Siong Tan, 2024).

The COVID-19 pandemic amplified the appeal of P2E gaming, particularly in the Global South, where it was marketed as a lifeline for economically vulnerable populations. *Axie Infinity* appealed to players in countries like the Philippines and Venezuela during the pandemic, with stories of players earning more than minimum wages. Players earn through in-game cryptocurrencies like Smooth Love Potion (SLP) and Axie Infinity Shard (AXS) to trade for income, yet their experiences are shaped by the volatility of cryptocurrency markets and insecure employment arrangements among other exploitative working conditions. () *Axie Infinity* allows users to secure asset ownership and enables trade on decentralized marketplaces, making digital rewards liquid and redeemable for fiat money. Yet, since players' earnings are directly tied to the cryptocurrency market, they are subject to unpredictable amounts of volatility. For example, SLP prices dropped 99.65% from their peak, eroding income potential. (Lally et al., 2010) Moreover, delayed token withdrawals exacerbate losses, as prices often decline before players can convert earnings to fiat. Security risks also threaten to compromise players' earnings, as the Ronin blockchain, which underpins Axie transactions, suffered a $625 million hack in 2022 that left many players unable to access earnings. The centralized oversight of *Axie Infinity* by the developer Sky Mavis means that the developer can change software code to

modify gameplay and rewards, often without warning, at the cost of destabilizing players' earnings and increasing their work intensity. (Werbach, 2018) Errors in detection algorithms have unfairly penalized innocent users, disrupting livelihoods.

P2E gaming can commodify leisure, leaving many players dependent on unstable cryptocurrency markets. Speculative economic models and exploitative labor practices exacerbate this labor precarity. Despite claims of decentralization and empowerment, blockchain-based games often replicate or amplify traditional forms of inequality and exploitation. There is additional to examine digital labor through a precarity lens while recognizing the socioeconomic vulnerabilities embedded in emerging technologies.

DAOs incentivizing sustainable behavior

Although blockchain network are energy intensive, DAOs can be used as tools to incentivize sustainable behavior and address global challenges such as climate change. KlimaDAO, one of the largest sustainability-focused DAOs, leverages blockchain technology to influence the voluntary carbon credit market. By using decentralized finance mechanisms, KlimaDAO and similar projects aim to align financial incentives with environmental responsibility.

KlimaDAO is a blockchain-based organization designed to drive up the price of carbon credits, thereby making pollution more expensive and encouraging businesses to offset emissions. It operates on the Polygon blockchain and utilizes a treasury-backed algorithmic token, KLIMA, which is backed by tokenized carbon credits. The core mechanics include carbon-credit backing and a bonding mechanism. KlimaDAO acquires carbon credits from traditional markets and tokenizes them into Base Carbon Tonnes (BCTs), allowing these credits to be used as financial tokens. Under the DAO's bonding mechanism, users can sell carbon credits to KlimaDAO in exchange for discounted KLIMA tokens. This helps the DAO continuously accumulate more carbon credits, removing them from the market. By increasing the demand for tokenized carbon credits and locking them in its treasury, KlimaDAO aims to create artificial scarcity in the carbon market, making carbon offsets more expensive and pressuring industries to adopt more sustainable practices.

The Toucan Protocol is another blockchain-based infrastructure that brings carbon credits onto the blockchain, allowing them to be traded, retired, and embedded into decentralized finance applications (Carbon Credit Market Infrastructure, 2023). By tokenizing carbon assets, Toucan introduces liquidity and transparency to what has traditionally been a fragmented and opaque market. (Zwitter and Hazenberg, 2020) It incentivizes sustainability by enabling DAOs and decentralized protocols to offset their emissions or build carbon-conscious features into their systems. Toucan's use of open governance allows stakeholders to collectively decide how carbon assets are sourced and used, (Zwitter and Hazenberg, 2020) aligning with Ostrom's principles of participatory rule-making and local knowledge.

Similarly, the Regen Network focuses on regenerating ecological systems through blockchain-based verification of environmental services (Regen Network, 2021). It leverages a proof-of-stake blockchain to issue ecological credits based on real-world data, such as improved soil health, biodiversity, or water retention. Farmers and land stewards can receive compensation for ecological improvements, while buyers can invest in verified environmental outcomes. (Mantius, 2022) Regen's governance model includes a broad network of scientists and ecologists who aim to ensure that ecological metrics are credible and regionally relevant. Its decentralized yet data-driven approach demonstrates how blockchain can support complex environmental coordination across dispersed actors.

Celo, a mobile-first blockchain platform focused on financial inclusion, integrates sustainability directly into its protocol-level economics (Ecosystem, 2020). A portion of its transaction fees and block rewards is allocated to a reserve of tokenized carbon assets, effectively building carbon offsetting into the foundation of the network. Celo also supports DAOs and projects that advance climate goals through its Climate Collective, which includes organizations like Toucan and Regen. (de la Roche et al., 2022) Celo's model shows how sustainability can be made an integral part of digital infrastructure, not just an optional add-on.

Through these examples, it becomes clear that DAOs have the potential to foster scalable, incentive-aligned environmental action, provided their governance structures remain transparent and adaptive to ecological complexity.

Assessment of potentials

Governance of digital commons by blockchain can be interpreted into "six affordances:" (Rozas et al., 2014) tokenization (Lin et al.), self-enforcement and formalization through collective arrangements (De Filippi and Hassan, 2016), shifts to automatization in digital regulation through DAOs (DuPont and Campbell-Verduyn, 2017), increased transparency in governance (De Filippi, 2018), and the codification of trust through upgradeable smart contracts (Werbach, 2018). These six affordances can be interpreted through the lens of Ostrom's principles for managing the commons. Tokenization enables clearly defined community membership and proportional resource contribution, reflecting Ostrom's principle that commons governance should establish clear boundaries of participation. By issuing governance tokens, blockchain communities define who has a stake in decision-making, similar to the traditional commons that require clear user rights. Self-enforcement and formalization through collective arrangements mirrors Ostrom's principle of collective-choice arrangements, where users directly shape rules. Blockchain-based governance formalizes agreements through smart contracts, ensuring that community-driven decisions are enforceable without reliance on centralized authorities. Increased transparency in governance reinforces Ostrom's principle that effective monitoring should be available to all participants. Because blockchain records all transactions immutably, it ensures that rules, votes, and resource distributions remain visible, reducing corruption and strengthening collective accountability. The codification of trust through upgradeable smart contracts supports graduated sanctions and conflict-resolution mechanisms, another key part of Ostrom's

principles. Blockchain systems enable programmable enforcement of rules, where non-compliance triggers predefined penalties or dispute resolution mechanisms, maintaining order without reliance on external enforcers. Decentralized resource management facilitated by blockchain aligns with minimal recognition of rights, ensuring that governance structures are recognized and upheld without excessive external interference. By giving users direct control over governance mechanisms, blockchain-based commons avoid centralized gatekeeping while maintaining self-determined rule-making.

A blockchain network's creation and management of tokens directly determines access to the blockchain's infrastructure. Digital commons governed by blockchain can grant tokens to people who have sufficiently contributed the infrastructure, or paid a certain price, to access the internet through the community network (Rozas and Hassan, 2016). Moreover, tokenization can determine the extent to which a user possesses governing agency. In large-scale digital commons and FLOSS Projects, permission and rights to modify the commons can further be determined using tokenization. As such, the application of tokenization to the digital commons can increase the network's capability to experiment with the use of different types of tokens in collaborative platforms (Rozas et al., 2014). More specifically, the implementation of the tokenization model to communally construct mediating blockchain-based artifacts can shed light on "invisible labor" (Pérez-Orozco, 2014) and address hidden power dynamics in CBPP communities.

Blockchain networks give CBPP communities the potential to collectively construct software and algorithms in which users' actions are more easily tracked and audited by other users. This aligns with the digital commons' open and participative nature. However, the commons-based approach depends on a reinterpretation of the trust or contract between participating users and the mode of governance. By nature, the algorithmic nature of blockchain networks' DAOs requires frequent updates, wherein users' trust in the governance model is tested. The upgradeability of smart contracts is consequently essential to enhance users' trust in the governance model (Rozas and Hassan, 2016). Moreover, the implementation of decentralized courts in blockchain networks can also bolster user buy-in to the decentralized governance model (Rozas et al., 2021a).

Since blockchain networks are largely regulated by autonomous DAOs, blockchain technologies rely on rules that are unambiguously understood by machines (Rozas and Hassan, 2016). The implication is that digital commons regulated by blockchain networks must have "formalized governance rules" (Rozas et al., 2021b) understood and executed by algorithms in natural language. As a result, members of the digital commons must discuss rule changes, or update smart contracts, and subsequently encode these changes. (Rozas et al., 2021b) This process faces complications as CBPP communities grow in size and scope. When CBPP communities begin upsizing, they normally try to decentralize control over infrastructure and increase the level of formalization in organizational processes (Schweik and English, 2013). Although these organizational changes align with Ostrom's principles of collective choice arrangements, they do not typically occur in scenarios of equitable power dynamics (Rozas et al., 2014). This organizational formalization can shift power to those coding the rules to govern blockchain networks and by extension the digital commons (Rozas and Huckle, 2021). Yet, those with more power in the community may experience higher pressure because of frequent rounds of negotiations, and the decentralized governance model would allot a higher degree of freedom and agency to local networks which emerge over time (Rozas and Huckle, 2021).

As DAOs evolve, several key research directions could enhance understanding and development, including empirical studies on governance participation, legal structures for compliant DAOs, and the integration of AI into DAO governance. Empirical studies investigating factors that influence DAO participation could better outline incentive structures, voting frequencies, and decision-making engagement. Studies should center around governance fatigue and voter apathy in DAOs, as well as power dynamics in DAO governance across reputation-based voting, quadratic voting, and SBT-based governance. As DAOs become more embedded in legal frameworks, empirical studies should explore how DAOs can adopt legal entities such as LLCs, cooperatives, or trusts while preserving decentralization. As AI exerts a larger role in the digital governance sphere, researching how AI models can assist in DAO proposal evaluation and governance automation can help streamline the regulatory process as well as assess the feasibility of DAOs that are entirely managed by AI-driven smart contracts.

Digitalized communitarianism through CBPP

By emphasizing use over exchange value, CBPP aims to establish autonomous systems that redistribute resources equitably within communities. Analyzing the example of FairCoop as case study for the efficacy of CBPP, it is evident that decentralized digital spaces can sustain and govern themselves if they can efficiently scale while regulating issues such as hierarchical power structures and uneven participation.

Founded in 2014 in Catalonia, Spain as an extension of the Catalan Integral Cooperative (CIC), FairCoop was established by activist Enric Duran using funds from loans taken from Spanish banks in an act of civil disobedience (FairCoop, 2023). FairCoop's mission is to create a global cooperative for equitable trade and redistribution of resources. The digital collective uses FairCoin, an alternative cryptocurrency, to sustain local economies and inject capital into commons. Unlike other cryptocurrencies, FairCoin used a "proof of cooperation" (PoC) validation system to align with environmental and social goals (Ettlinger, 2024). Internal governance is conducted through automated processes with participatory decision-making in chat assemblies. As opposed to exploitative forms of blockchain networks, FairCoin's approach emphasis sustaining the ecosystem through collective resource management. However, market volatility led to the devaluation of FairCoin, undermining its ability to sustain the network. Moreover, diverging interests among participants and external opportunists taking advantage of the system for personal gain contributed to the destabilization of the project. Freeloading also posed a barrier to efficient regulation. Despite democratic aspirations, the projects

exhibited power imbalances, with leadership eventually consolidating into a form of centralized decision-making (Blockchain Chicken Farm, 2015).

While automation through blockchain can enhance efficiency, it risks entrenching power imbalances if not carefully managed. The project highlights the need for a degree of human-centered, deliberative processes to complement algorithmic systems to scale communitarian systems across regions. Since larger networks introduce greater complexity and potential for value drift, addressing these gaps requires proactive measures to integrate marginalized populations and foster inclusive participation (BlockApps Inc, 2024).

Conclusion

Blockchain technology and Web3 have introduced transformative possibilities for decentralizing governance and establishing equitable digital commons. However, persistent challenges, from market dependencies to inclusivity gaps, require innovation and reflexivity. By addressing these complexities, communitarian governance models can evolve into scalable and inclusive frameworks that align with Ostrom's principles while adapting to the multifaceted nature of digital spaces. If blockchain governance is to embody Ostrom's, blockchain networks must address the complexities of digital commons management. While blockchain provides a novel toolkit for decentralized governance, its success depends on how communities structure governing power and accountability within these systems. Whether blockchain will serve as a tool for democratization or an extension of existing inequities will be determined not just by technical innovation, but by the collective choices of those who engage with and regulate these digital commons. In cases where states use blockchain to entrench their power, such as through surveillance or the centralization of digital identity systems, individuals and communities must resist passivity by building and participating in alternative, transparent, and community-governed networks. This resistance mirrors Ostrom's emphasis on collective-choice arrangements and the right of communities to self-organize without external interference. By designing blockchain systems that prioritize inclusivity, accountability, and participatory governance, individuals can protect digital freedom and ensure that blockchain remains a commons, managed by and for the people, rather than co-opted by dominant institutions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

No human studies are presented in the manuscript. No potentially identifiable images or data are presented in this study.

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